INSTRUMENT DEVELOPMENT

HIGH-FLUX BACKSCATTERING SPECTROMETER COMMISSIONED

The first vanadium spectrum from the NCNR high flux backscattering spectrometer (HFBS) was obtained in June of 1998 after a design and construction effort lasting more than six years. The measured energy resolution of 0.9 μeV is a factor of 50 better than that routinely obtained using any other spectrometer currently in operation at the NCNR (Fig. 1). This exceptional energy resolution will enable the investigation of many types of dynamical processes in materials, including molecular reorientations, diffusion, dynamics of liquids, glasses and polymers, and critical scattering near phase transitions.

A backscattering spectrometer can be viewed most simply as a limiting case of a triple-axis spectrometer where the scattering angles of the neutrons from both the monochromator and analyzer crystals are 180 degrees [1]. This geometry decouples the beam divergence from the energy resolution allowing the instrument to achieve an ultimate energy resolution defined by the properties of the crystals. The HFBS uses the (111) reflection from bent silicon crystals to both monochromate and analyze the neutron energies. The final energy, defined by the Bragg condition from the silicon analyzers, is 2.08 meV corresponding to a neutron wavelength of 6.27Å. The incident energy is varied by shaking the monochromator using a cam-operated drive system thereby Doppler shifting the incident neutron energy. To date, this device has been used to obtain energy transfers of +/- 45 μeV. The ultimate overall energy transfer range measured by this instrument will exceed 50 μeV.

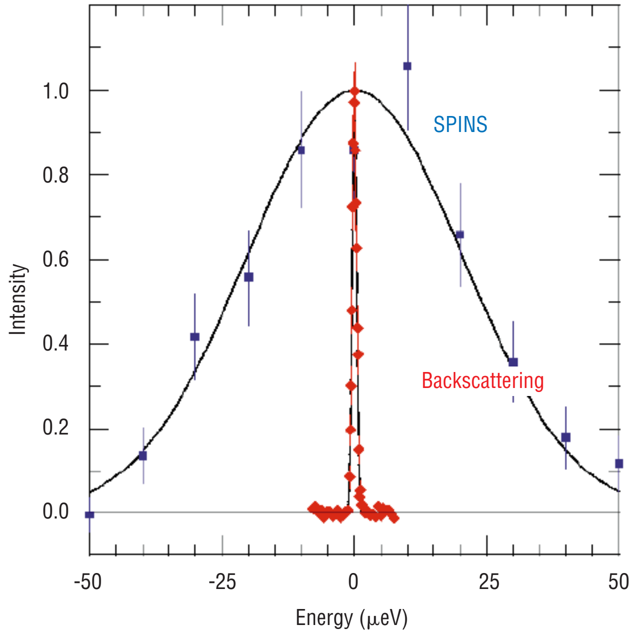

FIGURE 1. Comparison of resolution of HFBS to SPINS (Cold Neutron Triple Axis spectrometer).

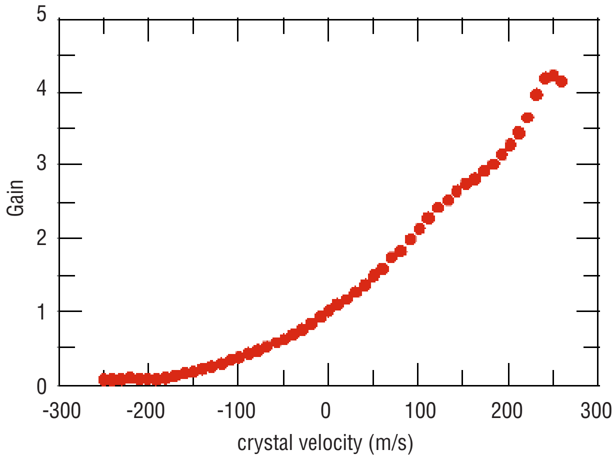

FIGURE 2. Measured gain from use of phase space transform chopper.

The primary design goal of this instrument was to maximize the count rate for a given experiment while maintaining an energy resolution of better than 1 μeV full width at half maximum (FWHM). This has been achieved by matching the divergence of the front-end of the instrument with the divergence of the secondary spectrometer, utilizing a phase-space transform (PST) chopper and by maximizing the area of coverage for the analyzer and monochromator crystals. The HFBS design incorporates a 4m long converging guide which increases the incoming beam divergence and results in 3.9 times more flux at the end of the guide. The PST is a novel device, conceived originally by Schelten and Alefeld [2], which acts as a premonochromator for the instrument: reflecting the beam of neutrons towards the monochromator while focussing their energy distribution towards the narrow value required by the backscattering monochromator crystal. Measurements carried out at the HFBS have demonstrated for the first time that this device increases the neutron flux from the monochromator by more than a factor of four from that obtained with a stationary crystal (Fig. 2). The spherically focussed monochromator and analyzer crystals cover very large

Robert Rathe Photography

FIGURE 3. Scott Slifer adjusting the analyzer assembly on the HFBS.

areas (the analyzer subtends 20% of the total solid angle) and make the instrument very efficient in its use of the available neutrons (Fig. 3). These flux enhancing devices together with the flux available from the NG-2 guide have resulted in a measured flux at the sample position of 1.4 x 10^5 cm^{-2}-sec^{-1} in good agreement with calculations. This flux makes the HFBS competitive with any instrument of its kind in the world.

