



*Office of Science and Technology Policy Interagency*

*Working Group on Neutron Science:*

*Report on the Status and Needs of Major Neutron Scattering*

*Facilities and Instruments in the United States*

*JUNE 2002*

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EXECUTIVE OFFICE OF THE PRESIDENT  
OFFICE OF SCIENCE AND TECHNOLOGY POLICY  
WASHINGTON, D.C. 20502

June 10, 2002

Dear Colleague:

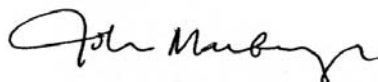
Advances in scientific instrumentation have led to new applications in medicine, microelectronics, and other fields that improve the lives of all citizens. One of these essential tools of modern science is neutron scattering. Neutron scattering plays an important role in opening new scientific frontiers and in establishing the nation's leadership in many fields of science and technology. In an effort to provide the essential tools for scientific discovery and technological advancement, the United States has made substantial investments in neutron scattering facilities that have reaped substantial benefits.

Since the initial development of neutron scattering techniques, we have seen remarkable changes in the science of neutron scattering, the range of applications, and the number of users. During the past decade, neutron scattering has found an increasing number of applications in materials and life sciences research. During this time, the number of users at U.S. neutron facilities nearly doubled, the overall number of instruments available dropped more than 15 percent, one major facility was closed, and the United States undertook the construction of one major new neutron facility, the Spallation Neutron Source. Such changes point to significant scientific opportunities as well as significant challenges in coordinating our efforts to assure that our vital national neutron scattering resources continue to play their essential role in science and technological development.

To this end, the Office of Science and Technology Policy asked an interagency working group to assess the state of the U.S. neutron scattering facilities and to make specific recommendations on how to maximize the impact and effectiveness of all of our facilities. In their enclosed report, the working group has reviewed the current status of the U.S. neutron scattering infrastructure and, for the first time, has made a detailed, comparative assessment of the performance of these facilities over the past 10 years. Using the lessons learned from this analysis the group recommends that the United States: (1) focus on developing high-quality instrumentation at the best sources; (2) establish a framework for using interagency partnerships to develop neutron instrumentation that ensures balanced use and access; (3) improve the coordination among all stakeholders in the nation's neutron facilities (agencies, facility management, and users); and, (4) invest in advancing the state of the art in neutron sources and methods. The group also ranks their recommendations in order of priority for implementation.

I am pleased to transmit to you the results of this review.

Sincerely,



John H. Marburger, III  
Director

## Table of Contents

Letter from the Director, Office of Science and Technology Policy .....	ii
Acronyms .....	iii
Executive Summary .....	1
Introduction .....	4
Neutron Science: Overview, Trends, and International Perspectives .....	7
Neutrons and their uses .....	7
What is neutron scattering? .....	7
Neutron sources for neutron scattering .....	8
Between sources and instruments .....	9
Scientific use of neutron scattering techniques .....	9
Trends in neutron scattering use .....	11
Biology research with neutrons .....	11
History of neutron facility development .....	12
Current status in the United States .....	13
Current international status .....	14
Findings .....	15
Conclusions .....	16
Assessment of U.S. Neutron Facilities .....	17
Comment on facility budget data .....	17
Facility data sheets .....	18
Facility Performance History .....	25
Detailed assessment for FY2000 .....	30
Conclusions .....	44
Recommendations and Priorities .....	45
Implementation of recommendations at U.S. neutron facilities: Priorities .....	48
Appendix: NSF-NIST Center for High Resolution Neutron Scattering .....	53
Table References .....	56
Figure References .....	59
Participation .....	60
References .....	62

## Acronyms

ANL	Argonne National Laboratory (DOE)
ANS	Advanced Neutron Source
BES	Basic Energy Sciences (DOE Office of Science)
BESAC	Basic Energy Sciences Advisory Committee
BNL	Brookhaven National Laboratory (DOE)
CHRNS	Center for High Resolution Neutron Scattering
DOC	Department of Commerce
DOE	Department of Energy
ENSA	European Neutron Scattering Association
ESF	European Science Foundation
HFBR	High Flux Beam Reactor (Brookhaven National Laboratory)
HFIR	High Flux Isotope Reactor (Oak Ridge National Laboratory)
ILL	Institut Laue-Langevin (Grenoble, France)
IPNS	Intense Pulsed Neutron Source (Argonne National Laboratory)
ISIS	Pulsed Spallation Neutron Source (Rutherford-Appleton Laboratory, UK)
IWG	Interagency Working Group
LANL	Los Alamos National Laboratory (DOE)
LANSCÉ	Los Alamos Neutron Scattering Center
NBSR	Neutron Beam Split Core Reactor (NIST)
NCNR	NIST Center for Neutron Research
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NNSA	National Nuclear Security Administration (DOE)
NSF	National Science Foundation
NSTC	National Science and Technology Council
OBÉR	Office of Biological and Environmental Research (DOE Office of Science)
OECD	Organization for Economic Cooperation and Development
ORNL	Oak Ridge National Laboratory (DOE)
OSTP	Office of Science and Technology Policy
SANS	Small angle neutron scattering
SNS	Spallation Neutron Source (Oak Ridge National Laboratory)

## **Executive Summary**

The use of neutrons as a probe of atomic or molecular structure and dynamics is an essential measurement tool for researchers in a wide variety of scientific fields including physics, chemistry, biology, materials science, earth science and engineering. Neutron scattering techniques are well suited to characterization of materials in high growth research fields such as nanoscience, biology, and polymer science, and demand for these techniques continues to increase. Production of high-intensity neutron beams for research requires large reactor- or accelerator-based neutron sources and advanced neutron scattering instruments to exploit the neutrons from those sources. The United States presently operates four major sources for neutron scattering, three at Department of Energy (DOE) laboratories and one at the National Institute of Standards and Technology (NIST). A fifth, the Spallation Neutron Source (SNS), is under construction at DOE's Oak Ridge National Laboratory. However, the United States is at a distinct disadvantage in overall neutron scattering capability per capita compared to Western Europe or Japan. Numerous reports have concluded that the vital role of neutron-based measurements in important scientific and technological areas will cause demand to outstrip the available supply in this country for the foreseeable future.

To explore ways to ensure that the U.S. neutron facilities, including the SNS, provide the maximum scientific benefit to the broadest possible research community in the most cost effective manner, the Office of Science and Technology Policy (OSTP) formed an Interagency Working Group (IWG) on Neutron Science. The initial charge to this IWG was to develop strategies to maximize the effectiveness of neutron facilities in the United States. Comprised of representatives from various federal agencies that either operate, or partner in the use of the major neutron facilities, the IWG was charged with conducting an in-depth review of the status of existing neutron scattering facilities and to recommend ways to maximize their use for U.S. science programs. Because of the impact of these facilities on a variety of scientific disciplines, several federal agencies share responsibility for various aspects of developing, operating or supporting their use. A primary goal of the IWG was to establish an effective mechanism of interagency collaboration to harness the benefits of constructive partnerships among these participating federal agencies for the U.S. neutron scattering infrastructure.

Based on findings from a detailed assessment of the U.S. neutron facilities, the IWG concludes: 1) the NIST facility is the only U.S. facility which currently provides a broad range of world-class capability, and 2) the completion of the SNS at Oak Ridge is the most significant new opportunity to provide world-leading neutron scattering capability in the United States. However, the IWG also finds that the SNS alone cannot provide the necessary neutron scattering capability and ways must be found to enhance the effectiveness of other sources as well. Thus, the IWG concludes that it is also important to improve both the number and quality of neutron scattering instruments at the Nation's best neutron sources and to broaden access to those facilities by the U.S. research community.



From these conclusions, the IWG recommends that:

**1. The highest priority for federal investments in neutron scattering is to fully exploit the best U.S. neutron source capabilities – including the SNS – for the benefit of the broadest possible scientific community.** Specifically, these investments should aim to:

- Fully develop at least 85% of available beam lines with neutron instrumentation that exceeds, or is at least competitive with international best-in-class instruments;
- Maximize the amount of beam time made available to the broad scientific community through an independent, peer-review based general user program;
- Provide resources to fully staff and support the high productivity operation of the neutron scattering instruments;
- Provide additional support for research using neutron scattering techniques.

**2. The steward agency for each of the major neutron facilities form partnerships with other federal agencies for the purposes of meeting the objectives of the first recommendation. These partnerships should be based on the following principles:**

- They must support the role of the steward agency;
- They must promote the role of the facility staff to manage and operate the instruments;
- They must provide adequate resources to develop instruments and to operate them in a robust user program;
- They must meet the needs of the U.S. research community and support the specific program objectives of the participating agencies;
- The scope and terms of the partnership should be mutually agreed upon by the partners and then clearly stated to all stakeholders;
- Participating agencies should use joint mechanisms to select and review projects in the partnership.

**3. A series of actions be undertaken to improve coordination between participating agencies, facility managers, and user organizations in order to maximize the overall effectiveness of the nation’s neutron resources. These actions include:**

- Continued interagency coordination through OSTP for the development and use of neutron scattering capability in the United States;
- The establishment of a regular venue for the management of the nation’s neutron facilities, to foster inter-facility cooperation, mutual planning and strategic planning for the neutron field, and to improve collaboration, and communication between the facilities;
- The steward agencies, in coordination with neutron facility management, should take steps to foster improved communication and coordination between the user communities (through their representative organizations) of the neutron facilities.

**4. Participating federal agencies promote and coordinate efforts to advance neutron scattering methods and neutron source technology needed for the future.**

Specifically, this includes promoting:

- Upgrades and enhancements to neutron scattering instruments;
- Research and development in neutron source (including moderator) technology;

- Efforts to develop new and improved neutron scattering methods; and
- Efforts to expand the application of neutron scattering to new areas of science.

The IWG has also established the priorities for applying these recommendations to the neutron facilities:

1. The Department of Energy, the National Science Foundation, and other interested agencies should immediately establish a framework for an interagency partnership to provide funding resources to develop and operate a robust suite of instruments, approximately 75% of full instrumentation, to address a broad spectrum of neutron scattering measurements at the SNS. To be timely, the framework for instrument development should be affected within the next six months.
2. NIST and the Department of Commerce along with their partners, including the NSF, should continue to fully support the operations of the NCNR, continue improvements in source and instrument capability, and seek increased levels of support for both the NIST research program and to support the general user program. In addition, because of the essential role of this facility to the nation's neutron measurement infrastructure, the IWG recommends that NIST and the Department of Commerce fully support all activities related to the license renewal for the NIST reactor by the Nuclear Regulatory Commission.
3. The Department of Energy should fully support the cold source and instrument upgrade project at the High Flux Isotope Reactor (HFIR) and ensure that the instruments are operated to support a robust general user program.

## Introduction

The scattering of low-energy thermal and cold neutrons from samples yields important and unique information about the atomic or molecular structure and the dynamics of materials. The importance and high scientific and technological impact of neutron scattering research activities has been well documented in a number of important reviews (many of which are referenced in the bibliography of this report). These reports find that neutron scattering plays a vital role in a very broad range of scientific and technological areas and that demand for this measurement capability will continue to far outweigh supply for the foreseeable future. As noted in *Neutron Sources for America's Future*<sup>1</sup> (hereafter referred to as the Kohn panel report):

*“Neutrons provide critical information that is impossible to acquire by any other means. For many purposes they provide a necessary complement to x-rays, and the parallel development of both neutron sources and x-ray synchrotron sources is essential.”*

The United States currently operates four major neutron sources for neutron scattering research. All of these facilities were developed between the late 1960's and early 1980's. The Department of Energy is host to three of these facilities, including the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory, the Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory, and the Los Alamos Neutron Scattering Center (LANSCE) at Los Alamos National Laboratory. Another DOE facility, the High Flux Beam Reactor (HFBR) at Brookhaven National Laboratory was permanently shutdown in 1999. The Department of Commerce is host to the fourth operating facility, the NIST Center for Neutron Research (NCNR), at the National Institute of Standards and Technology's main campus in Gaithersburg, MD. In addition to these operating facilities, the Department of Energy is constructing a major new neutron source, the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. The SNS will provide a world-leading neutron source capability in the United States for the first time since the early 1970's. These neutron source facilities represent a tremendous national investment; the SNS will cost \$1.4B to build and the four operating facilities have a combined replacement cost of over \$3B.

In spite of the size and cost of these major facilities, the United States is at a distinct disadvantage in the overall amount of neutron scattering capability per capita compared to Europe and Japan. Further, new advanced sources and instrumentation that are planned or under construction in Europe and Japan will keep these regions in a strong or superior position internationally for the foreseeable future. The recent report from the National Academy of Sciences, *Experiments in International Benchmarking of U.S. Research Fields*<sup>2</sup>, looked at indicators of leadership position in materials research and found that “in some areas, such as neutron scattering, U.S. facilities have not kept up with foreign competition.” Because of the very high cost of new neutron sources and the competing demands for limited resources for priority projects in other scientific areas, the immediate U.S. goal is to complete construction of the SNS source and to ensure that the U.S. neutron scattering infrastructure provides the maximum scientific resources to the broadest possible user community in the most cost effective manner.

The large investments required to develop, maintain and operate neutron source facilities combined with the diverse multidisciplinary use of these facilities by researchers has led to

a split approach to funding and managing these facilities, called the “steward-partner model”. This model was the focus of a recent report from the National Research Council, *Cooperative Stewardship: Managing the Nation’s Multidisciplinary User Facilities for Research with Synchrotron Radiation, Neutrons, and High Magnetic Fields*<sup>3</sup> (hereafter called the *Cooperative Stewardship* report). The steward-partner model for neutron facilities is based on making a functional distinction between the source and the research parts of the facility:

- The **source facility** is that portion of the neutron facility that produces the neutron beams. Typically this includes the development and operation of the reactor or accelerator and often the associated moderator systems.
- The **research facility** is the part of the facility that uses the neutron beams. Typically this includes the beam delivery systems, instrument systems, supporting shops and laboratories and all the staff and program support needed to conduct research and support a user program at the facility.

