Title: SNS Detector Plans

Section: DF-1

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Abstract: The Spallation Neutron Source at Oak Ridge, TN, USA is scheduled to begin operation in April 2006. As of October 2003, seventeen neutron scattering instruments have been approved for development. Unfortunately the detector requirements for many of these instruments exceed the capabilities of the systems that are available today. While improved detectors would significantly enhance the scientific capabilities of the facility, detector decisions have been made based on the current best option. This paper will present the detector requirements of the instruments, list the detector selections for initial operation, and review the deficiencies of these selections. The need for new detectors is significant and the SNS staff strongly endorses detector research that will eliminate these deficiencies. New detectors will not only improve the quality of the science being done at neutron scattering facilities, they will also open new areas of research.

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1. Introduction

Research into fields as diverse as condensed matter physics, materials science and engineering, geosciences, and biosciences have benefited from using neutrons as probes, and new high-intensity neutron sources are being built to further this science. New sources like the Spallation Neutron Source (SNS) and the Japanese Spallation Neutron Source (JSNS) will be an order of magnitude brighter that the most powerful facilities that are operating now and these improvements in brightness will make possible many new areas of research. Unfortunately, the neutron detectors available today lack the capabilities required to allow these facilities to achieve their potential or to meet the goals of the neutron scattering Users Community.

2. Detector selections

The SNS is scheduled to begin operation in April, 2006. As of October 2003, seventeen neutron scattering instruments have been approved. Descriptions of the instruments that have mature designs are available on the web [1]. Instrument requirements for detector systems are shown in table 1 and the detector selections for these instruments are shown in table 2. Taking each instrument in turn, the powder diffractometer will initially operate with approximately 10 m^2 of detector coverage, and it is designed to be expandable to 45 m^2. A major goal for this instrument is to perform real time parametric studies on powder samples. To reach this goal a scintillator that is more efficient for capturing neutrons than LiF/ZnS is required. The disordered materials diffractometer needs to detect 35 eV neutrons and would also benefit from a new bright, transparent scintillator.

The scintillator search is complicated by the inefficiency of the light collection schemes used in large area detection systems. For these systems the minimum light yield of the scintillator must be at least twice that of Li-glass, and to date only Lithium-Gadolinium-Borate has met this requirement. Unfortunately, this scintillator uses isotopically separated Gadolinium, which is prohibitively expensive.

The requirements for the primary detector systems for the high pressure and engineering instruments can be met with existing technology, but 100 μm resolution detectors that can measure the neutron capture times are needed. For the former, a high resolution detector is needed to characterize the small samples that will be used at the highest pressures, and for the engineering instrument it will be used for residual stress profile measurements.

To study large-unit-cell crystals the single crystal diffractometer will need detectors with <1 mm resolution. To meet this requirement we will use scintillators and segmented anode photomultiplier tubes operating in Anger mode. Using this technique sub-mm resolution has been achieved for neutron detection with small prototypes [2] [3]. However, this technology has yet to be developed into a full scale detector system. In addition to the single crystal diffractometer, a protein crystallography instrument is being designed that will have similar detector requirements.

At spallation sources, reflectometers and small angle scattering instruments use ^{3}He filled detectors to minimize the gamma ray background contamination of the data. Proportional chambers are the detectors of choice for these applications, but these detectors will saturate at the new high powered facilities. Estimates of the deficiencies of the detectors that are available today are shown in table 3. For the reflectometers and small angle scattering instruments, proportional counters will saturate at 1% of the maximum rate. In addition, a spin-echo instrument is being designed that will have similar rate requirements. These instruments would benefit from the development of high rate ^{3}He detectors.

The inelastic spectrometers can have detector coverage in excess of 20 m^2 and this makes detector expense a primary concern. To provide large area coverage these instruments will use ^{3}He filled linear position sensitive proportional counters (LPSDs). These detectors will meet the requirements for position resolution and gamma ray rejection, but the instantaneous rate of neutrons scattered into a detector from a Bragg peak will exceed the rate capability of the detector and cause it to saturate. Data from inelastically scattered neutron that arrive before the detector can recover will be lost. Two other inelastic instruments, chemical vibration and hybrid spectrometers, are planned that will also use LPSDs. These instruments do not yet have mature designs.

The last approved instrument is dedicated to fundamental physics research. The detector systems for this instrument will vary depending on the nature of the experiment being performed.

3. Additional information

At both reactors and spallation sources, improvements in neutron detector technology will enhance the science for several areas of research, such as condensed matter physics, materials science and engineering, geosciences, and biosciences. A list of specific examples of research that cannot be accomplished at the SNS without detector improvements has been compiled as part of a white paper titled "A Program for Neutron Detector Research and Development [4]." In addition, this paper contains suggestions for detector research and a plan to coordinate these efforts. This paper is meant to assist researchers who wish to develop detectors for neutron scattering facilities.

The SNS is designed to have 24 instruments in the first target building and a second building is being planned that would house another 24 instruments. In addition, a plan is in place to increase the power of the SNS and achieve higher instantaneous rates. These upgrades will reinforce the need for detector development.

4. Conclusion

Outfitted with the detectors listed in table 2, the instruments at the SNS will be among the best in the world, but the SNS and other high-powered facilities will not perform at full potential until significant improvements in detector technology take place.