MONTE CARLO SIMULATION OF NEUTRON BEAM LINES

Monte Carlo simulation of cold neutron beam tube performance is a powerful tool for predicting neutron fluxes and developing optimized neutron scattering instrumentation. A Monte Carlo program has been developed at the NCNR which makes use of modeled reflectivity curves and parameterized neutron cross-sections to simulate the neutron beam delivery system. The neutron beam system may consist of any combination of straight, bent, focusing and channeled guide sections, circular and rectangular diaphragms, neutron collimators, neutron velocity selectors and variety of commonly-used cooled and room temperature crystal filters. The program can also allow for non-ideal configurations such as random Gaussian guide section misalignments. Modeled guide coatings include natural Ni, ^{58}Ni, multilayer and supermirror. Using reference neutron spectrum data, gold foil activation data and measured reflectivity data obtained from two of the NCNR cold neutron beam tubes, the Monte Carlo program has been used to characterize the liquid hydrogen cold neutron source brightness. In turn, this brightness model has been incorporated into simulations of all the neutron beam tubes (NG-0-NG-7) installed on the NCNR cold source. Table 1 shows that the agreement of the simulated and measured capture fluxes is remarkably good. The program has been used extensively to predict and optimize the performance of projected future reconfigurations of the NCNR beam tubes as well as to characterize neutron fluxes per unit wavelength at locations where flux measurements are not yet available.

Table 1. A comparison of measured and simulated capture fluxes for various locations on the NCNR cold neutron beam tubes. The table also gives simulated integrated fluxes ($\phi_{int}^{sim}=\int(d\phi/d\lambda)d\lambda$) and average wavelengths ($\lambda = 1.8\ \phi_c^{sim}/\phi^{int}_{sim}$) in the guide at the reference positions.

Guide system	$\phi_c^{meas}(cm^{-2}s^{-1})$	$\phi_c^{sim}(cm^{-2}s^{-1})$	$\phi_{int}^{sim}(cm^{-2}s^{-1})$	<λ> (Å)
NG-0 before NDP chamber	2.56×10^9	2.336×10^9	6.020×10^8	6.976
NG-1 at reflectometer monochromator	3.1×10^9	3.376×10^9	1.023×10^9	5.93
NG-2 before filter	3.5×10^9	3.498×10^9	1.055×10^9	5.96
NG-2 at HFBS shutter	2.15×10^8	2.094×10^8	6.08×10^7	6.20
NG-2 at HFBS (after converging guide)	8.29×10^8	7.75×10^8	2.25×10^8	6.20
NG-3 before SANS filter	1.7×10^9	1.725×10^9	5.30×10^8	5.85
NG-4 at DCS shutter	2.7×10^9	2.62×10^9	7.94×10^8	5.93
NG-4 at DCS sample (Choppers removed)	9.92×10^8	9.96×10^8	3.39×10^8	5.28
NG-5 at Guide Hall entrance	2.3×10^9	2.148×10^9	6.42×10^8	6.02
NG-6 at Guide Hall entrance	2.3×10^9	2.197×10^9	6.66×10^8	5.93
NG-6 at end of guide	1.37×10^9	1.387×10^9	4.37×10^8	5.71
NG-7 at reflectometer monochromator	1.9×10^9	1.948×10^9	5.90×10^8	5.93
NG-7 before SANS filter	1.56×10^9	1.639×10^9	5.12×10^8	5.75

NEW CAPABILITIES FOR SAMPLE ENVIRONMENT AND PREPARATION

This year the NCNR added several new sample environment capabilities. The obtainable temperature equivalent magnetic field energy per Bohr magneton was increased from 0.4 Kelvin to 0.52 Kelvin by the procurement of a 9 Tesla vertical field superconducting magnet. In order to reach sample temperatures comparable with this field energy range, a pumped helium-3 refrigerator with a base temperature of 0.29 Kelvin is incorporated into the 9 Tesla magnet system. These low temperatures and high fields are critical for the NCNR's ongoing program of research on low dimensional magnetism. The new superconducting magnet system is top-loading which facilitates quick turn around for studies involving multiple samples. The horizontal field magnet, shown in Fig. 4, was recently returned to service.

