A PROGRAM FOR NEUTRON DETECTOR RESEARCH AND DEVELOPMENT

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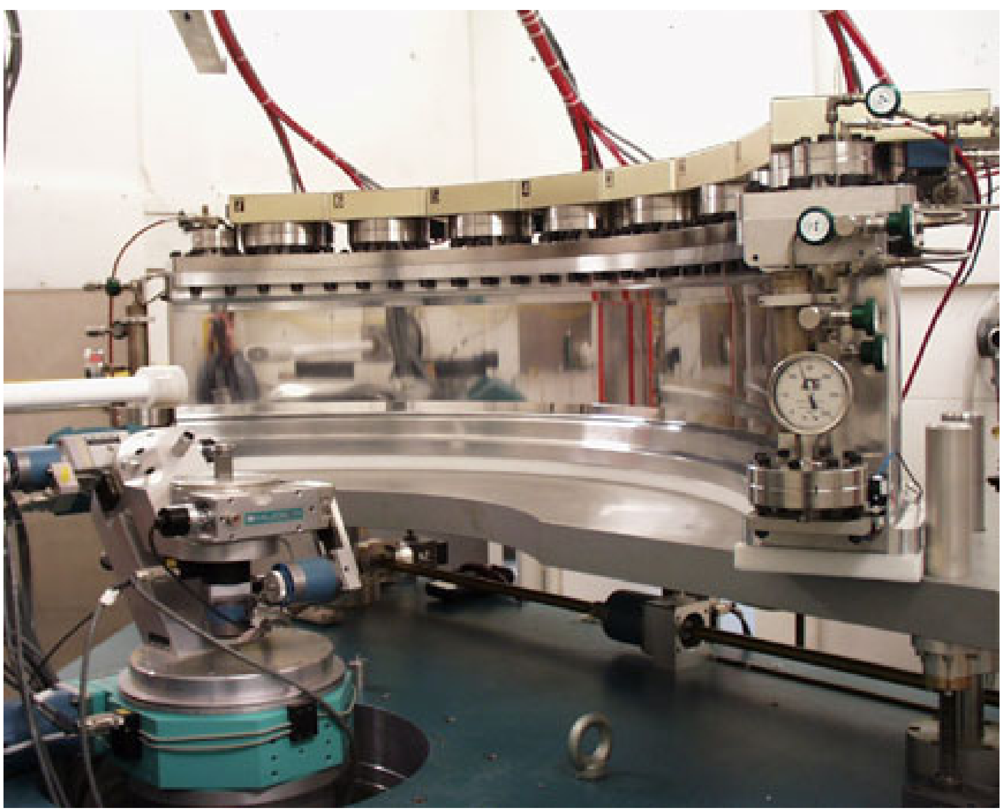

Detector for Protein Crystallography

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EXECUTIVE SUMMARY

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 and the Japanese Spallation Neutron Source 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 meet their potential or to meet the goals of the U.S. neutron users community.

The importance of these new facilities cannot be overstated, but it must be remembered that the brightness of a neutron source is several orders of magnitude less than charged particle or photon beams. Consequently, these new facilities will continue to be flux limited for many applications. In this environment, efficient detection of neutrons is essential. Because there is no excess of neutrons, new detector systems that can sense and process all of the available neutron flux are necessary. To bring these high-powered, neutron-scattering facilities to their full potential, a modest, sustained detector research and development effort is needed. This effort should be guided by the needs of the neutron user community, and because neutron users and detector researchers are from separate communities, the effort needs a mechanism to ensure coordination and accountability.

The detector development program proposed here addresses these needs by establishing a roadmap for detector research and a management plan to maintain the focus of that research. The roadmap contains a science case that defines the need for detector research and the detector requirements that need to be met for scattering instruments and neutron-scattering facilities to be used most advantageously. The details of this roadmap will be maintained in a white paper that is a living document and that will be upgraded as needed.

The proposed program also includes an outline for a management plan to oversee the program and ensure its success. An important consideration for detector development is the long-term nature of the work. Because major progress would be made by a sustained effort over several years, continued funding is essential. To ensure that efforts are focused and productive, we will assemble an oversight committee from the detector users community to coordinate the efforts, measure progress, and ensure relevance to the needs of the users community. The committee will review ongoing research and evaluate proposals for detector development. Once a coordinated detector effort is developed, the detector scientists and the oversight committee will become a pool of expertise that can review Small Business Innovation Research proposals and provide input to the U.S. Department of Energy and the National Science Foundation on any radiation detection issues. This detector development collaboration will also create a forum for cooperation, training, and dissemination of information.

A modest, sustained investment in detector development will yield significant enhancements to the scope of the research performed at U.S. neutron-scattering facilities and will allow them to use the full extent of their capabilities. Moreover, this investment will significantly benefit the research of hundreds of scientists for several decades, not only in the United States but worldwide.

1. INTRODUCTION

In 1609, when Galileo built a telescope and observed the night sky, he took science beyond the limit of our senses for the first time. The value of the telescope was immediately recognized, and many breakthroughs in astronomy followed. Today we have the Keck behemoths in Hawaii and the Hubble telescope, detectors that regularly make substantial contributions to our body of knowledge. After 400 years, this type of detector is still valuable.

Galileo did other detector development. He also invented a primitive thermometer, which others improved on over the next 50 years. This temperature detector was the primary tool that made possible the advances made in chemistry in the 17th and 18th centuries.

These examples demonstrate a fundamental rule in science: advances follow the development of new technology. Theorists can develop beautiful mathematical models, but progress comes from experimentalists' tests of theories against reality. Such experimentalists use detectors—the eyes of science—to test these theories. The high-energy physics community realized this almost 50 years ago and included detector development in every major particle search. Improvements in detector technology were required before the Charm, Tau, W, Z, and Top particles could be found, and these required improvements were included in the research proposals.

The scale of these high-energy physics searches required the components of the experiment to be divided and specialists focused on each area. Accelerator specialists developed machines to produce the particles under study, detector specialists created the eyes to see these particles, and the analysis specialists processed the data and presented the results. Although this arrangement produced successful results, an unfortunate phenomenon grew out of this division of labor that now adversely affects the advance of science in many fields. In recent years, hardware development has been labeled as an inferior science. This unsupportable view purports that research in accelerator, sample environment, and detector technologies is not "real" science, and this sentiment has reduced support for these crucial areas. Consequently, the advanced light sources and neutron-scattering facilities throughout the world suffer from inadequate detectors, making them near-sighted giants.

Although the need for better detectors is a significant issue at all sources, the need is compounded at neutron-scattering facilities by the relative lack of brightness of these sources. Fluxes at neutron facilities are several orders of magnitude lower than advanced light sources, and much of the science preformed at neutron facilities is flux limited: there is no excess of neutrons. Advances in neutron detector technology would not only significantly improve the quality of the science being conducted at these facilities but would also make possible research in several new areas.

Section 2, "Science Case," lists examples of important new science that detector development would make possible. Although these examples alone make a strong case for detector development, the list is not exclusive. Almost all of the advances that followed Galileo's work were unforeseen, as has been the case throughout history. The science case presented here is a guaranteed return, but advances in neutron detector technology could make significant contributions to many other areas such as nuclear medicine or homeland security. American tax payers want the maximum return on their investment, and this means facilities operating at their full potential. A modest, sustained investment in detector research and development (R&D) would significantly enhance the quality and quantity of the science coming from these facilities and would optimize their performance.