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[1] http://www.sns.gov/users/users.htm

[2] J.F. Cleargeau, http://www.ill.fr/News/36/INSTR_12.HTM

[3] R. Engels, R. Reinartz, J. Schelten, and B. Czirr, IEEE Transactions on Nuclear Science, Volume: 47 Issue: 3, June 2000 Page(s): 948 -951

[4] R. G. Cooper et al, http://www.sns.gov/documentation/pubs.htm

Table 1. Instrument requirements

Instrument	Number of pixels	Pixel area (cm^2)	Maximum neutron energy (eV)	Neutron capture Efficiency(a) %	Gamma efficiency (trigger/γ)	Time resolution (μs)	Peak pixel count rate(b) ($n.s^{-1}$)	Detector count rate(c) ($n.s^{-1}$)	Data transfer rate (Mb/s)
Powder Diffractometer	40,000	2.4	0.33	50	10^{-6}	1	100	3.5×10^6	28
Disordered Materials Diffractometer	150,000	0.25	35	20	10^{-6}	1	300	4.2×10^7	340
High Pressure Diffractometer	100,000	0.02	0.5	50	10^{-7}	1	1×10^4	3.0×10^5	2.4
Engineering Diffractometer	80,000	1.25	0.15	50	10^{-6}	1	2×10^5	2.4×10^6	20
Single Crystal Diffractometer	5×10^6	0.01	0.35	50	10^{-6}	10	2×10^4	3.0×10^5	2.4
Small Angle Diffractometer	40,000	0.25	0.08	50	10^{-7}	10	1,500	2.0×10^7	160
Liquids Reflectometer	40,000	0.01	0.02	50	10^{-7}	10	1×10^6	7.0×10^7	560
Magnetism Reflectometer	40,000	0.01	0.03	50	10^{-7}	10	1×10^6	9.0×10^7	720
Backscattering Spectrometer	4,500	1.3	0.01	50	10^{-6}	1	1×10^4	1.3×10^5	1
Wide Angle Spectrometer	70,000	2.5	1.0	50	10^{-7}	1	1×10^6 (Bragg)	5.0×10^5	4
Cold Neutron Spectrometer	15,000	6.3	0.05	50	10^{-7}	4	1×10^6 (Bragg)	7.0×10^6	56
High Resolution Spectrometer	70,000	2.5	1.0	50	10^{-7}	1	1×10^6 (Bragg)	4.0×10^5	3.2

(a) At maximum energy
(b) Rate during scattering condition
(c) Rate for entire detector system

Table 2. Detector Selections

Instrument	Detector Selection
Powder Diffractometer	LiF/ZnS scintillator screens with wavelength shifting fiber readout
Disordered Materials Diffractometer	Scintillator screens with wavelength shifting fiber readout Need a bright, transparent scintillator
High Pressure Diffractometer	Multiwire proportional chamber or Anger camera, 100µm resolution detector for small sample measurements
Engineering Diffractometer	LiF/ZnS scintillator screens with wavelength shifting fiber readout, 100µm resolution detector for residual stress measurements
Single Crystal Diffractometer	Scintillator with segmented anode photomultiplier tubes operating in Anger mode
Small Angle Diffractometer	Multiwire proportional chamber or Multitube linear position sensitive detector array
Liquids Reflectometer	Multiwire proportional chamber
Magnetism Reflectometer	Multiwire proportional chamber
Backscattering Spectrometer	^{3}He filled 15cm x 1.3cm linear position sensitive detectors in vacuum
Wide Angle Spectrometer	^{3}He filled 100cm x 2.5cm linear position sensitive detectors in vacuum
Cold Neutron Spectrometer	^{3}He filled Linear position sensitive detectors
High Resolution Spectrometer	^{3}He filled 120cm x 2.5cm linear position sensitive detectors in vacuum

Instrument	Parameter	Desired	Current	Comment
Liquids & Magnetism Reflectometers	Pixel area (cm^2)	0.01	0.02	0.02 is state of the art for ^{3}He gas detectors
	Maximum instantaneous rate/pixel (counts/s)	1.3×10^6	7×10^4	Beam attenuator will be necessary
	Maximum total instantaneous rate (counts/s)	1.2×10^8	1×10^6	Beam attenuator will be necessary
	Maximum time average rate/pixel (counts/s)	6.2×10^5	7×10^4	Beam attenuator will be necessary
	Maximum total time average rate (counts/s)	5.9×10^7	5×10^5	Beam attenuator will be necessary
	Transmission monitor pixel area (cm^2)	0.04	10	Characterize angular dependence of inc. beam
Powder Diffractometer	Neutron efficiency at 0.35 eV (%)	50	30	60% reduction in data rate
	Detector cost ($/$m^2$)	150K	250K	Wavelength shifting modules will cover more area for the same cost
	Transmission detector maximum time average data rate (counts/s)	3.4×10^7	1×10^6	Reduce uncertainty in beam normalization
Engineering Instrument	Spatial resolution (mm)	0.1	1.0	Needed for residual stress depth profile measurements
	Transmission detector maximum time average data rate (counts/s)	5×10^7	1×10^6	Beam attenuator will be necessary
Single-Crystal Diffractometer	Spatial resolution (mm)	1	3	Unit cells limited to 30Å or less
	Transparent scintillator brightness (photons/neutron)	30,000	10,000	Needed for 1-mm resolution detectors
	Dynamic range (peak counts/background counts)	1×10^3	1×10^2	Needed for diffuse scattering studies
Inelastic Chopper Spectrometers	Spatial resolution (mm)	10	25	Q resolution limited by detectors for small samples
	Time resolution (μs)	1	5	Needed for high-resolution energy measurements
	Maximum instantaneous rate per detector (counts/sec)	2×10^7	7×10^4	Detectors will saturate, and inelastic data will be lost
Disordered Materials Diffractometer	Detection efficiency for 35eV neutrons (%)	20	5	Needed to measure atomic connectivity and defect distributions
Extended-Q SANS	Maximum total time average rate (counts/sec)	5×10^7	5×10^5	Needed to study weakly scattering biological samples
	Maximum parallax error (mm)	5	20	Q resolution limited by detector parallax

Table 3. Detector deficiencies for SNS instruments