A new 2000 K variable temperature vacuum furnace was acquired this year providing new capability for neutron scattering experiments at high temperatures. The furnace is currently being used for powder diffraction studies of alloys and ceramics at high temperatures. Other instrumentation added this year includes: a new intermediate temperature 800 Kelvin furnace, and a third closed-cycle helium refrigerator-furnace. The refrigerator-furnaces cover the temperature range from about 20 K up to 650 K without the need for changing the sample environment, which is an important advantage for making background corrections and temperature comparisons. A new spinner with a laminar-flow hood was installed in the user polymer laboratory providing an important on-site capability to spin-coat polymer films from solutions for reflectivity measurements.

DETECTOR ELECTRONICS FOR THE HFBS

The recently commissioned High Flux Backscattering Spectrometer provided a unique design challenge for the ^{3}He neutron detector electronics. The combination of a large evacuated flight path together with close packing of the half inch diameter detectors meant that the traditional preamplifier/amplifier/discriminator (PAD) modules could only be utilized outside of the vacuum chamber. This option would have resulted in an unacceptable noise susceptibility for the weak detector signals being transmitted over long cables and through vacuum feedthrough devices. The HFBS project opted, instead, to design a small form-factor, fully vacuum rated PAD module that could be located within the vacuum flight chamber and then route the robust digital discriminator outputs to the outside data acquisition electronics.

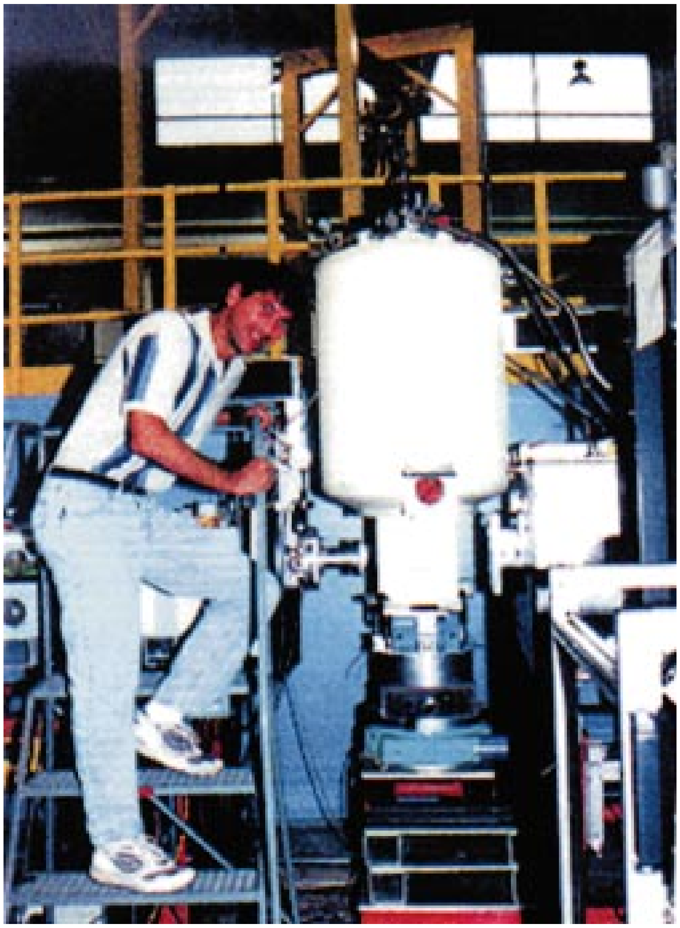

FIGURE 4. John Barker sets up the recently repaired superconducting horizontal field magnet on the NG-7 SANS.

The NCNR design is based on two commercially available hybrid circuits: a preamplifier/shaping amplifier, and an amplifier/discriminator. Both parts dissipate power at the milliwatt level and are fully vacuum (space) rated. The output stage uses a CMOS dual inverting/non-inverting driver which also exhibits very low power dissipation, even when driving large loads. The balanced output is used to provide ECL level logic output with excellent common mode rejection for the signal transmitted out of the flight chamber to the data acquisition electronics. Careful component selection and package design resulted in a small form-factor, flat-package design with a thickness of less than 0.45 inches consistent with the detector spacing requirements. Additional features in the NCNR design include: a robust input protection network to protect the preamplifier, on-board regulation of the discriminator level reference voltage, separate high and low level discriminator settings, and convenient on-board connections for daisy chaining high voltage and test pulse inputs to adjacent PAD modules.