2. SCIENCE CASE

Detector improvements will significantly enhance the performance of instruments at both reactor and spallation facilities. At high-powered reactors, detectors on small-angle scattering, reflectometer, and other instruments cannot handle the available flux. In some situations, in fact, detectors can process only 1% of the potential neutron signal. The situation is even worse at the new spallation sources being built, that is, the U.S. Spallation Neutron Source (SNS) and the Japanese Spallation Neutron Source (JSNS). Three major limitations contribute to the need for better detectors for pulsed sources: (1) lack of high-spatial resolution detectors that can be used with time-of-flight techniques, (2) detector speed limitations, and (3) low detector efficiency for short-wavelength neutrons. First, optimal use of SNS and JSNS requires the use of neutron time-of-flight techniques, and this restricts the useful detectors to those that can provide event-by-event time stamping. Therefore, high-spatial-resolution detectors, such as charge-coupled device detectors and image plates successfully used at reactors, cannot be used on pulsed source instruments because they are integrating detectors that do not preserve the timing information necessary for time-of-flight applications. Second, pulsed-source instruments typically make use of a broad band of wavelengths so that it is the peak instantaneous flux from the source that is useful, and these instantaneous fluxes can be much higher than monochromated reactor fluxes. At both SNS and JSNS, most instruments will suffer from detector speed limitations for at least some types of science. Finally, pulsed sources provide much higher flux at short wavelengths than is typically available at reactors. This availability of shorter wavelengths is important to some of the new science at pulsed sources, but the low detection efficiency of current detectors for short-wavelength neutrons constrains the use of such neutrons and limits the range of accessible science. In summary, at the new generation of spallation sources, the performance of almost every instrument will be limited for at least some types of science by the performance of the detectors.

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. The rest of Section 2 lists some specific examples of research that cannot be conducted without detector improvements. This list is organized by instrument and is characteristic of the science planned for optimized SNS instruments. Although these examples are based on specific SNS considerations, similar constraints caused by the limitations of current detectors can also be found at other pulsed and steady-state sources.

2.1 EXTENDED-Q SANS

The extended-Q small-angle neutron-scattering (SANS) instrument at SNS is designed to be a large dynamic ***Q***-range, high-precision, and high-intensity instrument. The instrument covers a ***Q***-range of 0.004 to 10 $Å^{-1}$. Its typical wavelength resolution is $\Delta\lambda/\lambda < 0.5\%$. With the shortest designed collimation length of 1 m, the flux at the sample position will be $> 5\times10^8$ $n/cm^2/s$. These unique features will enable the study of multilength scale systems, such as protein-membrane interactions, as well as nucleations and crystallizations in nanophase materials. The high flux on the sample will enable real-time kinetic studies on the second timescale. It will also allow the study of weakly scattering samples.

Because SANS instruments collect data in the direction of the incident beam, they require high-counting-rate, two-dimensional, position-sensitive detectors. In addition, because small-angle scatterers are typically weak scattering samples, which is particularly true for biological samples, SANS detectors have to maintain a low background. One of the major sources for detector background is γ rays; thus, detectors with low gamma sensitivities are required. The γ background from current scintillator detectors is too high for SANS applications. Because ^3He gas is a low-Z neutron detection material and is less sensitive to γ-rays, ^{3}He detectors have been used for most of the SANS machines that are in operation today. However, the counting rate of the current state-of-the-art ^{3}He detectors is limited to $<5 \times 10^5$ n/s on a 1- × 1-m^2 counting area. Although such detectors can be used effectively for a broad range of science, they are grossly insufficient for some of the research that could be carried out at a SANS instrument on a high-powered source, research that would require detectors with two orders of magnitude higher counting rate capability.

Current ^{3}He detectors have other disadvantages that will also affect the performance of the extended-Q SANS instrument. The depth of the activation gas in such detectors is typically several centimeters, which results in large parallax errors on instruments with short secondary flight paths such as this one. Because of the low pressure of the ^{3}He gas, the counting efficiency for short-wavelength neutrons is also very low. If these deficiencies were overcome and an optimized detector with high rate capability and high efficiency were produced, real-time studies using epithermal neutrons would be possible.

An example of science that is adversely affected by detector limitations on instruments like the extended-Q SANS is the study of protein structures and dynamics using the contrast variation technique. In this technique, the change of the protein contrast to the solvent buffer is achieved by varying the deuteration level of the buffer. At lower deuteration levels, the hydrogen in the buffer contributes an enormous component of incoherent scattering to the total scattered neutrons. On the extended-Q SANS instrument, this incoherent scattering can amount to 2×10^7 n/s on a 1- × 1-m^2 detection area. Because there is no current SANS detector technology that can handle such rates, the incident neutron beam has to be attenuated by two orders of magnitude. On the other hand, proteins are typically weak scatterers. Therefore, although the scattering from the solvent buffer is strong, long counting times are needed to gather enough counts from the protein signal. Attenuating the incident beam means that even longer counting times are needed, sometimes many days. For a large number of systems, this means that the experiments become impossible.

2.2 REFLECTOMETERS

Two reflectometers are included in the initial instrument suite at SNS [1]. These instruments will serve rapidly growing communities in the fields of nanoscience, membrane bioscience, surfactant chemistry, and related areas. The instruments are optimized to investigate magnetic and chemical density profiles in surfaces, thin films, interfaces, and multilayer systems, including free-standing liquid surfaces and interfaces. As next-generation instruments with a much higher available neutron flux, they will provide unprecedented experimental capabilities. Most importantly, they will be capable of routinely detecting weak off-specular scattering signals from chemical/magnetic structures within the layer plane. Such experiments are unreasonably slow on today’s instruments.

Areas of fundamental science that will be addressed by these instruments include flux penetration and flux-lattice ordering in superconductors; molecular magnets; nucleation and growth of structured surfaces; magnetic domains and patterned structures of magnetic dots; magnetic moment formation in thin films; interface polarization; interfacial coupling and quantum confinement; giant and colossal magnetoresistance; self-assembled layers and integrated materials such as polymers combined with magnetic materials, nanoparticles, spin glasses, or amorphous/polycrystalline films; interfacial studies in polymers; and surface chemistry involving thin layers of surfactants or other materials on the surfaces of liquids. New fundamental scientific insights gained by these instruments will be important in the development of future thin-film–based applications, such as new magnetic memory technologies, magnetic recording media and magnetic sensors for computers, [2] and new hard and soft magnetic materials to improve the efficiency of energy delivery systems (e.g., motors and transformers).[3] These instruments will also help elucidate important processes in the function of biomembranes, as well as open up for study a wide range of other surface chemistry applications.

Unique capabilities of these instruments include ultrahigh neutron intensity for in-plane diffraction and off-specular/grazing-incidence small-angle scattering measurements [4] and the combination of reflectometry and high-angle diffraction for resolving large-scale and nanoscopic structural/magnetic features under the same experimental conditions. Data rates and the Q-range covered at a single scattering angle setting will be sufficiently high to permit "real time" kinetic studies on many systems. Time-resolved experiments include investigations of chemical kinetics, solid-state reactions, phase transitions, and chemical and magnetic reactions in general, including responses to external stimuli such as pulsed magnetic, electric, light, or other fields, and in situ structural or magnetic phase-diagram determinations (e.g., temperature, pressure, atmosphere, and magnetic field).

2.2.1 Requirements for the Detector

Table 1 compares the current and desired detector parameters. The desired maximum values are based on calculated flux numbers that are expected when highly reflective samples (e.g., supermirrors) or high-intensity regions of ordinary samples (e.g., in a total reflectivity region or at multilayer Bragg peaks) are measured. The table shows that current state-of-the-art detector technology is about two orders of magnitude below the desired count rate capabilities. Consequently, partial beam-blocking devices have to be introduced in the neutron path, which is highly undesirable. Artificially lowering the neutron intensity would render a number of scientific projects impossible, such as time-dependent studies that require high temporal resolution (e.g., diffusion experiments or parametric studies in which temperature, magnetic/electric fields, chemical environment, and/or pressure are changed). If better detectors were developed that could handle the extremely high flux that will be available at SNS, in some cases, useful data sets could be produced on a pulse-by-pulse basis, sometimes even at fractions of a pulse.