In the steward-partner model, a single government agency (the steward) funds and manages the neutron source facility. Funding and management for the research facility, however, is diversified. It includes the steward, but it can also include other federal agencies, industries, or private institutions (the partners). Funding of major new scientific facilities routinely embody the principles of the steward-partner model when defining the scope of the source construction project. For example, DOE’s project funding for the SNS construction includes the full cost of developing the source, but only includes a small suite of about five instruments in the project baseline. Consistent with the steward-partner model, there is an expectation (although not a formal arrangement) that DOE will develop the remainder of the research facility outside of the formal project in conjunction with other partners.

The steward-partner model can satisfactorily provide facility resources to the scientific community if: 1) the steward meets its responsibility to operate the source; and 2) if there are adequate and stable resources from the steward and partners to provide full development and robust operation of the research facility. Indeed, the *Cooperative Stewardship Report*<sup>3</sup> noted that this approach has historically proven superior to other cost sharing models attempted for these types of facilities (including diversified funding of total facility costs, host-parasite models and cost recovery through user fees). However, a variety of issues can adversely impact the effectiveness of the steward-partner approach to funding and managing major research facilities.

To address these issues for U.S. neutron facilities, the Office of Science and Technology Policy (OSTP) formed an Interagency Working Group (IWG) on Neutron Sciences. The initial charge to the IWG was to develop strategies to maximize the effectiveness of the neutron facilities in the United States. This is a particularly opportune time since the effective use of the SNS by the science community depends upon promptly identifying specific mechanisms to fund the instrumentation and operation of the research facility. A primary goal of the IWG was to establish an effective mechanism of interagency collaboration so that the benefits of the steward-partner approach can be fully realized for the vitally important U.S. infrastructure in neutron scattering. This goal echoes calls for similar interagency mechanisms in the *Cooperative Stewardship Report*<sup>3</sup>, in the National Science and Technology Council (NSTC) report on *Improving Federal Laboratories to*

*Meet the Challenges of the 21<sup>st</sup> Century: An Action Plan*<sup>4</sup>, the report from the OSTP IWG on Structural Biology at Synchrotron Radiation Facilities, *Synchrotron Radiation for Macromolecular Crystallography*<sup>5</sup>, and the DOE's Basic Energy Sciences Advisory Committee (BESAC) report, *Subpanel Report of the Intense Pulsed Neutron Source at Argonne National Laboratory and the Manuel Lujan Center at Los Alamos National Laboratory*<sup>6</sup>.

The IWG was comprised of representatives from various federal agencies that either operate, or partner in the use of the major neutron facilities. OSTP charged the IWG with conducting an in-depth review of the status of existing neutron scattering facilities, including their operational schedules, facility budgets, staffing levels, neutron measurement capabilities, and the quality and scope of their in-house science program and external user program. The IWG was directed to use existing reviews and reports, drawing on external sources as needed, and to make recommendations on ways to maximize for the U.S. science program the availability, use and impact of these facilities. Specifically, the IWG was asked to consider, but not be limited by, the following questions:

1. Are existing neutron facilities scheduled to operate at the maximum extent possible and do they have the resources to meet that schedule?
2. What are the available opportunities to provide needed state-of-the art scientific capabilities at these facilities?
3. What are the issues facing (current and prospective) users of neutron facilities and what can be done to maximize the scientific impact of these facilities?

The following report is organized into three major sections: Neutron Science: Overview, Trends and International Perspectives; Assessment of U.S. Neutron Facilities; and Recommendations and Priorities. The first section provides an overview of neutron science, especially neutron scattering techniques, including a discussion of the multidisciplinary use of neutron scattering and expected trends in its use. The first section also gives an overview of neutron facilities, a historical review of their development, and a discussion of the current status of U.S. neutron capability compared with other international facilities. The second section provides a detailed review of the performance of U.S. neutron facilities. The assessment covers both a 10-year review of the operation of the U.S. facilities, and a detailed analysis of their performance over the last year. In both of these sections, the IWG includes findings and conclusions that were based on this analysis and related deliberations within the IWG. Based on these findings and conclusions, the final section presents the recommendations of the IWG and the priorities for implementing these recommendations.

## Neutron Science: Overview, Trends, and International Perspectives

### *Neutrons and their uses*

A neutron is a constituent of the nucleus of an atom (along with the proton) and is present in every element's nucleus except the lightest isotope of hydrogen. To be used for the purposes discussed below, a neutron must be liberated from its bound state within a nucleus by a nuclear reaction. A neutron has no net electric charge but possesses a magnetic moment from its nuclear spin. It interacts primarily through magnetic and nuclear forces. Neutrons are exploited and studied in many ways. Neutron-initiated nuclear reactions are exploited in nuclear fission for reactors and to make new isotopes (including radioactive isotopes for research and nuclear medicine). The secondary radiation from these nuclear interactions can also be used as sensitive probes of atomic species for analytical chemical analysis or to probe the structure and dynamics of a target material. Neutrons are also intrinsically interesting and used in nuclear and other medium energy physics experiments and as model quantum mechanical systems. The Kohn panel report<sup>1</sup> gives a good overview of these important areas of neutron research. All of these uses are important and many are part of the overall use of neutron sources in the United States.

The primary focus of the IWG was the use of neutrons as probes of atomic and molecular structure and dynamics in a process known generally as **neutron scattering** because it represents the largest use of the major U.S. neutron sources. The high demand for neutron scattering capability is currently the primary driver for neutron source development, upgrades and operations. Even facilities originally optimized for other uses, such as HFIR (isotope production), now are operated to maximize the effectiveness of their neutron scattering programs.

### *What is neutron scattering?*

In the process of scattering, neutrons are used as a probe of a target material usually referred to as the sample. Information about the properties of a sample can be obtained by measuring the properties of the neutrons before and after they interact with the sample. The scattering of low-energy neutrons from samples yields important information about the atomic or molecular structure and the dynamics of the sample because the neutron energy is similar to the energy of atomic and molecular vibrations and excitations and the deBroglie wavelength of the neutron is similar to atomic and molecular length scales. In this sense, neutron scattering is similar to other scattering probes of atomic and molecular structure such as x-ray photons, electrons, ions, muons, etc. However, because a neutron interacts with a sample very differently than these other probes, the information obtained about the sample from neutron scattering is often unique. Neutron scattering is most important when it can provide unique information unavailable by other means. Examples of specific areas where neutron scattering is particularly powerful include:

- Magnetic scattering;

- Sensitivity to specific isotopes and the ability to differentiate isotopically labeled molecules;
- Sensitivity to hydrogen;
- Sensitivity to low energy vibrations and excitations in materials.

Neutron scattering instruments can be separated into several classes:

- **Neutron diffraction** instruments measure atomic and molecular structure: i.e. the relative positions of atoms and molecules in a material. There are typically several neutron diffractometers at a given facility, each optimized to make a specific kind of measurement. Examples include single crystal diffractometers, powder diffractometers, liquids/amorphous materials diffractometers and texture or residual stress diffractometers.
- **Low- $Q$  diffraction** is a subset of neutron diffraction that is designed to measure the structures of very large molecules, or “macromolecules”. Two examples are small angle neutron scattering (SANS) and neutron reflectivity. Due to the tremendous growth of research in large molecule systems such as polymers, natural and man-made composites (and other multi-phase systems) and biological systems, neutron instrumentation in this class has become heavily oversubscribed, particularly at facilities with high-intensity cold neutron sources.
- **Inelastic neutron scattering** measures atomic and molecular motions in a sample. Instruments that perform inelastic neutron scattering are typically called neutron spectrometers. There are a wide variety of spectrometer types covering a broad measurement range of energy and length scales. Examples include triple axis, Time-Of-Flight (TOF), Backscattering, Spin Echo, etc. A combination of modern neutron methods allows measurements of dynamic processes in materials to be made over eight orders of magnitude in time and energy.

### ***Neutron sources for neutron scattering***

The essential criterion for an effective neutron source for scattering is to produce high fluxes of neutrons at the “right” energy. The processes of nuclear fission in a reactor and spallation by a particle accelerator both produce sufficient numbers of neutrons to be suitable sources for high-intensity neutron beams. However, the energy of the neutrons produced must be reduced from the millions of electron volts they possess after the nuclear reaction, to the several thousandths of an electron volt needed for neutron scattering. This is accomplished by allowing the neutrons to pass through a moderator where they dissipate energy. The temperature of the moderator is used to characterize the energy of the moderated neutrons. The most commonly used neutron energies for neutron scattering are thermal (corresponding to a room temperature moderator), and cold (corresponding to a moderator at cryogenic temperatures). Other components of a neutron source include neutron reflectors and absorbers to scatter neutrons to where they are wanted or to eliminate them where they are not wanted.

**Reactor-based sources** use the neutrons from fission of U-235 in a nuclear reactor. The reactor core provides thermal moderation of the neutrons, but additional types of moderators (hot or cold) can be added to vary the energies of the extracted neutron beams. Reactor designs optimized for use as high-intensity neutron sources have high power density cores and a moderator-reflector geometry that facilitates extraction of high intensity

thermal neutron beams while minimizing the number of “fast” (i.e. high-energy) neutrons. Reactor-based neutron sources nearly always operate as steady-state sources, producing high neutron intensities at a fixed power level that does not change with time. Neutron instruments at a reactor source are optimized to exploit the high average intensity of the source.

**Spallation-based sources** collide high-energy proton beams from an accelerator with a stationary target, typically a heavy metal such as tungsten, uranium or mercury. The resulting collision puts the neutron-rich target nucleus in an excited unstable state that decays by “boiling off” neutrons in a process called spallation. Most spallation sources utilize a storage ring as part of the accelerator that allows the proton beam to be “bunched” and then delivered in pulses (in time) to the spallation target. This mode of operation results in very intense neutron “bursts” from the target followed by periods of no neutron production. Moderators of various types are placed around the target both to slow the high-energy neutrons and to control the timing of the neutron pulse. Spallation sources are typically characterized by high peak intensity, but with lower average intensity than steady-state sources. Neutron instruments at a spallation source are optimized to exploit the time structure of the pulsed neutron beams, and the specific details of the time structure of the neutron pulses are an important part of the source characteristics.

***Between sources and instruments***

Neutron sources are weak in comparison to other scattering probe sources, such as synchrotron photon sources or lasers. The flux limitations of neutron sources ultimately limit neutron scattering capability in one way or another. As a result, one of the key features in any neutron facility is the optimization of the instruments to the source. Achieving full performance can mean optimizing the source performance to the desired instrument capability. This is often done with the moderator assemblies at spallation sources that, in this regard, have more flexibility than the moderator assemblies at reactor facilities. More universally, the instrument design must be optimized to fully exploit the performance characteristics of the source. Large performance gains today are usually the result of advanced neutron optical elements, large detection area or efficiency and other advanced beam delivery or beam tailoring techniques. This careful matching of instrument design to the specific capabilities of the neutron source has traditionally meant that the facility staff play a central role in neutron scattering instrument development.

***Scientific use of neutron scattering techniques***

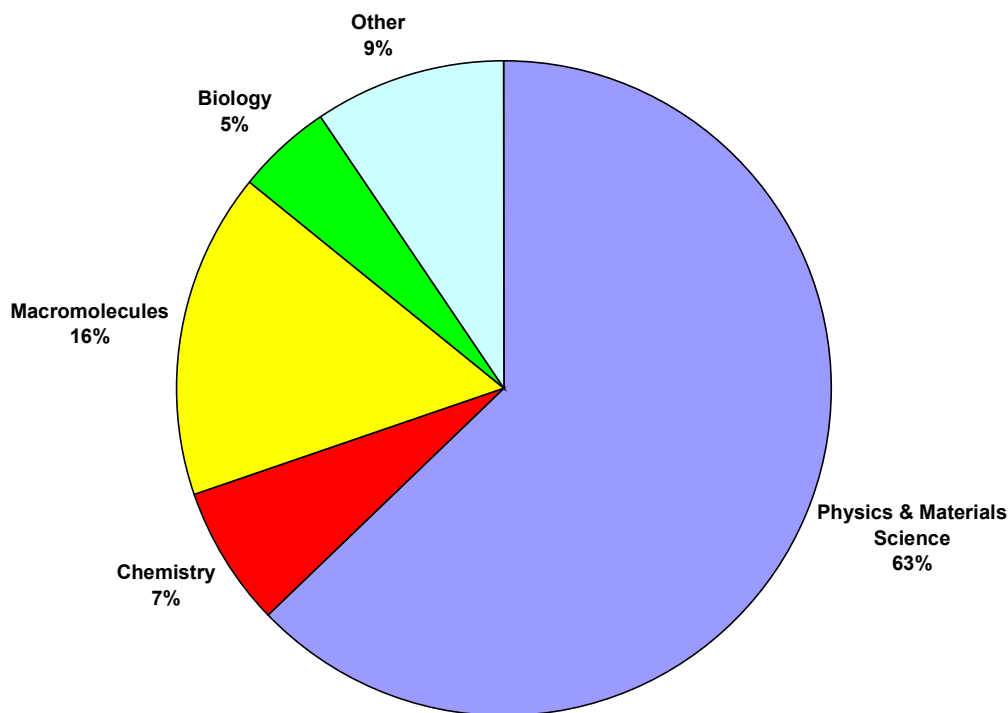
	<b>Diffraction</b>	<b>Low Q Diffraction</b>	<b>Inelastic Scattering</b>
Condensed Matter Physics	magnetic structures, short and long range order, ferroelectrics	flux line lattices in superconductors, Magnetic semiconductors, giant magnetoresistance (GMR) and colossal magnetoresistance (CMR) materials	phonons, magnetic excitations, rotons in He
Materials Science	structures of superconductors, magnetoresistive oxides, ceramics, hydrides	microstructures in metals, ceramics, cement, thin films, surface depth profiling	atomic diffusion



	Diffraction	Low Q Diffraction	Inelastic Scattering
Chemistry/Chem. Physics	Fullerenes, carbon nanotubes, catalysts, sieves, fuel cells	sol gels, polymer processing, electro-chemistry, Langmuir-Blodgett films	chemical spectroscopy, adsorbates on catalytic surfaces & molecular sieves, molecular rotation, diffusion
Macromolecules	polymer structures	structures of polymer melts, microemulsions, block copolymers, polymer thin films & interfaces	vibrational spectroscopy, polymer relaxation, diffusion, micelle/ colloid dynamics
Biology	protein crystal structures	tertiary structures of proteins, biological membranes	dynamics of biological macromolecules
Other (e.g. Geology and Engineering )	residual stress and texture of engineered materials	microstructures of engineered materials	

**Table 1** Examples of neutron scattering techniques in a number of scientific research areas. See table references.

The ability to measure basic materials properties with neutrons has led to their wide use in physics, chemistry, materials science, biomolecular science, engineering, environmental science and geosciences. Furthermore, all indicators are that this multidisciplinary scientific base in the use of neutron scattering is likely to grow broader as new neutron scattering capabilities are added. Table 1 shows some of the applications of various neutron scattering techniques in various scientific disciplines. Figure 1 shows the share of U.S. neutron users by scientific discipline in fiscal year 2000. The data illustrate the multidisciplinary nature of neutron scattering research.