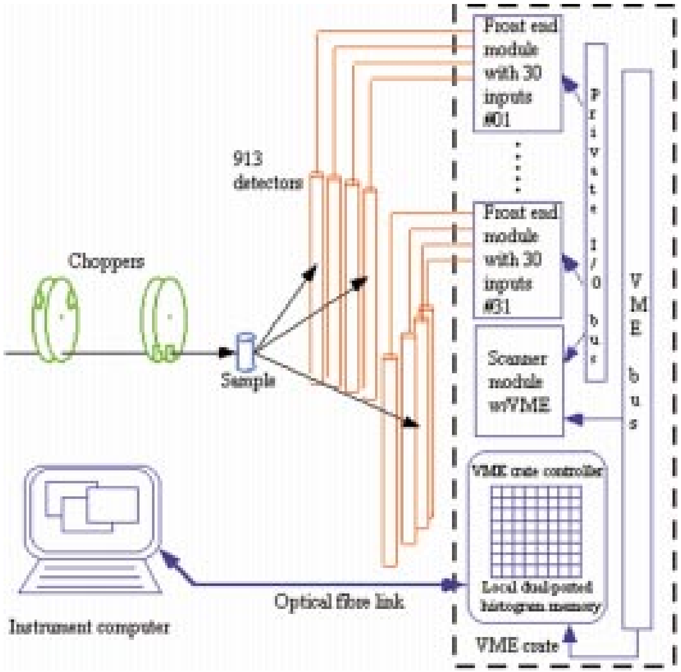

FIGURE 5. Diagram of the DCS neutron time-of flight data acquisition system.

DATA ACQUISITION ELECTRONICS FOR THE DCS TIME-OF-FLIGHT SPECTROMETER

The disk chopper time-of-flight spectrometer (DCS) presents a set of unique challenges for its data acquisition system. The choppers of the DCS periodically illuminate the sample with pulses of neutrons, some of which are then scattered towards its 913 detectors. The approach that has been adopted in the NIST design is to process data hierarchically, in a tree-like structure that mirrors data bandwidth requirements. The NCNR design (see Fig. 5) uses two types of single width 6U-sized VME modules to process incoming events and multiplex them for VME readout to the crate controller computer where the events are histogrammed. The input modules process events from up to 30 detectors creating time-stamped data words which are moved to a 64 deep FIFO memory for subsequent readout. Thus the DCS requires 31 input modules to handle its 913 detectors. Corresponding to every pulse at the sample position, the chopper system provides a synchronous signal to the input module that starts a free-running clock which is used to time-stamp the neutron events. The input modules create 30-bit words that encode both the time of the event and the detector number. A scanner module polls the 31 input modules over a private bus to see if they are holding event words for readout. If an input module's FIFO is not empty the scanner module reads an event and stores it for readout over the VME bus to the VME crate controller. The crate controller computer reads the events, filters valid events, processes the timing information, and histograms events by detector and time channel into a block of memory accessible to the data acquisition computer. The data acquisition computer is used to process the stored histograms from the measurement.The versatility of the DCS implies that the times of events must on occasion be measured with great precision (as small as 100 ns), and yet the time between pulses at the sample can be as long as 50 ms. Thus the dynamic range for timing measurements is almost six orders of magnitude. If the data acquisition had no event buffering capability, each detector registering an event must be read within the period of one time channel. If this channel is 100 ns for 1000 detectors, this implies an interrogation rate of at least 1010 bits per second. If events are buffered, the highly improbable worst-case event rate for the FIFO is that all neutrons in a pulse are scattered into detectors on a single input board. If the pulse at the detectors is roughly triangular, the peak neutron arrival rate at the detectors can be ~2x107 Hz at 20000 rpm. However, even if these events are evenly distributed over all detectors on one board, this exceeds the limit imposed by the detector dead time and the upper limit is around 2x106 based on 70 kHz/detector maximum. Because the total number of detected neutrons in one pulse can still exceed the depth of the buffer, the criterion for non-saturation of the input board *during detection of the pulse* can be expressed as: (Average peak event arrival rate-Event downloading rate) x FWHM(pulse) < 64. The second condition for non-saturation of the acquisition overall is that the scanner board can download events at least the time-averaged event arrival rate, which is more like 2x104 Hz at 20000 rpm if the detector is saturation limited. The scanner board can process events at a maximum rate of about 1.1 MHz, therefore, the saturation limits of the acquisition system are well matched to the saturation limits of the detectors for peak data rate handling and comfortably exceed the maximum average data rate handling requirements. For isotropic scattering, the peak arrival rate of neutrons on one input board cannot exceed about 4x104 Hz at 20000 rpm or 7x105 Hz at 1200 rpm.

The DCS data acquisition electronics were successfully tested under test-bench conditions and under "live" conditions during a recent reactor cycle.

REFERENCES

[1] P. M. Gehring and D. A. Neumann, Physica **B 64**, 241-243 (1998).

[2] J. Schelten and B. Alefeld, in Proc. of a Workshop on Neutron Scattering Instrumentation for SNQ, ed. R. Scherm and H. H. Stiller, Report July-1954 (1984)