Table 1. Desired and current detector parameters for the SNS magnetism reflectometer

Parameter	Desired	Current	Comment
Spatial pixel area (cm^2)	0.01	0.01	0.020 is state of the art for ^3He
Total no. of pixels	40,000	40,000	
Minimum time of flight (microsecond)	8,640	8,640	1.8-Å, 19-m flight path
Maximum time of flight (microsecond)	50,426	50,426	10.5-Å, 19-m flight path
Minimum time of flight binning (microsecond)	10	10	Value based on minimum moderator emission time (20 μs FWHM for 1.8 Å)
Max no. of time channels	1,667	1,667	
Max instantaneous rate/pixel (counts/s)	1.3×10^6	1.3×10^4	Partial beam absorber necessary
Max total instantaneous rate (counts/s)	1.2×10^8	1.2×10^6	Partial beam absorber necessary
Max time-average rate/pixel (counts/s)	6.2×10^5	6.2×10^4	Partial beam absorber necessary
Max total time-average rate (counts/s)	5.9×10^7	5×10^5	Partial beam absorber necessary
Minimum time per data set (s)	1	1	
Typical time per data set (s)	60	60	

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2.4 SINGLE-CRYSTAL DIFFRACTOMETER

The SNS single-crystal diffractometer (SCD) is optimized to collect full sets of Bragg diffraction data from small single crystals (<1 mm^3). The challenges for SNS SCD detectors are significant. The expected data rate from each Bragg reflection will be much higher than what is currently being detected at similar pulsed-source instruments. With an incident flux of about 100 times that at Argonne National Laboratory's (ANL's) Intense Pulsed Neutron Source (IPNS) SCD and 16 times that at the ISIS (Rutherford Appleton Laboratory, U.K.) SXD, the SNS SCD is expected to have one to two orders of magnitude higher count rates for each Bragg peak.

The design manual for the SCD lists the requirements for single-crystal neutron detectors (Table 2), but these requirements are not met with current detector technology.

Table 2. Design parameters for the SNS SCD

2-D position-sensitive detector	Type	Scintillation
	Area per detector unit	150 ×150 mm^2
	Distance from sample	1 m
	Position resolution	≤1 mm
	Quantity	~400
Resolution	$\delta t/t$	0.003 FWHM
	$\delta d/d$	0.005-0.01° FWHM

At IPNS and ISIS, Anger cameras and pixilated scintillator detectors are used. These are well matched to these current single-crystal instruments that focus on long-range molecular and atomic structure determination and refinement using centroid calculation of the Bragg reflection. The spatial resolution and time binning requirements are not very stringent for this type of measurement if the structures investigated are built of relatively small repeating units.

A challenge for the SNS SCD will be to resolve the atomic and molecular arrangements of larger structures, and better detector resolution is necessary to accomplish this. For example, for the proposed beam line, the FWHM resolution is $\Delta d/d = R = 0.005\text{-}0.01$, but with current detector technology the full width of the integrated peaks of Bragg reflections will be $R = 0.05$. As a result, the d-min values that determine the resolution for a structure refinement will be limited by the detector pixel size and can be calculated only to an uncertainty of 0.5, 1.5, and 3.0 Å for cubic unit cell sizes of 10, 30, and 60 Å, respectively. The targeted value for a structure analysis of atomic levels is the range of the shortest interatomic distances, which are ~0.8 to 1.3 Å. These are the lengths of the short hydrogen bonds to which neutron scattering is especially sensitive, a quality that complements X-ray scattering techniques. This means that on current instruments, atomic resolution can be achieved only up to unit cell sizes of ~30 Å. However, interest in larger unit cell materials, up to and beyond 100 Å, is increasing; with a spatial resolution of 1 × 1 mm, this unit cell size can be achieved.

Note that even with state-of-the-art data collection at low temperature on synchrotron radiation sources, X-ray diffraction cannot compete with the accuracy obtained from neutron diffraction when interactions involving hydrogen atoms are of interest. Many cases can be found in the literature where incorrect structures have been assigned based on refined positions of hydrogen atoms that eventually were shown to be erroneous when neutron diffraction results became available.

With suitable new detector technology, the SNS SCD will be able to contribute to research fields that can only be poorly investigated today. A new detector with 1 mm^2 resolution, high detection efficiency, and high dynamic range will make possible studies of diffuse scattering of weak scatterers and organic structures. These include studies of disorder caused by statistical effects, thermal effects, and phase transitions. Some research areas that will benefit from this capability include coordination chemistry, template-directed solid-state organic synthesis, reactivity in transition metal hydrides, and the study of ligands.

For the next generation of single-crystal diffractometers, the emphasis of the science and the required instrumental capabilities will shift considerably, from long-range structure refinements to functional structure determination. The instruments will need higher sensitivity for smaller crystal sizes, and to reach this goal they will need a new scintillator that can discriminate against γ-radiation. They will also need a scintillator that is transparent to light so that higher energy neutrons can be used to probe shorter length scales.

2.5 INELASTIC CHOPPER SPECTROMETER INSTRUMENTS

Chopper spectrometers are direct-geometry inelastic scattering instruments that use mechanical rotating devices to select, by time of flight, neutrons of a desired incident energy. These neutrons then scatter from a sample, and their final energy is determined by their time of flight to fixed detectors. This technique is complementary to triple-axis spectroscopy, which uses crystals to define the incident and final wavelengths for the measurement. Although chopper spectrometers do not take advantage of a wide band pass of neutrons, having very large areas of fixed detectors enhances their efficiency. Since inelastic scattering is weak, the detectors used must be of high efficiency with very low dark count rates. Typical research topics include studies of vibrational excitations and their relationship to phase diagrams and equations of state of materials, including materials with correlated electrons, and studies of spin correlations in magnets, superconductors, and materials close to metal-insulator transitions.

Overall, current ^{3}He detectors are just sufficient for the detector needs for chopper spectrometers. Given sufficient filling pressure, they are quite efficient even up to the epithermal energy ranges used at spallation neutron sources, and they have good gamma rejection and dark count rates. However, several areas could be improved. For spectrometers that use multiple-disk choppers optimized for cold neutrons, one major component of the energy resolution is the flight path uncertainty because the detectors are typically cylindrical with diameters of ~2.5 cm. This has been overcome for current reactor-based instruments by using flattened tubes, but these are not available with linear position resolution. Linear position-sensitive, flattened tubes would allow single-crystal experiments for cold neutron multichopper spectrometers. Another drawback with current linear position-sensitive detectors is that high intensity in one spot causes the loss of sensitivity for the entire tube for a recovery period. This can be caused by the elastic scattering from single crystals, where Bragg peaks can mask the subsequent inelastic signal. One way to lessen this effect is to use pixelated detectors so that only a few pixels are affected by the overload condition. This would also improve the spectrometer Q resolution, which would be preferable for detailed studies of single crystals. As a final area of improvement, the cost of the detectors for chopper spectrometers is a relatively large part of the instrument total cost. For current SNS instruments, this is estimated to be typically 25% or more of the budget. Improvements in the cost per square meter could open the possibility for improved instrument performance by making more detector coverage affordable.