**Figure 1** Share of U.S. neutron users in FY 2000 by field of research. See figure references.

### ***Trends in neutron scattering use***

Neutron scattering usage by the “traditional” fields of condensed matter physics, materials science and chemistry, will continue to be a large element of the research program at neutron facilities--they are well suited to neutron scattering techniques and continue to be very active areas of science. Worldwide, the largest growth in neutron scattering use over the past decade has occurred in fields that exploit low-Q diffraction and high-resolution spectroscopy instrumentation at high-intensity cold sources. These include polymer science, including the large growth in biopolymer research; materials science and nano-materials (composites, etc.); complex fluids and other areas of “soft” condensed matter physics and biology. These fields represent large growth areas in basic research and are also well suited to neutron scattering techniques. The Organization for Economic Cooperation and Development (OECD) report on *A Twenty Years Forward Look at Neutron Scattering Facilities in the OECD Countries and Russia*<sup>7</sup> provides a useful analysis for estimating future trends in the use of neutron scattering techniques and is shown in Table 2. This report, and the 1996 European Science Foundation (ESF)/European Neutron Scattering Associations (ENSA) workshop results on *Scientific Prospects for Neutron Scattering with Present and Future Sources*<sup>8</sup>, both emphasize the wide range of current and potential applications of neutron measurements.

	Solid State Physics, Magnetism	New Materials Chemical Aspects	Chemical Reactions	Amorphous Materials	Material Science	Biology	Soft Condensed Matter	Earth Science	Enginer.
<b>Diffraction</b>									
Single crystal	**	**				**		**	
Powder	***	***	***		**				
Diffuse				***					
Stress, texture								**	***
<b>Inelastic</b>									
TOF	**	**	***	***	***	*	*	**	
3-axis	***							*	
Spin Echo	*		**	***		*	***		
Backscattering	*	***	**	**	**	**	**	*	
<b>Low-Q diff.</b>									
SANS	*	**		**	***	**	***		***
Reflectivity	**	**	**		*	**	***		*

**Table 2** Estimate of future instrument needs by scientific prospect . Key: \* valuable, \*\* necessary, \*\*\*essential. See table references.

### ***Biology research with neutrons***

One area of particular interest for the IWG was the use of neutron scattering techniques for biology research. Motivated in part by the tremendous explosion of protein crystallography measurements at the U.S. synchrotron light sources<sup>5</sup>, the IWG was interested in identifying whether or not similar growth could be expected in neutron scattering. The consensus of the IWG was that use of neutron scattering by biologist was likely to increase in all three instrument areas (diffraction, low-Q diffraction, and inelastic techniques). However, the needed capability is just coming on-line in the United States and it will be difficult to project the ultimate demand until the new facilities at LANSCE (protein crystallography), HFIR (dedicated biology SANS), and the NCNR (dedicated biology reflectometer and SANS, and high resolution inelastic scattering capability) have

operated longer. The IWG agreed that demand in this area should be carefully monitored to see how usage grows in the biological research community.

### ***History of neutron facility development***

The development of nuclear reactors towards the end of WWII was quickly exploited for research applications. Early reactors were used as general-purpose research facilities for nuclear physics, reactor development, materials irradiation, neutron activation analysis and neutron scattering. The 1994 Nobel Prize in physics was awarded to Clifford Shull (United States) and to Bertram Brockhouse (Canada) for their pioneering work developing neutron scattering methods for structure and dynamics measurements. The years following the launch of Sputnik saw the development of a series of new neutron facilities. This new push led to the construction of the HFBR at Brookhaven, the HFIR at Oak Ridge and the Neutron Beam Split-core Reactor (NBSR) at the National Bureau of Standards (now NIST) in Maryland. They were all commissioned between 1965 and 1969. These reactors were optimized for specific research programs – neutron scattering at the HFBR and NBSR and isotope production at the HFIR. The combination of these new facilities with the strong science programs at these laboratories resulted in U.S. scientific leadership in neutron scattering that lasted through most of the 1970's.

In 1972, the Institut Laue-Langevin (ILL) began operation of a new high flux reactor in Grenoble, France. The reactor design concept was similar to the HFBR, but with larger beams and an optimized cold neutron source. In addition, the scientific management of this new international facility (France, England and Germany were the primary partners) focused on attracting outside users to the facility and on using the in-house staff to develop and operate new instrumentation. By the late 1970's it was becoming increasingly evident that this "user facility" approach was effective both at developing high quality instrumentation and at attracting robust use by the scientific community. Also during this period, significant new reactor-based neutron scattering capability was being added in Germany and France, while older facilities were closed in the United States.

The late 1970's and early 1980's also saw the development of spallation-based sources for neutron scattering research. In 1981, the Intense Pulsed Neutron Source began operations at Argonne. Using an existing accelerator infrastructure from high energy physics projects, the IPNS was the world's first dedicated spallation neutron source and gave the U.S. an early lead in this new approach to neutron source technology. A similar facility (KENS) was developed at the Japanese high-energy physics lab KEK and began operations at the same time. In 1985, a dedicated spallation neutron source in England (ISIS) with twenty times the beam power of IPNS quickly erased the U.S. leadership role. As the data in the next section will show, attempts to provide ISIS-class performance at the Los Alamos spallation-source (LANSCE) have not resulted in a competitive capability. By the mid-1980's it was clear that leadership in neutron scattering had shifted to Western Europe.

### ***Early Policy Developments***

In response to these developments, a series of studies and reports were initiated in the United States beginning in the late 1970's. They culminated in a 1984 study requested by

President Reagan's Science Advisor, George Keyworth III, to address U.S. capabilities and needs for large materials research facilities including neutron sources. The resulting study, known as the Seitz-Eastman report<sup>9</sup>, was based on several earlier reports dating back to 1977 that generally endorsed the development of new source capability, adding capability to existing sources and expanding the level of instrumentation support at the facilities. The recommendations of this report played a central role in defining the priorities for investments in major scientific facilities, including neutron facilities, for more than a decade. The Seitz-Eastman report called for the following priorities for neutron sources in the United States:

- development of an advanced reactor-based neutron source;
- development of a plan towards a major spallation neutron source;
- major upgrades at the HFBR and NIST to provide cold neutron capability; and
- a new experimental hall and neutron scattering instrumentation at Los Alamos.

### *Current status in the United States*

Today it is clear that the success at implementing these recommendations has been mixed. Some of the successes include:

- The Spallation Neutron Source, a 1-2MW pulsed spallation neutron facility that will provide the world's highest performance neutron source capability when completed, is under construction at Oak Ridge National Laboratory.
- A new major cold neutron capability was added at NIST beginning in 1987 that has resulted in substantial growth in the number of users – it is now the most widely used neutron facility in the United States.

However, the neutron scattering infrastructure in the United States has suffered several major setbacks:

- The Advanced Neutron Source (ANS) project to build a 300MW reactor facility at Oak Ridge with a peak thermal flux of over  $7 \times 10^{15}$  neutrons/cm<sup>2</sup>·sec was cancelled in early 1995 before construction began due to concerns over nonproliferation and major cost escalations.
- Proposals to add cold neutron capability to HFBR were not acted on. Then, in 1999, DOE decided to permanently close the Brookhaven HFBR facility following a two-year shutdown caused by the discovery of a tritium leak from the fuel storage pool.
- The Manuel Lujan Scattering Center was built at the LANSCE facility at Los Alamos. However, despite several efforts to improve reliability and capability at LANSCE, a recent BESAC report concluded that the LANSCE facility has failed to perform up to expectations, leaving the United States without an ISIS-class spallation neutron facility.

### *Current international status*

The international neutron scattering community has settled on a facility strategy that is very similar to the one adopted in the United States. Namely, it calls for developing neutron scattering capabilities in three areas:

- new sources.
- new or expanded capability at existing neutron sources;
- robust support for instrumentation development and facility operations.

Based on this strategy, the following major neutron facilities developments are underway or have recently been completed:

- Japan has approved development of a 1MW pulsed spallation neutron facility to be completed in 2006 – the Japanese Spallation Neutron Source (JSNS);
- Europe is presently negotiating on a multinational project to construct a 5MW pulsed spallation facility, the European Spallation Source (ESS);
- The ISIS facility is seeking funding for a second target station;
- Germany is seeking startup authority for the new FRM-2 reactor neutron source at the Garching campus of the Technical University of Munich. The FRM-2 is a 20MW facility with nearly ILL class neutron performance;
- Japan replaced the reactor vessel at an existing facility, creating a new 20MW neutron source, the JRR-3;
- Australia is developing a new 20MW reactor-based neutron facility at Lucas Heights, near Sydney;
- In Taiwan, a new 20MW reactor, the TRR-2, is under development and will support a significant neutron scattering research program;
- A 20MW research reactor facility has come on line in Korea and the neutron scattering instrumentation is under development;
- A continuous beam spallation neutron source, SINQ, has come on line in Switzerland, and the neutron scattering program is now reaching a mature phase;
- Canada has proposed replacing the NRU reactor facility with a new 20MW research reactor capability.
- The ILL has begun their “Millennium Program” to upgrade and modernize the instrumentation at the ILL facility.

These developments are further summarized in Table 3. It should be noted that peak flux (number of neutrons per square centimeter of area per second – a measure of intensity) is only meaningful when comparing sources of the same type (continuous or pulsed). In addition, other factors including beam number and size, geometric factors, sources of background, etc., will also significantly affect the final performance of the source for neutron scattering.

Facility	Start	Cease	Country	Type	Time structure	Peak Flux		Total	Instruments		
	Operation	Operation				x 10 <sup>-14</sup>	Power		Diffraction	Low Q	Inelastic
NRU	1957	2005	Canada	Reactor	Continuous	3	120MW	5	2	1	2
R-2	1960		Sweden	Reactor	Continuous	1	50MW	6	5	0	1
IBR-2	1961		Russia	Reactor	Pulsed		2MW	13	5	4	4
FRJ-2	1962	2006	Germany	Reactor	Continuous	2	23MW	15	5	5	5
DR3	1963	2000	Denmark	Reactor	Continuous	1.5	10MW	7	2	3	2
HFBR	1965	1999	US	Reactor	Continuous	4	30MW	13	7	2	4
HFIR	1966		US	Reactor	Continuous	12	85MW	10	3.7	3	3.3
NCNR	1969		US	Reactor	Continuous	2	20MW	17	2	6	9
ILL	1972		France	Reactor	Continuous	12	58MW	34	15	4	15
BER-2	1973		Germany	Reactor	Continuous	2	10MW	15	10	2	3
Orphee	1980		France	Reactor	Continuous	3	14MW	25	12	6	7
KENS	1980		Japan	Spallation	Pulsed	3	3kW	15	5	4	6
IPNS	1981		US	Spallation	Pulsed	5	7kW	12	5	4	3
ISIS	1985		England	Spallation	Pulsed	20-100	160kW	19	9	3	7
LANSCE	1988		US	Spallation	Pulsed	30	56kW	7	3	2	2
JRR-3M	1990		Japan	Reactor	Continuous	2	20MW	23	7	5	11
SINQ	1996		Switzerland	Spallation	Continuous	2	1MW	10	5	2	3
<b>Under development</b>											
FRM-II	2002		Germany	Reactor	Continuous	7	20MW	17			
RR	2005		Australia	Reactor	Continuous	4	20MW	18			
SNS	2006		US	Spallation	Pulsed	200	2MW	24			
JSNS	2006		Japan	Spallation	Pulsed	100	1MW	24			
ESS†	2010		Europe	Spallation	Pulsed	2000	5MW	40			

**Table 3 Major international neutron scattering facilities. († Proposed: not yet funded.) See table references.**

### *Findings*

- Neutron scattering is an important and essential part of the measurement infrastructure for the study of molecular and atomic structure and dynamics of materials. Its use is complementary to other probes such as x-rays, electrons, etc.
- Neutron scattering use is broad and multidisciplinary with use in physics, chemistry, materials science, macromolecular science, biology, engineering and geosciences.
- Recently the areas of highest growth have been low Q diffraction and high-resolution spectroscopy. Both techniques are well suited to sources producing intense cold neutron beams. Fields impacted include materials sciences, chemistry and macromolecular science, including both polymer and biological macromolecules.
- Use of neutron scattering methods in biology is likely to increase, but it is too early to project the specific areas of high demand (diffraction, low Q, or inelastic) or how large the demand will become.
- Europe enjoys a substantial lead over other regions of the world, including the United States in neutron source capability. The leading facilities in each class are the ILL in France (reactor) and ISIS (spallation) in the U.K.
- The United States is currently constructing the SNS which will be the first high power (megawatt-class) spallation source in the world.
- The number of neutron scattering instruments available in the United States now and in the future will be less than half that available in Western Europe and less than available in Japan. On a per capita basis, the United States has half the neutron scattering capacity of either Western Europe or Japan – and this shortfall is unlikely to change for the foreseeable future.

## ***Conclusions***

An overview of neutron scattering capabilities in the United States demonstrates a dichotomy. On one hand, the evidence is clear that neutron scattering techniques are an essential component of the U.S. scientific infrastructure for measurements of the molecular structures and dynamics of materials. These powerful techniques are broadly applicable across many scientific fields, including the traditional areas of physics and materials science, and also chemistry, engineering, earth sciences and biology. Furthermore, with increased interest in research fields well served by neutron-based measurements (nanosciences, biology, polymers, complex fluids, and other types of soft condensed matter science), it is expected that demand for these techniques will grow in the future. On the other hand, in spite of early roots in North America, leadership for neutron scattering capability moved to Western Europe in the 1970's and has remained there ever since. With the majority of new sources developed in Asia and Europe, the United States finds itself with a serious shortfall in overall neutron scattering capability. This shortfall is apparent both quantitatively, in terms of the number of instruments available for needed science, and qualitatively, in terms of the leadership position of the ILL and ISIS facilities in Europe.