2.6 DISORDERED MATERIALS DIFFRACTOMETER

Most of the structural controls on the physical, thermodynamic, and optical properties of amorphous and glassy materials result from structural differences in the intermediate range ordering, which is often difficult to probe for amorphous materials. Understanding and controlling structural features that give rise to intermediate range order (IRO) in templated amorphous materials remains a fundamental yet unresolved question. Recent demonstrations have shown the possibility of employing principles of crystal engineering to design specific patterns of IRO within amorphous zinc-chloride networks by using alkylammonium cationic templates. As such, amorphous materials have been engineered that exhibit strong, low Q-space diffraction peaks. As materials are designed with larger features of IRO, the low Q limit of the Glass, Liquid, and Amorphous Materials Diffractometer on the IPNS has been reached (the practical low Q limit is 0.5 $Å^{-1}$). The disordered materials diffractometer (NOMAD) at SNS will uniquely facilitate the characterization of these materials with its Q range of 0.015 to 50 $Å^{-1}$. The resolution at high Q is required to obtain accurate measurement of the atomic connectivity and distributions of defects, whereas the low Q resolution is required to probe features of intermediate range order on nanometer length scales.

In addition, some classes of materials have been shown to undergo a series of amorphous (i.e., amorphous and pressure induced crystalline) transformations with the application of pressure and temperature. Only recently are we beginning to understand the true nature of such transformations through detailed structure factor and pair distribution function analysis, although details of the intermediate range order of such amorphous systems are still lacking (particularly the extent to which pressure amorphized solids retain a memory of the original crystalline structure). Water ice and supercooled liquid water are extremely important, and we do not yet have relevant examples of such materials where the detailed nature of these transformations is well understood. The higher real-space resolution enabled by the larger reciprocal space coverage of the NOMAD when combined with modern reverse Monte Carlo and molecular dynamics modeling techniques should provide much more detailed understanding of the mid- to long-range order in such systems. In addition, the intense neutron flux at SNS will allow certain data to be acquired on the minute time-scale facilitating kinetic studies of the transformation processes.

Neutron scattering from liquids, glasses, and amorphous materials imposes several rather limiting constraints on instrument geometry and detector type. Two of the requirements are conflicting, namely the need to correct for inelastically scattered neutrons and the requirement for large Q-space or momentum transfer coverage, and a modern high-performance instrument must strike a careful balance between the two. Low momentum transfer (i.e., low Q) data are often required to probe the intermediate and longer length scales within a material; this is critical when studying disorder in nanophase materials. A $Q_{min} = 0.015$ $Å^{-1}$ can be achieved in the lowest angle banks with ~4-Å neutrons. In addition, large momentum transfers are generally required to increase the real-space resolution and help reduce the introduction of spurious oscillations during the Fourier transform of the data into real space. The current design goal is to provide data at $Q \sim 50$ $Å^{-1}$, which can generally be obtained only in the higher angle detector banks. To place the measured scattering function on an absolute scale, the inelastically scattered component must be calculated and removed. Although this is fairly well understood and straightforward, systematic problems are frequently encountered because the magnitude of this correction increases substantially with increasing scattering angle and increasing neutron wavelength (absorption and multiple-scattering corrections also increase with wavelength). Thus, all the data must usually be collected below $2\theta = 40\text{-}50^o$.

Given these primary constraints, it can be shown that a momentum transfer of $50Å^{-1}$ at $2\theta = 40\text{-}50^o$ is obtained using <0.1-Å neutrons. Thus, this instrument requires detectors that are as efficient as possible, not only at longer wavelengths but also in the 0.05- to 0.5-Å epithermal region of the spectrum. To achieve these goals, a new bright, transparent scintillator is needed. A detection system based on a transparent scintillator should be able to achieve a 20% detection efficiency for the shortest wavelength neutrons, where the neutron capture cross section is smallest. The standard scintillator is LiF-ZnS, which is opaque to its own light and cannot be made thick enough to efficiently detect epithermal neutrons. This severely limits the accuracy of the Fourier transform and the resolution of the data. Although standard ^{3}He detectors have also been used for such instruments, they cannot provide the desired efficiency at short wavelengths and suffer from data rate limitations that would prevent optimal use of such an instrument at SNS.

2.7 ENGINEERING DIFFRACTOMETER

The engineering diffractometer (Vulcan) at SNS is optimized for the study of a variety of structural features important in engineered materials and systems. This includes such diverse research as the study of residual stress in fabricated components and study of the microstructure and its variations throughout fabricated parts and processed materials. The desired performance for Vulcan, as determined by the user community, includes two measurement capabilities. The first is rapid volumetric (3-dimensional) mapping with a sampling volume of 1 mm^3 and a measurement time of a few minutes, and the second is very high spatial resolution (0.1 mm) measurements in one direction with a data acquisition time of minutes. The requirements also include the ability to measure ~20 well-defined reflections for in situ loading studies, the characterization of kinetic behavior on subsecond timescales, and simultaneous characterization capabilities, including dilatometry, weight, and microstructure.

To achieve these performance goals, four types of detectors are envisioned for Vulcan:

A. high-angle detectors for diffraction experiments,
B. an area detector for small-angle scattering,
C. a linear position-sensitive detector for imaging with 0.1-mm spatial resolution, and
D. a linear position-sensitive detector with a high data rate capability for transmission measurements.

For type A detectors, the primary requirement is count rate. For in situ studies with a large sample, the estimated instantaneous data rate is 2×10^5 counts/s/cm^2. A high data rate is absolutely essential for the study of kinetic behavior. Examples include phase transformations as well as development of residual stress in a composite material during cooling. A second requirement for type A detectors is efficiency, especially for short-wavelength neutrons (>50% at 1 Å). A third requirement is spatial resolution (6-12 mm) in the scattering plane. The second and third requirements must be considered within the context of cost. The rate and resolution requirements for Vulcan are similar to those for the SNS powder diffractometer, and the detector that is developed for that instrument should suffice for this application as well.

Requirements for the type B detector are 1-mm spatial resolution and a 20- × 20-cm^2 active area. This resolution requirement is a factor of two smaller than can be achieved with a standard 2-dimensional multiwire proportional counter. A higher resolution detector would allow study of 1-mm samples.

For type C detectors, the primary requirement is spatial resolution on the order of 0.1 mm, while operating in time-of-flight mode. A 10- × 10-cm^2 active area should be adequate. Applications include determining the evolution of residual stress depth profiles in surface-engineered components. Great progress has been made in neutron optics for imaging with 0.1-mm spatial resolution; the detector is the bottleneck. Although detectors exist that will meet this resolution requirement, none operate in time-of-flight mode.

Type D detectors will be useful for fast measurement of residual stress. Because this application involves transmission geometry, the data rate will be in the 0.1- to 1-GHz range. A spatial resolution of ~1 mm should be adequate. This requirement is similar to that for the high-rate SANS detector, only scaled down in size to 10 × 10 cm^2.

2.8 POWDER DIFFRACTOMETER

The general-purpose powder diffractometer at SNS represents the next generation in time-of-flight diffractometers. Through the use of a converging supermirror guide and a large pixelated continuous detector bank, a very high flux on sample is achieved with high-resolution data collection over a large Q-range. These combined capabilities will enable users to perform full parametric studies on complex crystallographic solid-state materials. To take full advantage of this instrument, the detector count rate at high-***Q*** (i.e., *d*-spacings 0.4–0.8 Å) must be sufficient to allow precise crystal structure refinement. This implies that the detector must be efficient for measuring epithermal neutrons. In a parametric or stroboscopic experiment where there might be only 30 pulses of the source (i.e., 0.5 seconds of data) for each diffraction measurement, the count rate at high-***Q*** will limit the complexity of the material that can be studied. Complex materials with large unit cells naturally divide their Bragg intensity between greater numbers of reflections over the 0.4- to 0.8-Å *d*-spacing range. For a precise crystal structure refinement, however, a threshold number of counts must be recorded for each Bragg reflection. Consequently, when a short measurement time is used, the unit-cell complexity attainable is related to the absolute count rate of the detector configuration.