The main charge to this IWG was to identify the opportunities for improving the access of U.S. researchers to high quality neutron scattering capability, with the available neutron source infrastructure and the SNS. As the first megawatt-class spallation source to be constructed in the world, the completion of the Spallation Neutron Source at Oak Ridge will be the most significant new opportunity to provide world-leading neutron scattering capability in the United States. Nevertheless, the addition of the SNS cannot alone make up for the overall shortage of neutron scattering capability in the United States compared to Europe or Japan. In this context, the IWG also explored ways to improve the quality of and access to U.S. neutron scattering capability. The objective was to identify opportunities to provide the broadest possible scientific community access to the best possible neutron instruments using the entire U.S. neutron source infrastructure, including the SNS. In the following section, the IWG assesses the condition of the U.S. neutron facilities with the objective of identifying these opportunities.

## **Assessment of U.S. Neutron Facilities**

The IWG was specifically charged with reviewing the status and capability of existing U.S. neutron facilities. This review includes the SNS as it will have a dominant impact on the overall neutron scattering capability in the United States once it is operational. However, until then, no performance data for that facility will be available. For context, the IWG also examined data from the recently closed High Flux Beam Reactor (HFBR) facility at Brookhaven National Laboratory. The HFBR was an important element in the U.S. neutron infrastructure until operations ceased in 1997. The review conducted by the IWG was based on information collected from a number of different sources:

### ***Existing reports on U.S. neutron facilities***

The IWG was able to utilize a significant number of published reports regarding the planning, capability and performance of the neutron scattering infrastructure in the United States and on the impact and importance of neutron techniques to specific scientific areas. The majority of reports were either conducted by the advisory committee for Basic Energy Sciences at DOE, or by committees of the National Academy of Sciences. Reports cited in this assessment are included in the Reference section at the end of this report.

### ***Data collected from U.S. neutron facilities***

To supplement the available reports, the IWG requested additional data from the neutron facilities in the United States. Much of these data were is routinely collected by the steward agencies, but it is not generally compiled in a report format. Because two steward agencies are involved for neutron facilities (DOE and NIST), there are significant differences in the type of data collected by the facilities. To make useful comparisons, the IWG refined some of the questions, requested follow up information, and, with input from neutron facility management, made some adjustments to the data. Specific data and their treatment are described in the Figure Reference section for each figure at the end of this report.

### ***Benchmarking Data***

The IWG also collected data on other neutron facilities from around the world to compare with the U.S. neutron scattering effort. Much of these data were was assembled from public information for the facilities and from data made available by members of the IWG. Key reports from international organizations on neutron scattering facilities and neutron scattering programs are noted in the reference section at the end of this report.

In addition, the IWG assembled data on the available instruments from the Institut Laue-Langevin (ILL) in Grenoble, France and from the ISIS facility at the Rutherford Appleton Laboratory near Oxford in the UK. These two facilities are widely considered to be the best in class for reactor-based and spallation-based neutron facilities respectively.

### ***Comment on facility budget data***

The IWG was asked to examine facility budgets as part of its charge to assess whether resources were adequate to maximize operations. However, after a preliminary examination, the IWG concluded that a budget comparison between the facilities was not a useful way to understand the resources available for operations because of the large



differences in the cost basis between each of the facilities. For example, a large accelerator complex and a reactor have significantly different operating costs, but these differences say little about the resources available for robust operation and more about the technical complexity of operating the source. Therefore, the IWG focused on other types of needed resources, such as staffing, in the assessment.

### ***Organization of assessment data and analysis***

The IWG assessment of the U.S. neutron facilities is organized into three main sections:

1. **Facility data sheets** – These provide a summary description for each facility, performance history data since 1990, and highlights.
2. **Performance history since 1990** – This section is organized into two sub-sections that examine:
  - a. **Source facility performance**
  - b. **Research facility performance**
3. **Detailed assessment for FY 2000** – This section analyzes the use, performance and resources available to U.S. neutron facilities in fiscal year 2000 in the following areas:
  - a. **Instrument ownership and access**
  - b. **Instrumentation**
  - c. **Research facility staffing**
  - d. **User demographics**
  - e. **Research facility outputs and outcomes**

Specific findings are summarized at the end of each of the bolded sections identified above and general conclusions are presented at the end of the Assessment section of the report.

### ***Facility data sheets***

The following data sheets provide a summary description for each facility, including the steward agency, year that operations began (and, if applicable, ended) and major research programs using the source facility. A table summarizes the performance history since 1990. Highlights are described at the end.

## Spallation Neutron Source (SNS)

**Host laboratory:**

Oak Ridge National Laboratory  
Oak Ridge, Tennessee

**Steward agency:** Office of Basic Energy Sciences, DOE

**Start Operations:** 2006 (planned completion of source construction)

**Facility Description:** The Spallation Neutron Source is a 1 MW spallation neutron source under construction at Oak Ridge, Tennessee. The SNS is a high power, 60Hz short-pulsed spallation source using protons from a 1.0GeV full power linac and accumulator ring on a mercury (flowing) target. Four moderator assemblies are planned for the target, 2 ambient and 2 cryogenic. The target assembly and target building are designed to accommodate up to 24 neutron instruments. The design provides for a possible future source expansion consisting of a second, low-repetition rate (15Hz) target station, which could accommodate an additional 18 instruments.

**Program Description:** Neutron scattering

**Highlights:**

- Source construction is on schedule to begin commissioning in 2006.
- Project cost is \$1.4B with anticipated operating costs of approximately \$150M per year.
- The SNS will be the world's first advanced-design, high power spallation neutron source. Many of its design features are being incorporated in the development of other spallation sources being planned for construction in Europe and Japan.
- SNS design provides for the possibility of future expansions in source capacity through the addition of a second target station. An NSF-funded proposal to study a low-repetition rate target station facility, called the long-wavelength target station, was withdrawn in order to focus attention on developing instrumentation at the "high power" target station currently under construction.
- Project funding includes 5 neutron instruments plus some shared component development for other neutron instruments.
- Funding for an additional 2 spectrometers has been provided to university investigators by DOE/BES.
- Negotiations have begun between the DOE and NSF, and with other interested partners, on arrangements to fund development of additional instruments at the SNS.

## High Flux Isotope Reactor (HFIR)

**Host laboratory:**

Oak Ridge National Laboratory  
Oak Ridge, Tennessee

**Steward Agency:** Office of Basic Energy Sciences, DOE

**Started Operations:** 1966

**Facility Description:** The High Flux Isotope Reactor is an 85MW (100MW design power) beryllium-reflected, light-water cooled and moderated research reactor. The reactor design is optimized for isotope production and incorporates a “flux trap” region in the center of the reactor core for high intensity irradiations. Four major beam ports provide high intensity beams for neutron scattering.

**Major Programs:** HFIR supports a strong multi-component research program at the facility. Major programs include neutron scattering, isotope production, materials irradiation and neutron activation analysis.

**Instrumentation:** HFIR presently operates 10 instruments and is considered fully instrumented *in its present configuration*. (Additional instrument capability is being added as part of ongoing upgrades.)

Year	Beam Days Scheduled	Beam Days Delivered	Availability	No. of Instruments	Instrument Days Delivered	Users
1990	N/A	214	59%	4	858	38
1991	N/A	214	59%	4	858	95
1992	223	153	42%	7	1072	102
1993	235	192	53%	7	1347	91
1994	174	174	48%	8	1393	128
1995	209	209	57%	10	2085	130
1996	230	230	63%	10	2300	146
1997	167	167	46%	10	1674	167
1998	219	159	44%	10	1594	168
1999	237	226	62%	10	2258	176
2000	261	242	66%	10	2424	153
2001	0	0	0%	10	0	0

**Table 4 Performance data from the High Flux Isotope Reactor neutron scattering program. See table references.**

**Highlights:**

- HFIR is completing a planned shutdown for a replacement of the beryllium reflector and to install new instrumentation.
- A second shutdown is planned for 2003 to install a new cold source in beam tube HB-4.
- A new guide hall for cold neutron instrumentation is being developed adjacent to the reactor building.
- The upgrade project includes significant new or improved neutron scattering instruments, especially for cold neutrons (see Table 12).

## High Flux Beam Reactor (HFBR)

**Host laboratory:**

Brookhaven National Laboratory  
Brookhaven, New York

**Steward Agency:** Office of Basic Energy Sciences, DOE

**Started Operations:** 1965

**Ceased Operations:** 1999

**Facility Description:** The High Flux Beam Reactor was a 60MW (but operated at 30MW) light-water cooled, heavy water moderated research reactor. The reactor design was optimized for neutron beam research. Nine major beam ports provided high intensity beams for neutron scattering.

**Major Programs:** HFBR operated primarily as a neutron scattering facility, although some irradiations and activation analysis were performed as well.

**Instrumentation:** HFBR typically operated with a full complement of 12-15 neutron scattering instruments.

Year	Beam Days Scheduled	Beam Days Delivered	Availability	No. of Instruments	Instrument Days Delivered	Users
1990	N/A	0	0%	9	0	0
1991	N/A	60	16%	9	539	168
1992	261	227	62%	14	3177	272
1993	110	107	29%	15	1599	192
1994	240	150	41%	15	2250	194
1995	240	192	53%	14	2694	277
1996	270	264	72%	15	3960	280
1997	35	35	N/A	13	458	89

**Table 5** Performance data from the High Flux Beam Reactor neutron scattering program. See table references.

**Highlights:**

- The HFBR ceased routine operations in 1997 after it was discovered that low-level tritium contaminated water had leaked from the fuel storage pool into ground water on the laboratory site.
- The Secretary of Energy decided to permanently close the HFBR in 1999. The facility is presently being decommissioned.
- When operating, the HFBR was one of the premier neutron facilities in the world. The research performed at the HFBR resulted in over 2500 peer-reviewed publications in its 35 years of operation.

## Intense Pulsed Neutron Source (IPNS)

**Host Laboratory:**

Argonne National Laboratory  
Argonne, Illinois

**Steward Agency:** Office of Basic Energy Sciences, DOE

**Started Operation:** 1981

**Facility Description:** The IPNS is a 30 Hz short-pulsed spallation neutron source using protons from a linac and rapid cycling synchrotron to produce neutrons in a depleted uranium target. Proton power on target is 7kW. Three cryogenic methane moderators produce short pulses of slow neutrons. Twelve beam lines currently serve 13 instruments, one of which is a test station for instrument development.

**Program Description:** The IPNS is essentially a single program facility, operating a successful user program in neutron scattering.

**Instrumentation:** The IPNS currently operates 12 neutron scattering instruments and is considered fully instrumented in its present configuration.

Year	Beam Days Scheduled	Beam Days Delivered	Availability	No. of Instruments	Instrument Days Delivered	Users
1990	119	113	31%	10	1130	254
1991	112	106	29%	10	1064	236
1992	98	93	26%	10	931	181
1993	91	86	24%	10	865	186
1994	98	93	25%	10	930	172
1995	112	106	29%	11	1171	199
1996	161	154	42%	11	1697	201
1997	147	139	38%	12	1671	228
1998	168	164	45%	12	1964	221
1999	171	156	43%	12	1872	208
2000	158	160	44%	12	1921	230
2001	161	165	45%	12	1980	240

**Table 6** Performance data from the Intense Pulsed Neutron Facility neutron scattering program. See table references.

**Highlights:**

- Upgrades are in progress to significantly enhance the performance of five instruments (HERMCS, GLAD, SCD, SAD, and GPPD – see Table 12).
- New scientific and support staff have been added to the program.
- Currently, there are no funded upgrades to the source or target facilities at IPNS.

## Los Alamos Neutron Science Center (LANSCE)

**Host Laboratory:**

Los Alamos National Laboratory  
Los Alamos, New Mexico

**Steward Agency:** National Nuclear Security Administration, DOE

**Started Operation:** 1985 (Lujan Center)

**Description:** The Los Alamos Neutron Science Center (LANSCE) is based on the 800 MeV LANSCE linac which can simultaneously accelerate both H<sup>+</sup> and H<sup>-</sup> beams and route them to separate experimental areas and a proton storage ring (PSR). The neutron scattering program is operated out of the Manuel Lujan Jr. Neutron Scattering Center (Lujan Center) which operates as a 20Hz short-pulse spallation source with a proton beam power of 56kW (80kW design) on a tungsten target. The Lujan Center target has three water moderators and one liquid hydrogen moderator.

**Major Programs:** LANSCE supports a multi-component program in weapons, energy and materials research. Major programs include: neutron scattering, proton radiography, materials irradiation, isotope production and weapons research.

**Performance History (Lujan Center only):**

Year	Beam Days Scheduled	Beam Days Delivered	Availability	No. of Instruments	Instrument Days Delivered	Users
1990	N/A	69	19%	10	693	183
1991	N/A	21	6%	10	206	79
1992	N/A	46	13%	9	414	120
1993	N/A	48	13%	10	479	108
1994	N/A	16	4%	10	158	73
1995	N/A	35	10%	9	318	47
1996	117	98	27%	7	683	62
1997	150	135	37%	7	945	126
1998	0	0	0%	7	0	0
1999	108	30	8%	7	213	20
2000	39	31	8%	7	215	25
2001	120	98	27%	6	588	114

**Table 7 Performance data from the LANSCE neutron scattering program (Lujan Center). See table references.**

**Highlights:**

- The Lujan Center began full user operations in July 2001 for a six-month period ending in December 2001. This was the first extended operations period since 1997.
- Four new spectrometers have been successfully commissioned at the Lujan center, and several more are under development (see Table 12).
- The LANSCE/Lujan Center is presently shutdown to perform planned routine linac maintenance and for upgrades to the spallation target. Routine operations are scheduled to resume July 1, 2002.
- LANSCE and LANL management have begun to respond to recommendations from a recent BESAC review<sup>6</sup> that was highly critical of the governance of the LANSCE facility. These changes aim to clarify lines of responsibility for the source facility and for the integration of projects from all three DOE program offices that use the facility.

## NIST Center for Neutron Research (NCNR)

**Host Laboratory:**

National Institute of Standards and Technology (NIST)  
Gaithersburg, Maryland

**Steward Agency:** National Institute of Standards and Technology, DOC

**Started Operation:** 1969

**Description:** The NCNR facility source is a 20 MW, heavy water cooled, moderated and reflected neutron beam split-core reactor (NBSR). The reactor core is optimized for neutron beam research with the fuel arranged in a split-core design, which provides a fuel-free gap at the center plane of the beam tubes. In addition to nine thermal beam tubes, a large diameter beam tube is installed with a liquid hydrogen cold source illuminating a large guide tube and cold beam tube network. The reactor design also includes several irradiation facilities and a graphite moderated thermal column.

**Major Programs:** The NCNR is primarily operated for the neutron scattering program, although other programs use the facility, including: neutron activation analysis, neutron radiography, neutron dosimetry, standards and physics.

**Instrumentation:** The NCNR presently operates 21 beam instruments, 17 are for neutron scattering. The facility is considered fully instrumented.

Year	Beam Days Scheduled	Beam Days Delivered	Availability	No. of Instruments	Instrument Days Delivered	Users
1990	210	202	55%	8	1613	207
1991	290	256	70%	8	2044	265
1992	290	257	70%	9	2311	332
1993	290	274	75%	12	3290	397
1994	120	115	32%	12	1386	498
1995	0	0	0%	12	0	0
1996	266	249	68%	12	2991	549
1997	266	248	68%	12	2975	593
1998	238	231	63%	13	3008	679
1999	266	268	73%	15	4020	705
2000	228	196	54%	17	3328	723
2001	240	240	66%	17	4080	750

**Table 8 Performance data from the NIST Center for Neutron Research. See table references.**

**Highlights:**

- The NCNR recently installed a new cold source, replaced the reactor cooling tower (plume abatement design) and performed planned maintenance.
- The new advanced design liquid hydrogen cold source yielded a performance gain of two over the previous design.
- The NCNR is licensed by the Nuclear Regulatory Commission through 2004. NIST will apply for a 20-year license renewal.
- A major instrument upgrade and expansion project is funded and underway (see Table 12).
- The NIST/NSF Center for High Resolution Neutron Scattering (CHRNS) was expanded in 2000 to include three new inelastic spectrometers (see Appendix).

## Facility Performance History

### Source facility performance

The performance of neutron facilities can be measured by their ability to produce neutron beams for the maximum number of days per year. For purposes of this comparison, facility availability is defined as the number of beam days operated divided by the number of days per year.

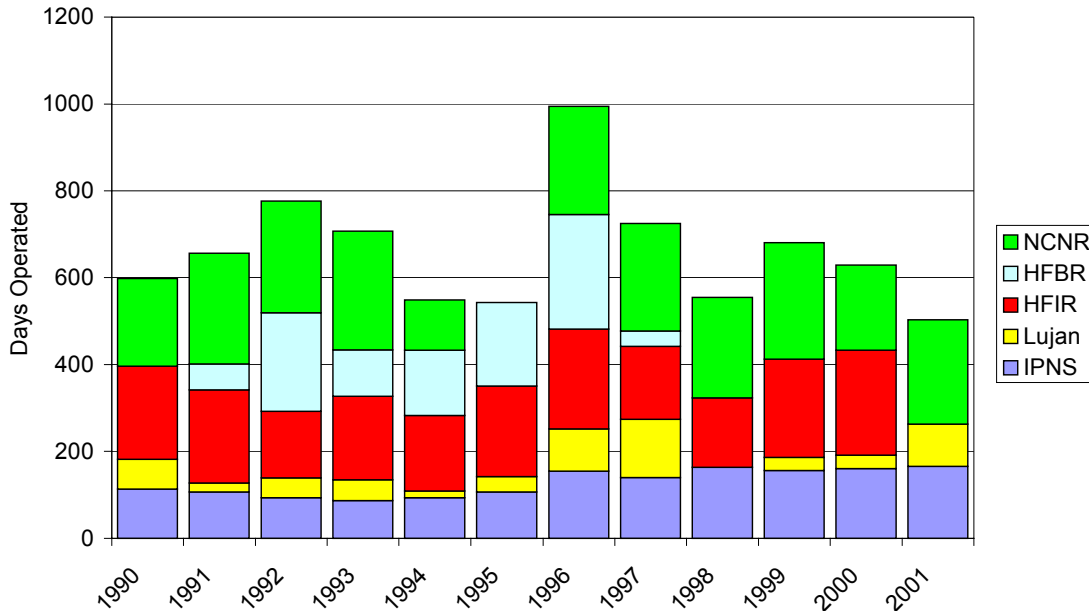


Figure 2 Number of beam days operated at U.S. neutron facilities. See figure references.

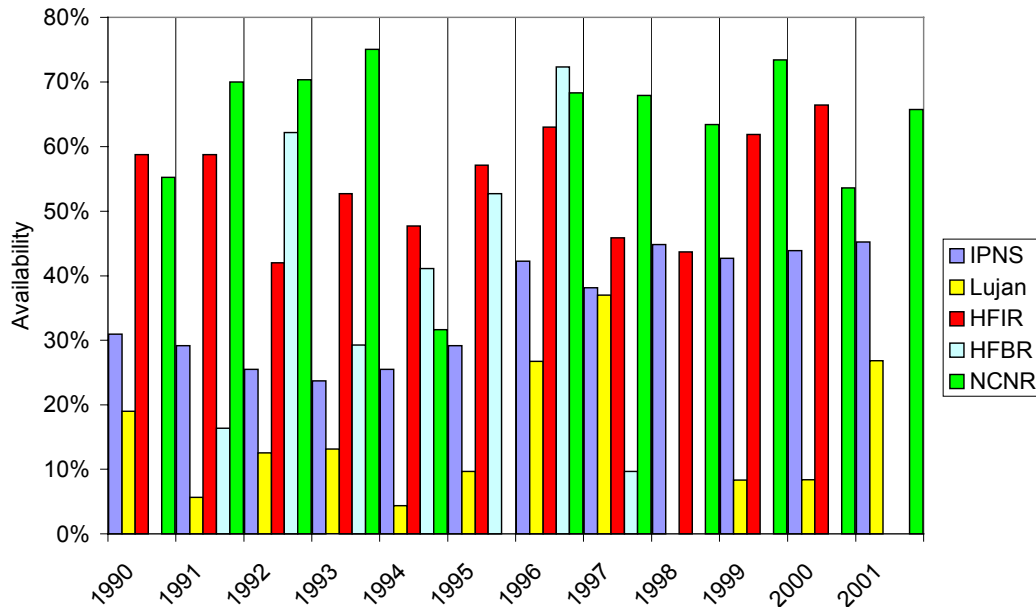


Figure 3 Availability of U.S. neutron facilities. See figure references.

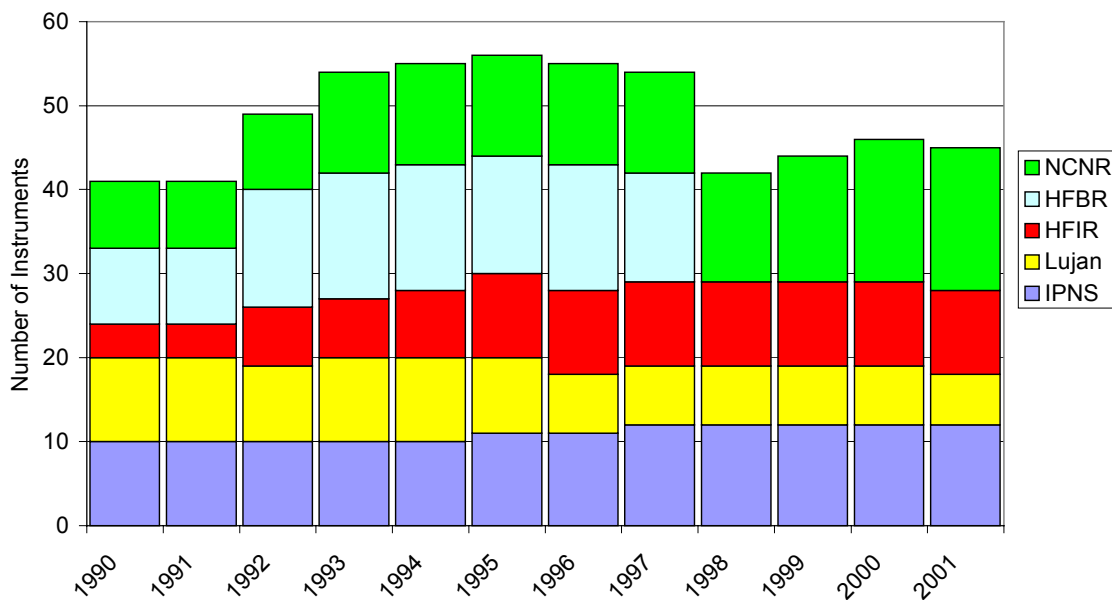


### ***Findings – source performance***

- The peak year in neutron production was 1996 (coinciding with a DOE funding initiative for major facilities).
- Neutron beam days operated dropped sharply in 1997 with problems at LANSCE and the end of operations at the HFBR.
- Facility availability data show that reactor sources generally operated more beam-days per year than their spallation counter parts. Based on these data, reactors typically operate approximately 250 days per year (68% available) and spallation sources about 150 days per year (41% available). Variations from these maximum levels depend on maintenance requirements, funding for operations and other interruptions to planned service.

### ***Research facility performance***

To analyze the overall performance history of the research facilities, levels of instrumentation and number of users per year were examined for each facility. Other types of research facility output - such as publications, research outcomes, etc. – were not used for this historical analysis. Generally, the outputs of the facility, and its scientific impact, will be directly related to the number of instrument-days operated and to the number of scientific researchers who utilize the facility, all other things being equal. Later sections will look in more detail at facility performance in FY2000 to examine research facility output and effectiveness.



**Figure 4** Number of neutron scattering instruments reported at U.S. facilities. See figure references.

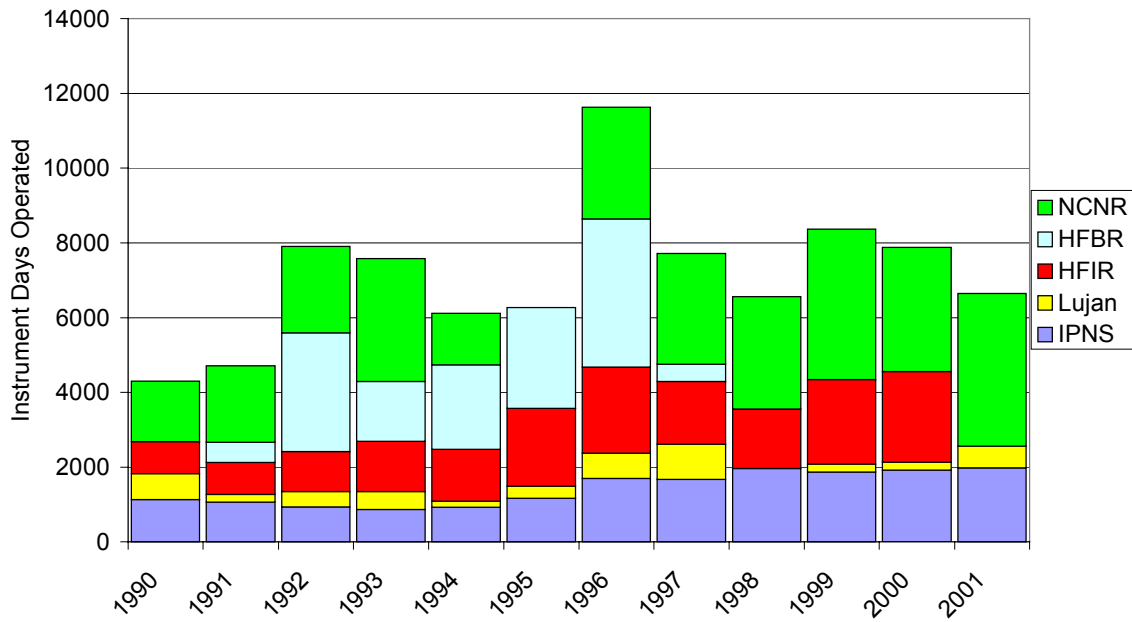


Figure 5 Neutron scattering instrument days operated at U.S. facilities. See figure references.

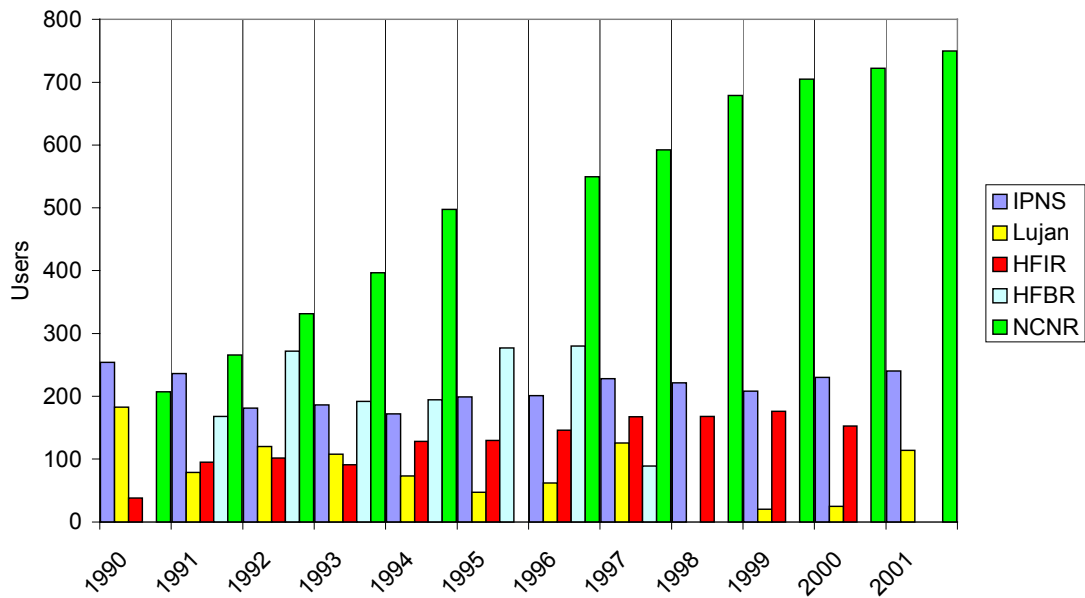


Figure 6 Number of users at U.S. neutron facilities. See figure references.