Today's benchmark in large pixelated scintillator technology was developed by ISIS and is used on the General Materials Diffractometer (GEM) and the High-Resolution Powder Diffractometer (HRPD). The ISIS detector modules have two significant shortcomings, low absorption efficiency for short-wavelength neutrons and high fabrication cost for individual detector modules. The low absorption efficiency is a particular concern for the SNS diffractometer because it will typically use only 0.5- to 1.5-Å wavelength neutrons compared with GEM and HRPD, which use a much broader range of wavelengths (0.5–4.0 Å). The development of a bright transparent scintillator would lead to a 60% increase in count rate of the SNS diffractometer at high Q (40% increase at low Q) and would significantly improve real-time data. Since such an improved scintillator would allow the use of alternative cheaper detector module designs (e.g., wavelength shifting cross-fiber modules), a significant count rate increase could be achieved by installing more detector modules for the same cost.

2.9 SUMMARY

An important milestone for research at neutron-scattering facilities will be to collect real-time parametric data, and this will not be possible without new detector technology. The ability to study dynamic systems is crucial for advancement in condensed matter physics, materials science and engineering, and geosciences. For biosciences, new detectors are needed before studies of weakly scattering samples become feasible, and these studies are a core component of research in this field. Moreover, not only will successful detector development improve current research, it will also make possible important new research in several scientific fields.

SNS will be an unmatched neutron-scattering facility and will be useful for a wide range of science, even if forced to continue using current detector technology. However, as shown in the few cases illustrated here, without improved detector systems, it will not reach its potential. The capabilities of the beam transport and data acquisition systems are well matched to the source brightness—only the detector systems lag behind. Because SNS will be the most powerful facility for neutron scattering in the United States, the examples provided here were drawn from needs specifically identified for SNS instruments. However, realization of any of the improved detection capabilities identified here would quickly find its way to existing and new instruments at reactor sources and other spallation sources in the United States and elsewhere. A modest investment in detector development, directed specifically at solving some of the most pressing problems identified here, would pay back again and again as it will significantly benefit the research of hundreds of scientists for several decades.

2.10 CONTRIBUTORS

John Ankner:	Instrument Scientist for the Liquids Reflectometer at SNS
Jason Hodges:	Instrument Scientist for the Powder Diffractometer (Pow-Gen 3) at SNS
Christina Hoffmann:	Instrument Scientist for the Single-Crystal Diffractometer (SNS-SCD) at SNS
Frank Klose:	Instrument Scientist for the Magnetism Reflectometer at SNS
Chris Tulk:	Instrument Scientist for the Amorphous and Liquids Diffractometer (NOMAD) and the High Pressure Diffractometer (SNAP) at SNS
Xun-Li Wang:	Instrument Scientist for the Engineering Diffractometer (Vulcan) at SNS
Jinkui Zhao:	Instrument Scientist at SNS for the Extended Q-range SANS at SNS

Additional Contributors to the NOMAD Science Case:

Josef W. Zwanziger:	Indiana University
James Martin:	North Carolina State University
Martin Wilding:	University of California, Davis
R. Weber:	Containerless Research Inc.

3. DETECTOR DEVELOPMENT ROADMAP

3.1 INTRODUCTION

In July 2002, a workshop was held at SNS to address the gap between detector requirements at high-powered neutron-scattering facilities and the performance of the current generation of neutron detectors. Representatives attended this meeting from the neutron users community, the neutron detector research community, the European neutron-scattering community, and SNS. Presentations outlined detector requirements for the new neutron-scattering facilities and reviewed the state of detector research in the United States and Europe. A schedule of the workshop is attached.

Subcommittees were formed to evaluate the instrument requirements in detail and to suggest possible detector research that could reach these goals. The subcommittees were organized by detector category. Separate groups considered the applications for ^{3}He detectors, scintillator-based detectors, solid-state detectors, and detector electronics. A plenary session was then held to combine these contributions into a detector development roadmap.

A summary of the results from this meeting was presented to DOE in August 2002. During that meeting, the detector development collaboration was encouraged to document the detector deficiencies and the roadmap for R&D that would systematically eliminate them. This section presents these items and defines the situation as of February 2003.

3.2 INSTRUMENT REQUIREMENTS

Because the sciences that use neutron-scattering facilities are so diverse, the instruments at these facilities are customized to address the needs of specific fields. There are, for example, diffractometers that measure the structure of crystals, powders, engineering materials, and amorphous materials. There are also spectrometers that measure inelastic processes in different energy and momentum transfer ranges, reflectometers that are used to study surfaces and magnetic materials, and small-angle scattering instruments to study biological systems. The emphasis of an instrument's design is driven by the requirements of the fields under study, and to make a significant contribution to the given science, neutron-scattering instruments must meet certain specifications. They must be able to measure the neutron energy, scattering angle, energy transfer, and position resolution with an accuracy that guarantees useful data. Not all instruments measure all of these parameters; only spectrometers measure energy transfer for example. The emphasis also varies greatly. The position resolution needed on a radiographic instrument might be 100 μm, whereas it could be several centimeters on a powder diffractometer. The instruments must also collect data in a reasonable amount of time, with "reasonable" ranging from milliseconds to days, depending on the experiment. Real-time parametric studies favor a complete data set in less than a second;, but for inelastic experiments, days may be required to complete a run.

To define the requirements posed by such diverse scientific applications, the SNS instrument scientists were surveyed, and extensive discussions were held to ensure that the requirements were being interpreted properly. Neutron energy resolutions and peak data rates were redefined using detector system parameters. Because the time-of-flight method is used to determine neutron energy, energy resolution in the detector system is determined by the timing accuracy of the detector and the pixel size. Peak data rates are given in the units that are the most demanding for a detector system. To generate these parameters, both the spatial distribution and the time of arrival of scattered neutrons on the detector system were considered for a typical high rate data set.

Table 3 shows the detector portion of the instrument requirements for the first set of SNS instruments. The data are for fully populated detector systems. This table will be expanded as more facilities are surveyed and more results come in. Note that although they are not specifically listed, detector requirements for SANS and reflectometer instruments at high-powered reactors should be similar to the values listed. The requirements in this table set new precedents—in some cases, the values are two orders of magnitude higher than at any other spallation source. When these requirements are met, SNS will be operating at its full potential.

Table 3. Instrument requirements

Instrument	Number of pixels	Pixel area (cm^2)	Maximum neutron energy (eV)	Neutron capture efficiency %	Gamma efficiency	Time resolution (μs)	Peak pixel count rate ($n.s^{-1}$)	Detector count rate ($n.s^{-1}$)	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	50	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
SANS 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
ARC Spectrometer	70,000	2.5	1.0	50	10^{-7}	1	1×10^6 (Bragg)	5.0×10^5	4
CNC Spectrometer	15,000	6.3	0.05	50	10^{-7}	1	1×10^6 (Bragg)	7.0×10^6	56
HRC Spectrometer	70,000	2.5	1.0	50	10^{-7}	1	1×10^6 (Bragg)	4.0×10^5	3.2

3.3 DETECTOR DEFICIENCIES

Although many of the instrument requirements can be met with the present generation of detectors, for almost every instrument there is at least one serious detector deficiency that will limit its performance. Table 4 lists these deficiencies and clearly shows that detector R&D can make a significant impact. Although the magnitude of the needed improvements ranges from two orders of magnitude in rate capability to a 60% increase in efficiency, each individual improvement has the potential to open up significant new scientific possibilities.