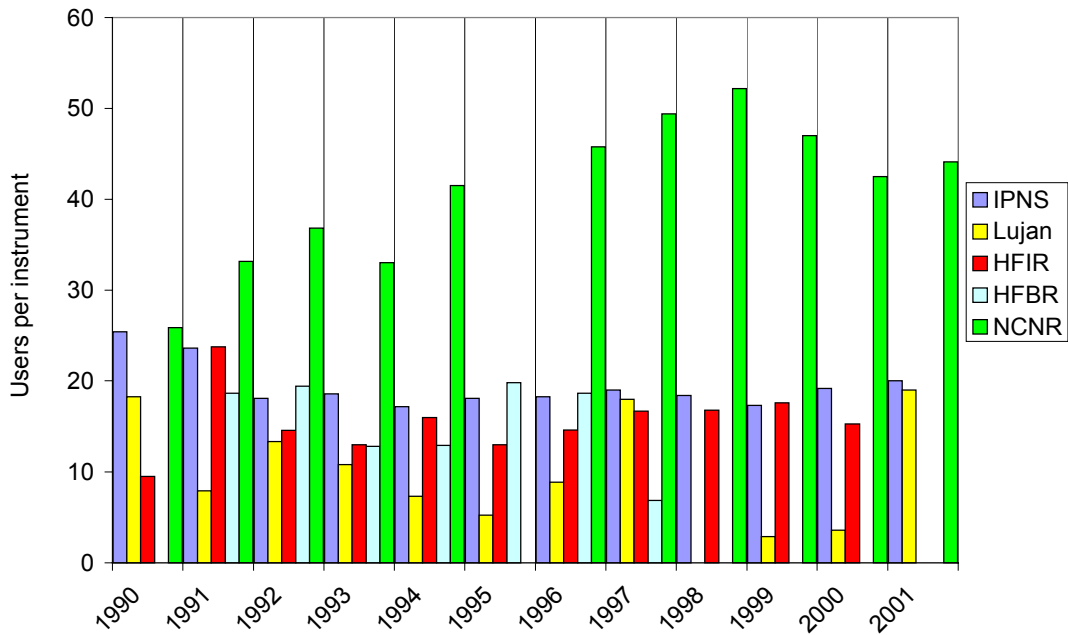


Figure 7 The average number of users per instrument at U.S. facilities. See figure references.

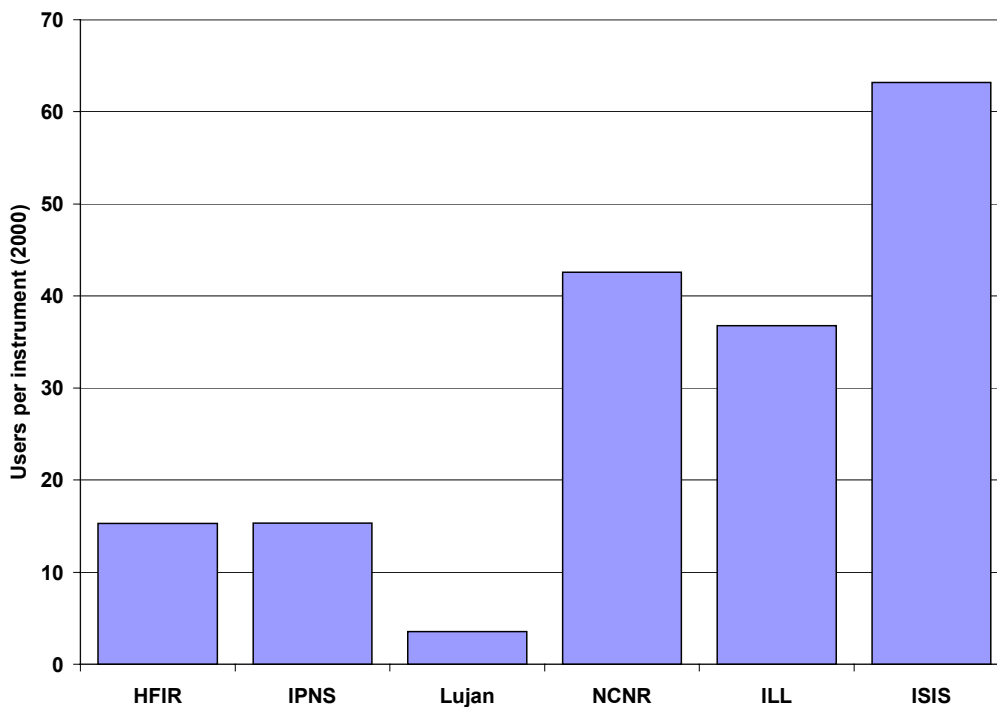


Figure 8 Instrument throughput: users per instrument at selected neutron facilities in 2000. See figure references.

### *Findings – research facility performance*

- The overall number of neutron scattering instruments available in the U.S. dropped more than 15% since 1998 with the loss of the HFBR facility. Other trends include the doubling of instruments at the NCNR (due to an added cold neutron guide hall facility) and increases at the HFIR. The number of instruments at LANSCE decreased during this period.
- Instrument operation data (instrument days operated) demonstrate the very large impact of the HFBR shutdown after 1996. Other notable trends include the nearly insignificant impact of LANSCE due to the source facility problems.
- The number of U.S. neutron scattering users has nearly doubled over the past decade, but all of the growth has occurred at the NIST facility. The NCNR now supports nearly twice the number of users as all of the other facilities combined.
- The increase in the number of users at the NCNR is too large (nearly a four-fold increase) to be attributed to the increased number of instruments alone. Looking at the number of users per instrument for each year over this period demonstrates that the most significant difference between the NCNR and other U.S. neutron facilities is the dramatic increase in user throughput.
- Comparing the number of users per instrument in 2000 at the U.S. neutron facilities with the ILL and ISIS facilities in Europe shows that user throughput is higher at the NCNR, ILL, and ISIS facilities and lower at the HFIR, LANSCE and IPNS.

### ***Detailed assessment for FY2000***

To further examine the differences in instrument productivity at the U.S. facilities, the IWG looked at several additional factors:

- Instrument ownership and access to neutron facilities
- Neutron scattering instrumentation installed at U.S. facilities
- Levels of support for instrument operations and neutron research

#### ***Instrument ownership and access policies***

Instrumentation use is related to the mode of user access and to the levels of user support for the facility. User access modes typically vary between facilities, and often between specific instruments at a given facility. The following general observations and distinctions are made to frame the discussion:

**Instrument ownership:** Instrument ownership is determined by who provides funding to build and operate an instrument. Typically instruments are either owned as “sole proprietorships” with one owner or as “partnerships” with a group of owners. Most sole owner instruments are built and operated by the facility. Partnership owned instruments roughly fall into two specific types:

- Partnership teams that invest in a particular instrument. These teams have different names at each facility: Instrument Development Team (IDT) at the SNS, and Participating Research Team (PRT) at LANSCE and the NCNR.
- Interagency partnerships that invest in a suite of instruments (this was referred to as a “sub-facility” in the *Cooperative Stewardship* report<sup>3</sup>). The NIST/NSF Center for High Resolution Neutron Scattering at the NCNR is the primary example of this type of partnership (see Appendix).

The motivating factor for investments by partners in neutron instrumentation is to control beam time on that instrument. The consequences of instrument ownership on instrument access are discussed below.

**Apportioning instrument time:** Instrument time is allocated to meet a variety of needs beyond serving the general science community. These include the needs of the facility to operate, calibrate and maintain the instruments and the research needs of the instrument owners. Facility access policies must be designed to balance these needs.

The IWG made a distinction based on how instrument use for research is controlled:

- ***Collaborative access*** means that beam time is controlled by the instrument owners, either the facility scientists or the partners in a jointly owned instrument. Collaborative access does not refer to the relative formality of the system for requesting beam time and reviewing the requests.
- ***General user access*** means that instrument time is controlled by a panel that is independent from the instrument owners. Typically, this process is based on formal submission and peer-review of proposals for beam time. However, the IWG used the existence of an independent panel, which awards time on the instruments based on scientific merit, as the test for general user access.

It is important to note that both types of access are “merit based” – only quality research should be performed – even though they are not both “peer reviewed”.

**Consequences of different access modes:** Collaborative access tends to create stable, long term relationships with particular users. This arrangement is often preferred for highly specialized types of measurements, and is in general very efficient when measured on the basis of productivity per user. This mode of operation also ends up requiring less support because the frequent collaborators become expert users of the instruments.

General user access is the preferred mode of access for the “casual user”, or less frequent user. This mode of operation is most appropriate for general techniques that are not highly specialized or that require extensive specialized expertise. This mode of operation is more efficient than collaborative access at attracting large numbers of users and is very efficient when measured on the basis of productivity per instrument. This mode of operation requires a facility that can train and support users, regardless of their level of expertise with the instruments. Because of the demands placed on support staff by large numbers of non-expert users, a facility will often limit general user access when there are insufficient levels of user support.

<b>Facility</b>	<b>Facility owned</b>	<b>Partner owned</b>	<b>Total FY 2000 Instrument Time to General Access</b>
HFIR	8	3	0%
IPNS	13	0	75%
LANSCE	7	0	0%
NCNR	11	6*	60%

**Table 9 Breakdown of the number of facility owned, partner owned (including interagency partnerships) at U.S. neutron facilities in FY 2000. The total fraction of instrument time allocated in FY 2000 through the general user program (with an independent panel) is shown in the last column. \*Includes instruments in the NIST/NSF Center for High Resolution Neutron Scattering. See table references.**

### ***Access policies at U.S. facilities***

Neutron facilities in the United States employ a variety of ownership modes for instruments. Based on differences in ownership and on available support for general user operations, facility managers have adopted different access policies to control the allocation of instrument time to users of their instruments. Table 10 summarizes the access policies in place at U.S. neutron facilities in FY 2000.

### ***Findings***

- NCNR and HFIR both employ a variety of ownership models for neutron scattering instrumentation. At LANSCE and IPNS all instruments are owned by the facility. The SNS will have both facility-owned and partnership instruments.
- Access policies have been developed to control the allocation of beam time that is consistent with the needs of the instrument owners and with the available level of user support.
- In FY 2000, only NCNR and IPNS used an independent panel to allocate instrument time to the general users. LANSCE typically uses such a panel but did not in FY 2000 due to the limited operating time.
- The amount of beam time available through the general user programs is being limited to some degree at all facilities by the amount of resources available for full user support.

Facility	Highlights
SNS	<ul style="list-style-type: none"> <li>• Two ownership modes: Instrument Advisory Teams (IAT, facility-owned) and Instrument Development Teams (IDT, partnership-owned)</li> <li>• For IAT instruments, 75% of instrument time is scheduled through an external program advisory committee (PAC) and 25% is facility controlled.</li> <li>• For IDT instruments, up to 65% of instrument time is scheduled by IDT partners (in proportion to level of cost sharing for full development and operating cost contributions over a five year period) and the remainder is scheduled by the facility.</li> <li>• IDT partnerships are re-evaluated every five years and the access allotment adjusted accordingly.</li> </ul>
HFIR	<ul style="list-style-type: none"> <li>• Prior to 2001, all access was controlled by facility staff (collaborative), following a peer review process.</li> <li>• After 2001, the access model will be the same as for the SNS.</li> </ul>
IPNS	<ul style="list-style-type: none"> <li>• All instruments are facility owned.</li> <li>• Up to 75% of the instrument time is scheduled through an external program advisory committee (PAC) and 25% is facility controlled.</li> <li>• The fraction of time in the general user program is adjusted for levels of available user support. Currently access to several instruments is limited by available user support.</li> </ul>
LANSCE	<ul style="list-style-type: none"> <li>• For facility owned instruments, up to 75% of the instrument time is scheduled by an external Program Advisory Committee and the remainder is scheduled by the facility.</li> <li>• For partnership owned instruments (PRT), up to 75% of the instrument time is scheduled by the partners (fraction depends on amount of cost sharing to build/operate instrument) and the PAC schedules the remainder.</li> <li>• The fraction of time in the general user program is adjusted for levels of available user support. Currently general access to several instruments is limited by available user support.</li> </ul>
NCNR	<ul style="list-style-type: none"> <li>• For facility owned cold neutron instruments, 67% to 75% of the instrument time is scheduled through an external PAC the remainder is scheduled by the facility.</li> <li>• For facility owned thermal neutron instruments, up to 25% of the instrument time is scheduled by the PAC and the remainder by the facility.</li> <li>• For partnership owned (PRT instrument), up to 75% of the beam time is scheduled by the partners (in proportion to cost sharing on instrument development/operation) and the remainder is scheduled through the PAC.</li> <li>• For the NIST/NSF Center for High Resolution Scattering instruments (interagency partnership), control over the schedule is assigned as it is for PRT instruments, but the NSF fraction of time is scheduled through the PAC.</li> <li>• The fraction of time in the general user program is adjusted for levels of available user support. Currently access to most thermal neutron instruments is limited by available user support.</li> </ul>