Table 4. Detector deficiencies for SNS instruments

Instrument	Parameter	Desired	Current	Comment
Liquids & Magnetism Reflectometers	Pixel area (cm^2)	0.01	0.02	0.02 is state of the art for ^3He 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 1 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 50eV 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

3.4 DETECTOR DEVELOPMENT

Because neutron instrumentation uses scattered neutrons in a number of ways, detector requirements vary greatly. As shown in Table 4, detector systems range from small, high-resolution imaging devices to large detector banks that cover 20 m^2. In addition, neutron-detection efficiency requirements vary by nearly two orders of magnitude, and maximum pixel rates can vary by a factor of 10,000. The dominant criterion that drives detector choice could be efficiency, gamma sensitivity, time resolution, cost, etc. Consequently, several types of detectors have evolved. For convenience, here we review detector requirements by detector type.

3.4.1 Gas Detectors

For SANS, spin-echo, high-pressure, and reflectometer instruments, the detector design is driven by gamma sensitivity and rate. The gamma sensitivity issue forces the detector to be a gas-based, 2-dimensional, position-sensitive detector rather than a scintillator. At the workshop, the gas detector subcommittee concluded that multiwire proportional counter technology would not meet the high rate requirements. The detector will need to have discrete pixels that are read out in parallel, and the chamber will need to operate in ionization mode. For almost all applications, the maximum desired number of pixels per detector is fixed at ~40,000. This is because small detectors have small pixels and large detectors have large pixels.

During discussions following the workshop, it became clear that other options such as multilayered GEM or Micromegas-based detectors might fulfill the requirements for a subset of these instruments. However, because of its broad range of applications, the ionization mode detector with individual pixel readout remains the highest priority.

3.4.2 Scintillator Detectors

For the powder, engineering, single-crystal, and disordered materials diffractometers, the area coverage of the detector systems ranges from 5 to 10 m^2. This large coverage combined with small pixel sizes, high neutron detection efficiencies, and 1-μs time resolution eliminates all but the scintillator option. The scintillator detector subcommittee reported that because of the severe limitations caused by the opacity of the standard LiF-ZnS scintillator, research into a new bright, transparent neutron scintillator was the highest priority. In addition, new readout schemes such as wavelength shifting fibers and advanced Anger cameras should be developed to maximize the performance of these large detector systems, while keeping them affordable.

3.4.3 Proportional Counters

When fully instrumented, the three inelastic chopper spectrometers will each have ~20 m^2 of detectors; this makes cost the driving factor for detector selection. Other considerations include stability for experiments that take several days, very low gamma sensitivity, high detection efficiency, and 1-μs time resolution. These criteria make 2.5-cm-diameter, linear position-sensitive proportional tubes the only current viable solution. Unfortunately, these detectors have significant shortcomings. Position resolution is a minimum of 1.5×2.5 cm^2, which can limit the Q-resolution. The tubes are cylindrical, which introduces a time-of-flight uncertainty that can be the limiting resolution factor for cold neutrons. Finally, a tube will saturate when it detects the neutrons from a Bragg peak and will not be sensitive to important inelastic data that arrive after the peak. To resolve these issues, research is needed on neutron-sensitive straw tubes, flattened linear position-sensitive detectors, or inexpensive multitube detectors.

The backscattering spectrometer nearly meets its design goals with small, linear position-sensitive tubes. Its performance could be maximized with an ionization mode detector system. Research into a high-rate SANS detector would provide the expertise to construct this detector as an upgrade.

3.4.4 Solid-State Detectors

In addition to these primary detector systems, some instruments need specialized, high-resolution imaging detectors and very high rate transmission detectors. Although no high-resolution detectors exist that will operate in time-of-flight mode, the solid-state detector subcommittee recommended research into solid-state detectors with conversion layers, or bulk converters, as the highest priority. These detectors, coupled with real-time readout systems, could fill this need. Other options include detectors based on Microsphere or Micromegas technology. Versions of these detectors redesigned for higher rates and lower resolution would also work for transmission detectors.

3.4.5 Electronics

The final category for development is electronics, which is needed to collect data from the detectors. Pixilated, high-rate detectors will need customized electronics mounted within the gas volume of the detector. This is necessary to optimize the signal-to-noise ratio of the detector and to minimize the penetrations through the pressure vessels. This will require research into integrated circuit materials that are radiation hard and will not contaminate the detector gas. With 40,000 channels of electronics in the chamber, heat transfer issues will also need to be resolved.

Electronics development will also be necessary to handle the large data sets that will be generated at the new high-power sources. The latest technologies for data transfer, processing, and storage will need to be applied. Fortunately, PC-based fiber-optic communication networks can be adapted for this task. The challenge is to monitor the progress within the communications arena and design systems that can take advantage of improvements in those fields.

3.4.6 Feasibility Studies for Other Technologies

The development areas listed previously are all aimed at near-term improvements. However, history has shown that occasionally quite new detection techniques are found, and these can sometimes open up exciting new types of scientific measurements. Therefore, the roadmap strongly endorses the concept of continuing to provide funding for small-scale feasibility studies in promising new areas. This is absolutely essential if we are to meet the increasing demands on detectors that are certain to arise in the future.

3.5 COORDINATION OF EFFORT

The roadmap includes support for workshops and collaboration meetings to ensure that detector research stays focused on the needs of the user community and on the forefront of detector technology. The communication task is especially important because the users and the detector development communities do not share common research interests. Information concerning desired or required detector capabilities will flow from the users community through the instrument scientists to an advisory panel. The panel will then make sure the detector research community is informed. Likewise, reports of significant progress will flow back to the user community by the same route.

In addition, support for detector research is very limited, worldwide. International cooperation will be necessary to optimize the progress for this modest effort. Fortunately, cooperation is in everyone's best interest, and the path forward is clear. The European community is concentrating most of its effort on detectors for steady-state sources, and the United States is focusing more on time-resolved measurements for spallation sources. The one exception is scintillator detector development. Several laboratories are working on these systems, and it is hoped that with better communication this effort can be streamlined. To further this international collaboration, researchers from Oak Ridge National Laboratory (ORNL) and Brookhaven National Laboratory (BNL) have submitted requests to be part of the European Framework Program 6 that is being organized. By becoming part of this effort, the research these scientists perform will not be duplicated in Europe. These scientists will also be observers on European research projects and will be kept current of progress made in the European laboratories.

Figure 1 shows the areas of detector research that are ongoing throughout the world and the number of institutions involved. The U.S. effort in orange (proposed) is not yet funded and represents the effort that is outlined in this roadmap. Note how this effort is complementary to the international effort that is under way.

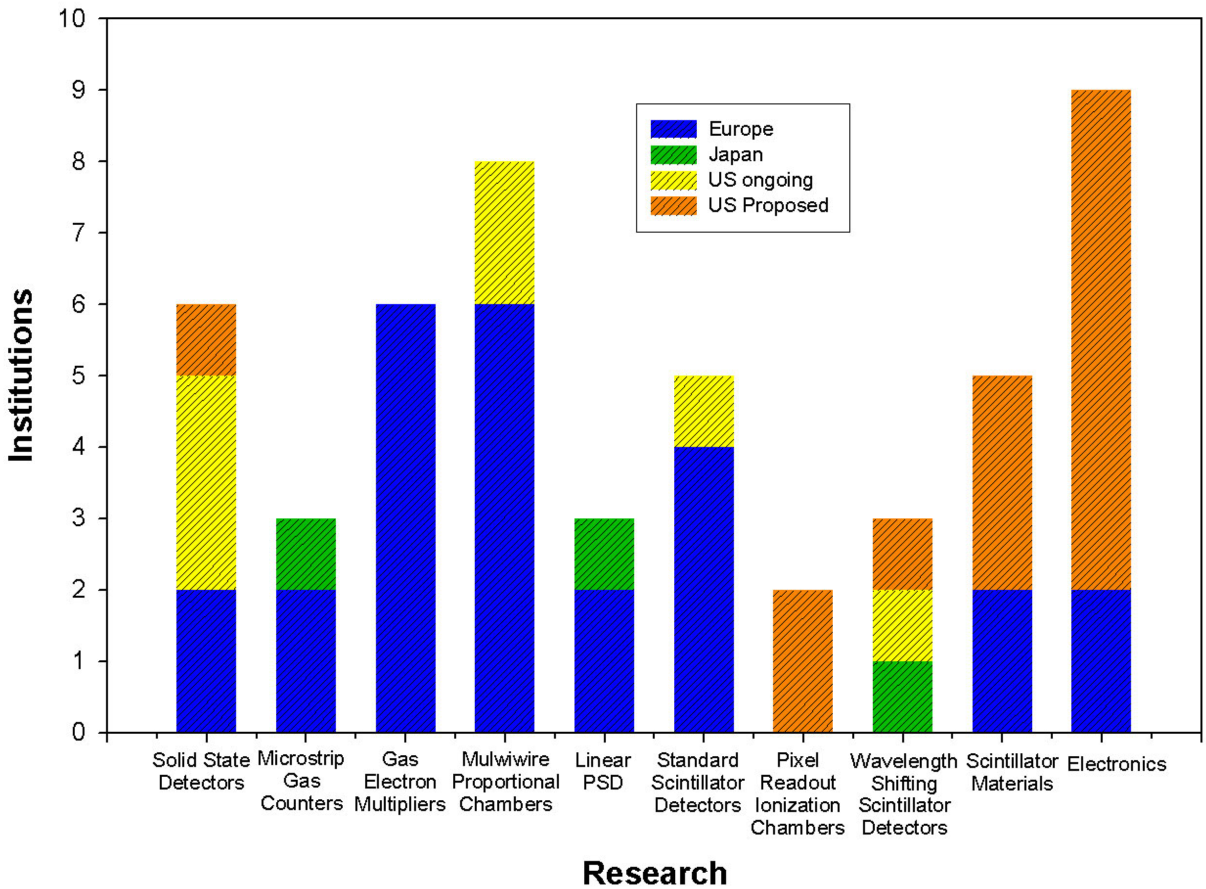

Figure 1. Worldwide detector research.

3.6 SCHEDULE AND FUNDING

3.6.1 Schedule

The need for detector development is immediate. Spallation sources such as ISIS and IPNS could benefit significantly from a new bright, transparent scintillator and improved scintillator readout schemes. High-powered reactor sources such as Institute Laue Laugevin (ILL), the National Institute for Standards and Technology (NIST), and the High Flux Isotope Reactor (HFIR) need high-rate SANS detectors and high-resolution imaging detectors. In the next few years, the need will become more immediate as SNS comes on line in 2006, JSNS comes on line in 2008, and ISIS is upgraded.

Because of the long lead time for detector development, it is already too late to provide optimized detectors for the initial suite of SNS instruments. The detectors that will be installed initially will significantly restrict the performance of the instruments. Nevertheless, the scientific benefit of improving the detectors is so significant that upgrade paths are already being planned. Where possible, the data acquisition electronics systems and detector enclosures are being designed to handle future detectors.

3.6.2 Funding

The roadmap calls for principal investigators to submit research proposals directly to the funding agency, which will allow for the greatest flexibility. However, detector development projects are long-term efforts that require a minimum of three years of sustained support, and a mechanism for providing continuing funding is needed. To achieve this, we hope that a new initiative for neutron detector development can be established, with a funding level of approximately $3M per year. This funding would provide support for the development of prototypes for high-rate pixel detectors, scintillator materials, scintillator detector systems, solid-state detectors, and electronics. These efforts are the core of the roadmap. In addition, this initiative would fund small speculative projects and the coordination efforts. New prototype efforts would be added when funds became available.

3.6.3 Coordination

The need for this development is great, and while the new initiative may take time to be established, the detector community plans to do all it can in the interim. In the near term, we plan to assemble an executive committee and an advisory panel to help make certain that proposed detector development activities are well matched to near-term and long-term national goals and that development activities in the areas having the greatest scientific payoff are strongly encouraged and given highest priority. Once assembled, a management plan will be put in place, and this system will be made available to the funding agencies and principal investigators to support the proposal review process.

The detector development collaboration plans to hold a second workshop at the Indiana University Cyclotron Facility this spring. The purpose of this workshop will be to reinforce the collaborative efforts we began last July and to expand the membership to include researchers at universities. The user-driven science case and the present version of the roadmap will be presented to the attendees. In addition, the management plan and contact information will be covered to help these researchers work within the roadmap. Finally, we will increase our efforts to coordinate projects with the European and Japanese communities.

Members of the detector community will continue to submit proposals through their respective funding channels, but stable support remains a serious issue. Only BNL, SNS, and Pacific Northwest National Laboratory (PNNL) support detector development with program funding. At BNL this is limited to ~1 full-time equivalent for gas detector development. At SNS the support level is similar for scintillator detector development. Unfortunately, the PNNL support is not focused on the needs of the neutron-scattering community.

Collaboration members have had recent success with Laboratory Director's Research and Development (LDRD) grants. These include a solid-state development effort at ANL, an unrelated solid-state effort at PNNL, and a transmission detector development effort at ORNL. Combining the program and LDRD support, the community is providing approximately 25% of the required funding. We hope that we will be able to receive support for a limited number of prototypes before the initiative is in place, and we will continue to work toward this goal.

When resources are limited, coordination and communication are critical. Funded research needs to be part of the roadmap so that it will be focused on the needs of the user community and have scientific merit. A great deal of progress is needed, but with a modest, sustained, and coordinated effort, the challenges can be met, and the high-powered neutron-scattering facilities will operate at their full potential.

4. MANAGEMENT PLAN

4.1 INTRODUCTION

To ensure that detector R&D activities make optimal use of the resources available, it is important to coordinate and streamline these activities with a national plan or roadmap. This plan will be designed to meet the detector needs defined by a broad user community. To provide the best scientific and technical guidance for this research activity, we propose a modest centralized coordination effort, guided by an advisory panel made up of technical experts and scientific representatives. As usual, R&D proposals will be submitted to funding sources by principal investigators of individual R&D groups, which will lead the specified R&D efforts. The role of the central coordinating organization will be to review the proposals, where necessary, making suggestions for improvements to bring the proposals more in line with the national plan. This central organization would endorse those proposals that are scientifically feasible and aligned with the plan. This endorsement would be transmitted to the funding agency that received the proposal and would indicate that the proposal has scientific merit and contributes to the plan, or roadmap.

4.2 NATIONAL PLAN FOR DEVELOPMENT OF NEUTRON DETECTORS

The purpose of a national detector development plan is to make sure that neutron detector R&D meets the needs of the neutron-scattering facilities and hence of the broad community of scientific users of neutron scattering. The plan will provide guidance to help make sure new U.S. detector development efforts are coordinated with other efforts in the United States and worldwide and will provide a guiding strategy to help prioritize the use of scarce R&D resources for detector development. To achieve these goals, three components are planned: (1) an executive committee to supervise the initiative, (2) an advisory panel composed of representatives from the neutron users community and detector development experts, and (3) a roadmap that outlines the detector development needs. These combined resources will make it possible to focus and coordinate detector development efforts within the United States. These resources will be able to provide direction to detector researchers and advice to the funding agencies. They will also establish a forum for monitoring the progress of the research efforts, updating detector development needs, and educating the next generation of scientists.

4.3 EXECUTIVE COMMITTEE

As shown in Figure 2, an executive committee will supervise the initiative. This committee will be staffed with a rotating membership drawn from representatives of the major neutron-scattering facilities. This representation will guarantee that the development roadmap will be kept current and focused on the needs of the user community. As part of these responsibilities, the executive committee will maintain close communications with the user community to keep the community informed about detector developments and ensure that the roadmap remains current. To achieve this, the executive committee will administer workshops, periodic reviews, and other meetings that support the roadmap and will call on the advisory panel for advice as needed. SNS will coordinate the activities of this executive committee.