**Table 10 Summary of access policies at U.S. neutron facilities. See table references.**

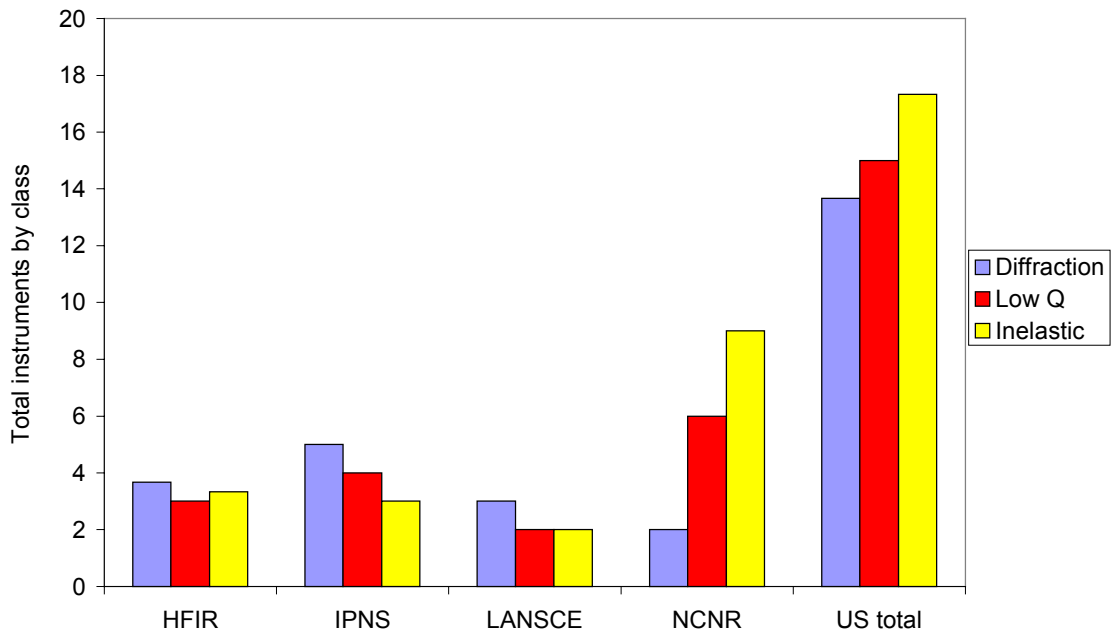
## Instrumentation

Data were examined for FY 2000 for the *neutron scattering* instruments operated at each U.S. neutron facility. Other types of instruments (such as testing stations, activation analysis, physics research, etc) are not included in this assessment. Data collected on neutron instrumentation operated in FY 2000 are shown below:

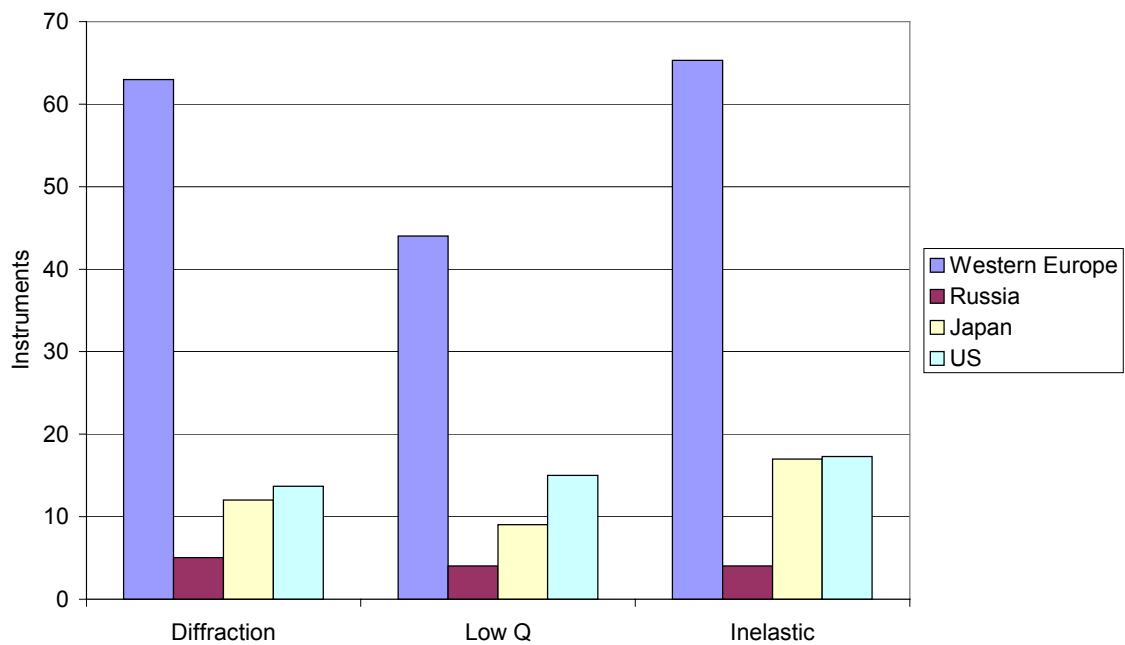
	Instrument	Type	Year	World Class?	Instrument Class	Ownership	Main Access Mode
HFIR	SANS reflectometer	SANS reflectometer	1986	N	Low Q	Facility	Collaborative
	USANS	double-crystal spectrometer	1990	N	Low Q	Facility	Collaborative
	HB1	polarized triple-axis spectrometer	1995	Y	Low Q	Facility	Collaborative
	HB1A	fixed incident energy triple-axis spectrometer	1968	Y	Inelastic	Facility	Collaborative
	WAND	high intensity diffractometer	1990	N	Inelastic	Partnership	Collaborative
	HB4A	high resolution powder diffractometer	1980's	N	Diffraction	Partnership	Collaborative
	HB2B*	residual stress diffractometer	1980's	N	Diffraction	Facility	Collaborative
	HB2*	triple axis spectrometer	1990's	Y	Diffraction	Partnership	Collaborative
	HB3	triple axis spectrometer	1969	Y	Inelastic	Facility	Collaborative
	HB2A	triple axis spectrometer	1968	Y	Inelastic	Facility	Collaborative
	HB2A	4-circle single-crystal diffractometer	1995	N	Diffraction	Facility	Collaborative
IPNS	GLAD	Glass, Liquids and Amorphous Mat. Diffract.	1990	Y	Diffraction	Facility	General
	QENS	Quasielastic Neutron Spectrometer	1987	Y	Inelastic	Facility	General
	HRMECS	High Resolution Med. Energy Chopper Spect.	1982	N	Inelastic	Facility	General
	SAND	Small Angle Neutron Diffractometer	1996	Y	Low Q	Facility	General
	POSYI	Polarized Neutron Reflectometer	1985	N	Low Q	Facility	General
	POSYII	Neutron Reflectometer	1987	N	Low Q	Facility	Collaborative
	SAD	Small Angle Diffractometer	1982	N	Low Q	Facility	General
	GPPD	General Purpose Powder Diffractometer	1981	Y	Diffraction	Facility	General
	HIPD/MiDaS	High Intensity Powder Diffractometer	1995	N	Diffraction	Facility	Collaborative
	LRMECS	Low Resolution Med. Energy Chopper Spect.	1981	Y	Inelastic	Facility	General
SEPD	Special Environment Powder Diffract.	1981	Y	Diffraction	Facility	General	
SCD	Single Crystal Diffractometer	1981	Y	Diffraction	Facility	General	
LANSCE	NPD	High resolution powder diffractometer	1988	Y	Diffraction	Facility	Collaborative
	HIPD	Low resolution powder diffractometer	1983	Y	Diffraction	Facility	Collaborative
	SCD	Single crystal diffractometer	1981	N	Diffraction	Facility	Collaborative
	FDS	Filter Difference Spectrometer	1981	N	Inelastic	Facility	Collaborative
	LQD	SANS	1986	Y	Low Q	Facility	Collaborative
	SPEAR	Reflectometer	1993	Y	Low Q	Facility	Collaborative
	PHAROS	Chopper spectrometer	1992	N	Inelastic	Facility	Collaborative
NCNR	BT-1	High resolution powder diffractometer	1990	N	Diffraction	Facility	Collaborative
	BT-2	Spin-polarized triple-axis spectrometer	1980	N	Inelastic	Facility	Collaborative
	BT-4 FANS	Filter analyzer spectrometer	2000	Y	Inelastic	Partnership	Collaborative
	BT-5 USANS	Double perfect crystal SANS	2000	Y	Low Q	Partnership	General
	BT-7	Fixed-incident energy triple axis	1999	N	Inelastic	Facility	Collaborative
	BT-8 DARTS	Residual Stress Diffractometer	1996	Y	Diffraction	Facility	Collaborative
	BT-9	Triple axis	1985	N	Inelastic	Facility	Collaborative
	NG-1 Reflect.	Reflectometer	1996	Y	Low Q	Facility	General
	NG-1 8m SANS	8m SANS	1990	N	Low Q	Facility	Collaborative
	NG-2 HFBS	High Resolution Backscattering Spectrometer	1998	Y	Inelastic	Facility	General
	NG-3 30m SANS	30m SANS	1992	Y	Low Q	Partnership	General
	NG-4 DCS	Disk Chopper TOF Spectrometer	2000	Y	Inelastic	Facility	General
	NG-5 SPINS	Spin-polarized triple-axis spectrometer	1994	Y	Inelastic	Partnership	General
	NG-5 NSE	Neutron Spin Echo Spectrometer	2000	Y	Inelastic	Facility	General
	NG-6 FCS	Fermi Chopper TOF Spectrometer	1992	N	Inelastic	Facility	Collaborative
NG-7 Reflect.	Horizontal sample Reflectometer	1994	Y	Low Q	Partnership	General	
NG-7 30m SANS	30m SANS	1991	Y	Low Q	Partnership	General	

**Table 11 Neutron scattering instruments operating at U.S. facilities in FY 2000.** Access mode refers to the access mode for the majority of beam time on that instrument for FY 2000. \* Note: The HB2 and HB2B instruments share time on a common beamline at the HFIR. The time sharing is approximately 1/3 HB2 (triple axis) and 2/3 HB2B (residual stress). See table references.

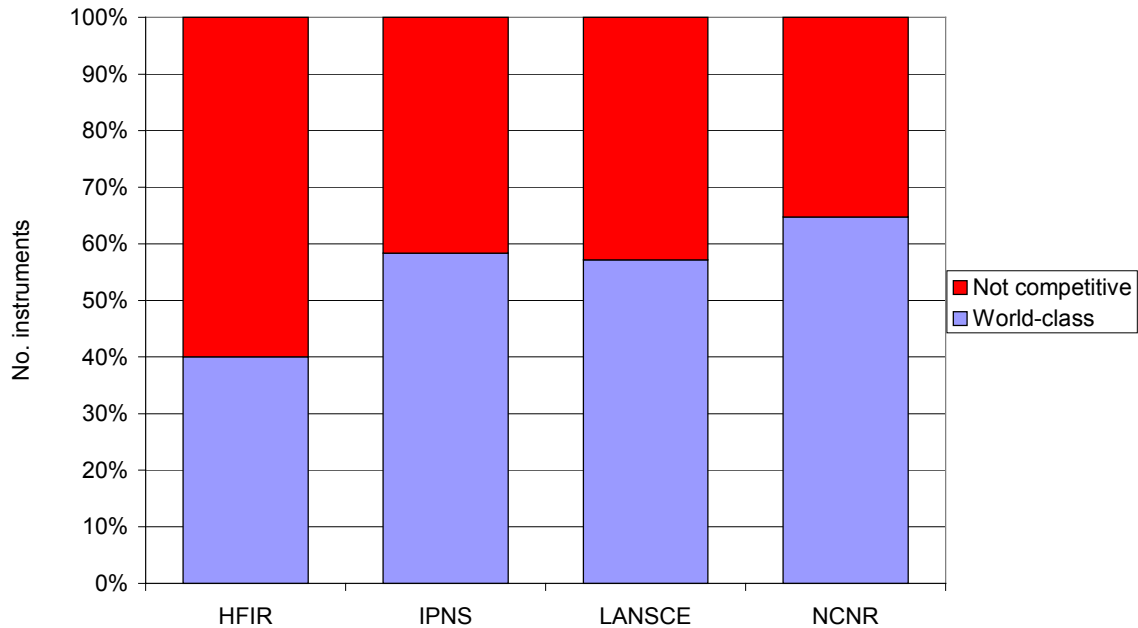




**Figure 9** Number of instruments by class at U.S. neutron facilities in FY 2000. See figure references.



**Figure 10** Comparison of instrument totals by instrument class between major international neutron facilities. See figure references.



**Figure 11** Fraction of instruments claimed as “world class” by each U.S. neutron facility in FY 2000. See figure references.

***New and upgraded instruments***

The IWG also looked at instrument development or upgrade efforts at all of the facilities. For comparison, only projects that are funded are included for each facility.

**Spallation Neutron Source:** The SNS project baseline includes a fixed budget of \$60M for instrument development and not a fixed number of completed instruments. Current plans project that approximately five instruments as well as all of the common component instrument systems will be provided under the project baseline. DOE/BES has funded two additional instruments to be built by university partners.

**Other facilities:** New instrument development or major instrument upgrades are summarized in the table below:

	Instrument	Type	New (N) or Upgrade (U)	Instrument Class
	SANS1	40m SANS	N	Low Q
	SANS2	35m Biology SANS	N	Low Q
	reflectometer	reflectometer	U	Low Q
	STAR	cold neutron triple axis	N	Inelastic
	USANS	double-crystal spectrometer	U	Low Q
HFIR	HB1	polarized triple-axis spectrometer	U	Inelastic
	WAND	high intensity diffractometer	U	Diffraction
	HB2A	high resolution powder diffractometer	U	Diffraction
	HB2B	residual stress diffractometer	U	Diffraction
	HB2D	triple axis spectrometer	U	Inelastic
	HB3	triple axis spectrometer	U	Inelastic
	HB2A	4-circle single-crystal diffractometer	U	Diffraction
IPNS	GLAD	Glass, Liquids and Amorphous Materials Diffract.	U	Diffraction
	HRMECS	High Resolution Medium Energy Chopper Spect.	U	Inelastic
	SAD	Small Angle Diffractometer	U	Low Q
	GPPD	General Purpose Powder Diffractometer	U	Diffraction
	SCD	Single Crystal Diffractometer	U	Diffraction
LANSCE	PCS	Protein diffractometer	N	Diffraction
	SMARTS	Engineering powder diffractometer	N	Diffraction
	HIPPO	Texture powder diffractometer	N	Diffraction
	ASTERIX	Polarized beam reflectometer	N	Low Q
	IN500	Chopper spectrometer	N	Inelastic
	PHAROS	Chopper spectrometer	U	Inelastic
NCNR	BT-7	Triple axis	U	Inelastic
	BT-9	Triple axis	U	Inelastic
	NG-0	Cold Neutron Triple Axis (NSF funded)	N	Inelastic
	NG-1 Reflectometer	Biology Reflectometer (NIH funded)	N	Low Q
	NG-1 9m SANS	9m SANS (CHRNS)	N	Low Q
	NG-3 30m SANS	30m SANS (CHNRS)	U	Low Q
	NG-5 SPINS	Spin-polarized triple-axis spectrometer (CHRNS)	U	Inelastic
	NG-7 30m SANS	30m SANS	U	Low Q

**Table 12 New or upgraded instrument projects (with committed funding) at U.S. neutron facilities to be developed over the next five years at existing facilities. Outside agency funding is shown in parenthesis, if applicable. See table references.**

### *Findings – instrumentation*

- There are significant differences in the instrument distribution by class between the U.S. facilities. Instruments for low Q and inelastic scattering represent a higher fraction of the total instrument suite at the NCNR compared to the DOE facilities. The difference is largely attributable to the focus at the NCNR on providing instrumentation that is well matched to its cold neutron capability.
- Western European facilities provide substantially greater instrument capability in all instrument classes over other regions of the world, including the United States.
- The level of instrumentation identified by U.S. facilities as being “world class” only represents 40-65% of the total instrument capability at any facility. This indicates that a substantial fraction of U.S. neutron instrumentation is not considered to be in the same competitive class with ILL/ISIS instruments. The highest rate of competitive instrumentation in FY2000 exists at the NCNR and the lowest at the HFIR.
- Instrument projects underway (either new or upgrades) will improve the quality of neutron instruments at U.S. facilities.
- The largest unmet instrumentation need is at the SNS. This facility has capacity for, up to 25 neutron instruments at the target station. Presently, only 7 have committed funding. A suite of approximately 15 instruments will be needed to provide a basic, broad range of measurement capability.