We hope that all or at least most of the proposals for funding for neutron detector R&D activities will be directed to this executive committee for review. The committee can receive proposals from the principal investigator before submission to the funding agencies or from the funding agencies upon receipt of the proposal. The role of the executive committee regarding such proposals will be limited to providing recommendations to the principle investigators and reviews to the funding agencies when requested. Principle investigators who request assistance will be advised about the goals of the roadmap and how the proposal can be made relevant. Funding agencies will receive recommendations as to whether or not the proposal is in line with the national plan and will contribute to the plan. The committee will call on the scientific and technical panel for guidance in this process. If the proposal is judged to be in keeping with the national plan and to represent an effective use of resources, the committee will issue an endorsement to this effect. If not, the committee may recommend improvements to the proposal to help bring it in line with the national plan. The funding agencies will continue to follow their usual process for deciding whether or not to fund specific proposals, but they will have the additional piece of information provided by an endorsement or lack thereof from the executive committee.

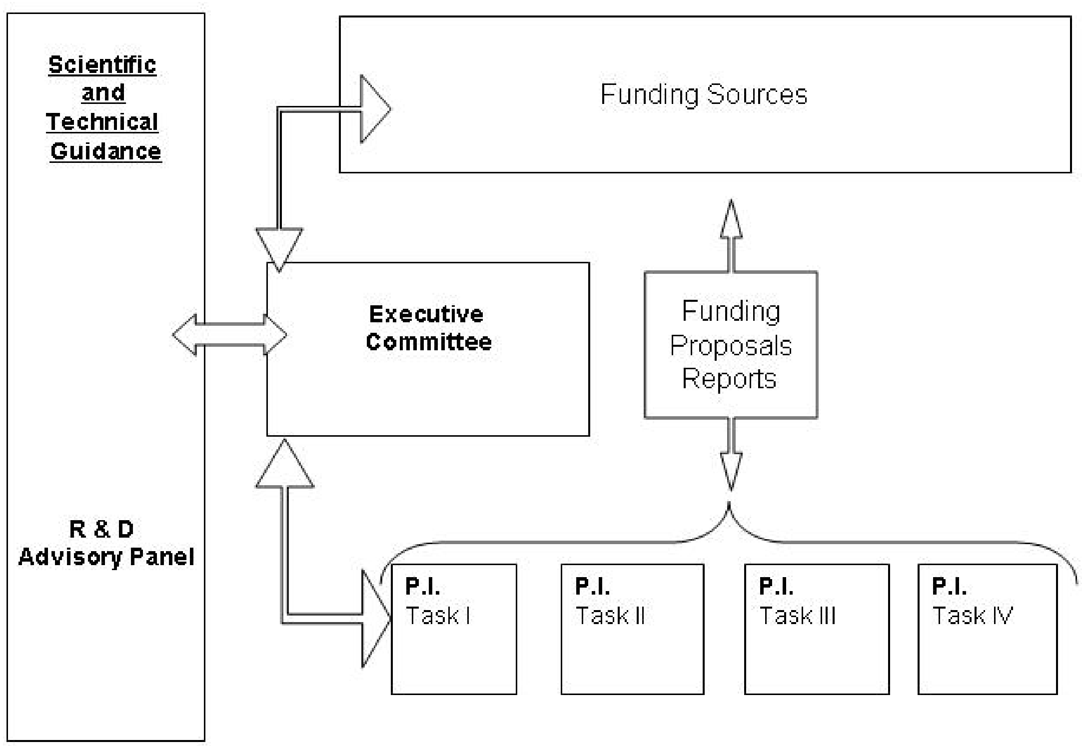

Figure 2. Detector development management plan.

The other responsibility of the executive committee will be to establish the national plan, keep this plan current, and track progress on the plan. The plan will be maintained in the form of a "white paper," which will be a living document that is revised periodically. This document represents the current version of the plan. Technical and user workshops have played and will continue to play an important part in this process. All actions of the executive committee will be documented through meeting minutes and/or periodic reports.

4.4 R&D ADVISORY PANEL

The R&D advisory panel will supply expert support to the executive committee. It will review proposals for scientific merit and neutron science relevance and will provide advice on technologies worthy of development consistent with the needs identified in the roadmap. This panel will consist of neutron detector experts and scientists from the user community. Membership from the user community should be large enough to accurately represent the needs of this diverse community. Instrument scientists are well suited for this task as they are aware of the needs of a number of groups. The detector experts will be chosen to represent the major areas of specialization within the field of neutron detector research. We estimate that approximately 12 people will serve on this panel. To help coordinate activities in the United States with those elsewhere, some members will be from Europe and Japan.

4.5 ROADMAP DOCUMENTATION

The roadmap will serve as the reference document that guides neutron detector research. It will contain a description of the instruments that can benefit from detector development, a list that summarizes the detector deficiencies, and an overview of the science case for detector research. It will also contain technical descriptions of the detector requirements that can serve as a basis for proposals.

The roadmap will be developed by the executive committee based on input from the R&D advisory panel, user workshops, and other sources. A set of detector requirements for both steady-state and pulsed sources will be established. These detector requirements will be compared with present-day detector capabilities, and detector requirements and deficiencies tables will be generated. This process will be repeated on a periodic basis to keep the roadmap current.

APPENDIX

JULY 2002 DETECTOR WORKSHOP AGENDA

Detector Workshop July 2002

List of Attendees:

Ian Anderson	SNS	Don Hutchinson	ORNL
Jennifer Brand	UNL	Lee Magid	UTK
Chuck Britton	ORNL	Nick Maliszewskyj	NIST
Bill Bryan	ORNL	Steven Naday	ANL
Ron Cooper	SNS	Anthony Peurrung	PNNL
Kent Crawford	ANL	Karl Pitts	PNNL
Lowell Crow	SNS	Roger Richards	ORNL
Pat DeLurgio	ANL	Brian Robertson	UNL
Al Ekkebus	SNS	Graham Smith	BNL
Bruno Guerard	ILL	Vincent Yuan	LANL
Bill Hamilton	HFIR		

Agenda

Friday, July 12, 2002

8:30 A.M. Continental Breakfast at SNS Building

9:00 A.M. Opening Remarks - Ian Anderson, SNS

9:10 A.M. European Detector Development - Bruno Guerard, ILL

9:40 A.M. Detector Development at BNL -Graham Smith, BNL

10:10 A.M. Break

10:30 A.M. Detector Development at ANL - Istvan Naday, ANL

11:00 A.M. Detector Development at ORNL - Don Hutchinson, ORNL

11:30 A.M. Detector Development at PNNL - Tony Peurrung, PNNL

12:00 P.M. Lunch

1:00 P.M. Detector Development at LANL -Vinny Yuan, LANL

1:30 P.M. SNS Detector Plans - Ron Cooper, SNS

2:00 P.M. European Framework Program 6	-	Ian Anderson for Mike Johnson, ISIS
2:30 P.M. Break		
2:45 P.M. Tour of SNS Site		- Al Ekkebus, SNS
6:30 P.M. Reception at the Italian Market		
7:00 P.M. Dinner at the Italian Market		

Saturday, July 13, 2002

8:30 A.M. Continental Breakfast	
9:00 A.M. Straw Man Collaboration	- Ron Cooper, SNS
9:30 A.M. Breakout Sessions	- Group
10:30 A.M. Break	
10:45 A.M. Sessions Continue	- Group
12:15 P.M. Lunch	
1:15 P.M. Review Sessions	- Group
2:45 P.M. Break	
3:00 P.M. Develop Preliminary Roadmap	- Group
4:00 P.M. Meeting Ends	