**Research facility staffing**

The IWG requested facilities provide their staffing levels for all aspects of research facilities operations. This includes all staff except those that operate the neutron source (including reactor/accelerator operators, target/moderator support staff, etc.).

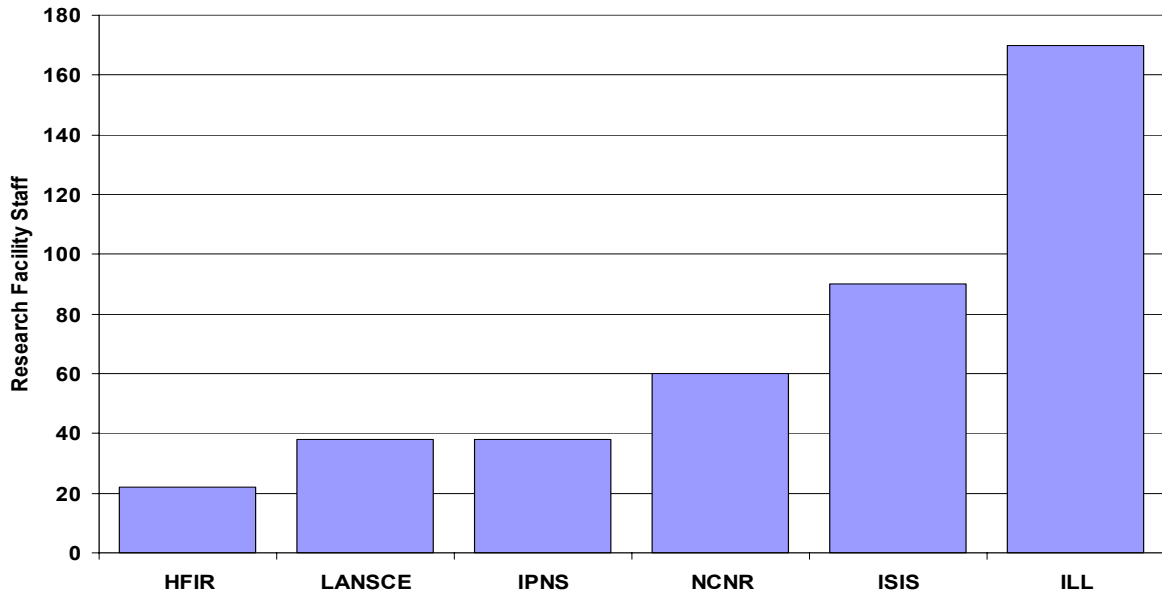


Figure 12 Number of research facility support staff at selected facilities in FY 2000. Research facility staff includes all staff that support use and operation of the neutron instruments, but excludes staff that support operation of the source. See figure references.

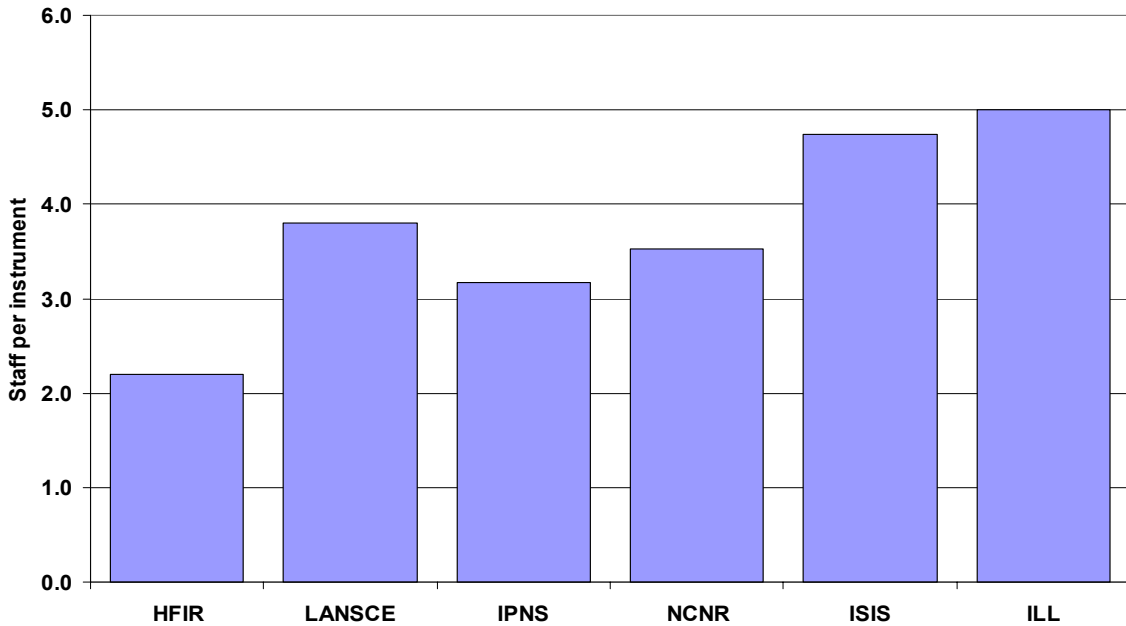
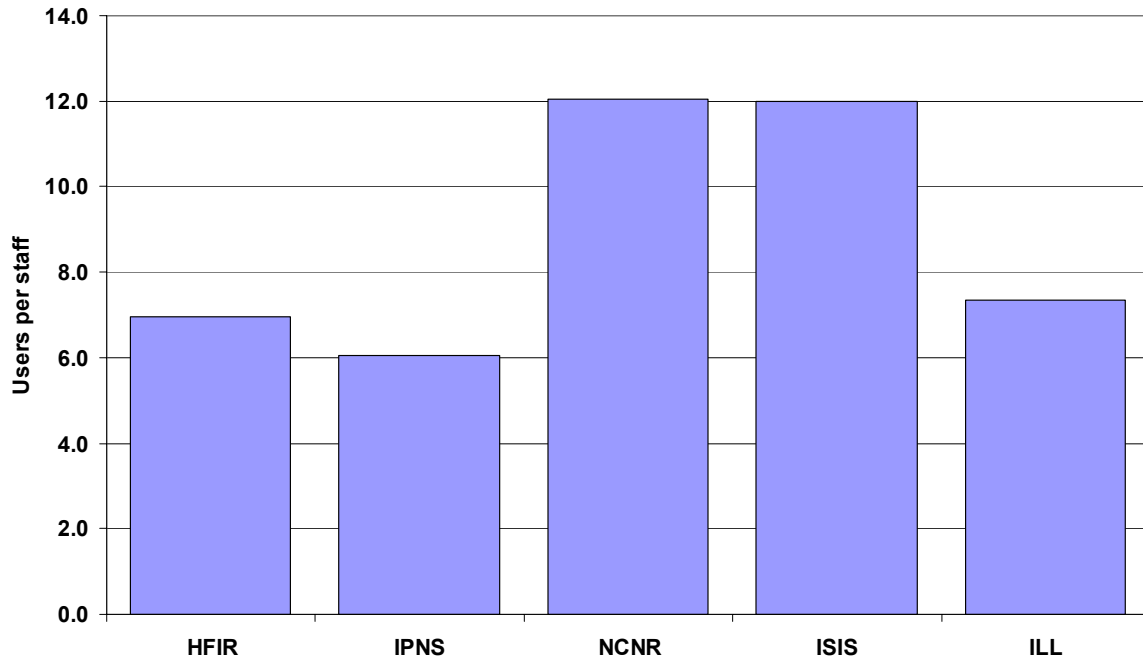


Figure 13 Research facility support staffing per neutron scattering instrument at selected facilities in FY 2000. See figure references.



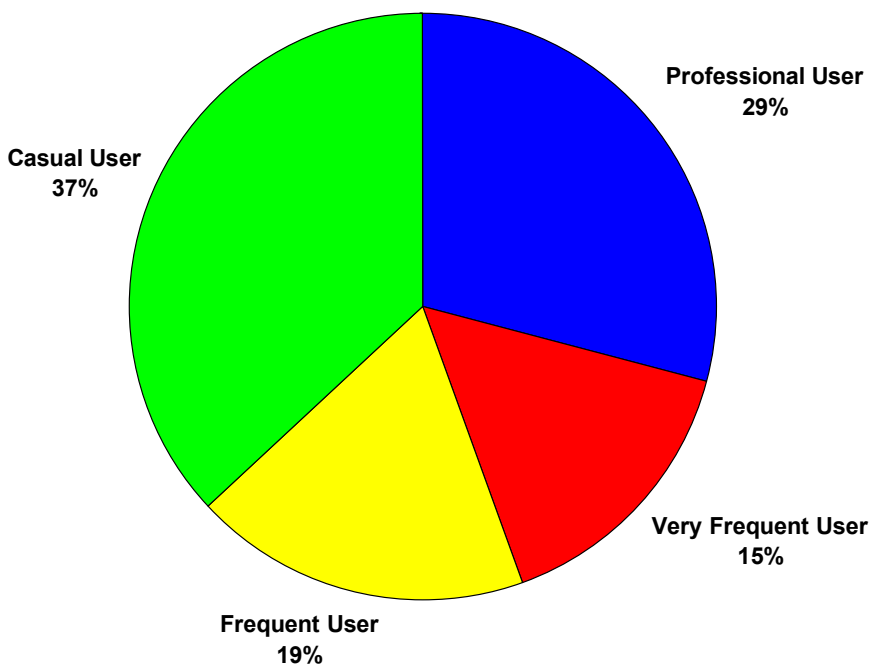
**Figure 14** Users per research facility support staff member at selected neutron facilities. See figure references.

***Findings – facility staffing***

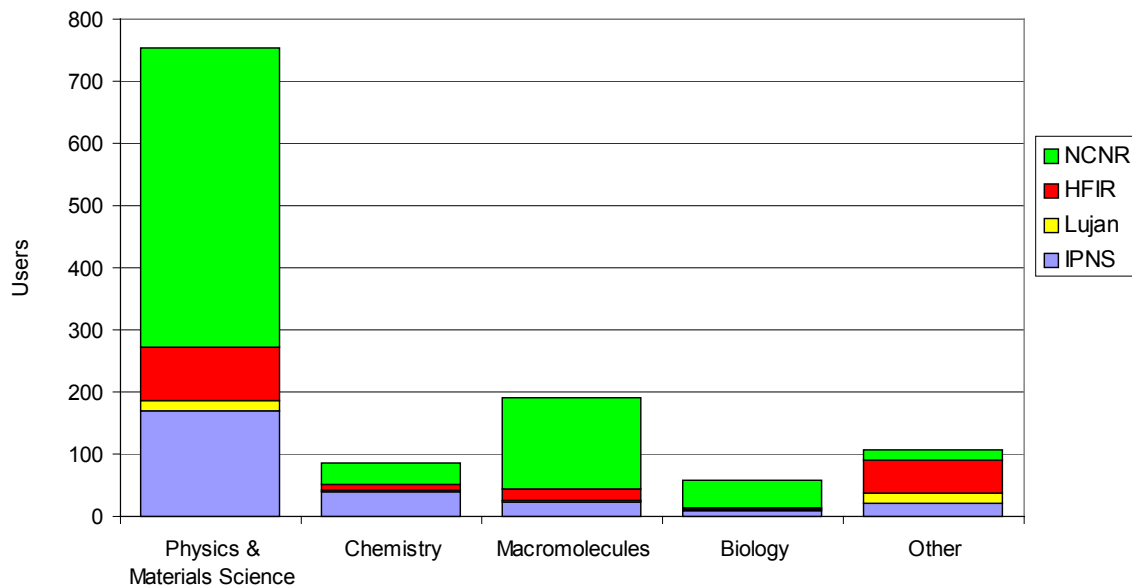
- Traditionally U.S. facilities have been staffed at a lower level per instrument than at ILL and ISIS. Normal staffing levels are considered to be 3-4 per instrument in the U.S. and 5-6 per instrument at ISIS and ILL. Only HFIR is staffed below these “nominal” levels.
- The number of users supported per staff member can be interpreted as a number representing the “load” on staff. Staff loads are similar at HFIR, IPNS and ILL, but approximately 70% higher at the NCNR and ISIS facilities.
- Since user throughput at the SNS can be expected to be similar to ISIS, the demand on the support staff at SNS will be considerable if traditional U.S. support levels of 3-4 staff members are used as a benchmark.

***User demographic data***

The IWG looked at the available data for FY 2000 on the users of the U.S. neutron facilities. These data were supplemented with survey results from the European Neutron Scattering Association in order to estimate the composition of the U.S. neutron users.



**Figure 15** European neutron scattering community by usage. Users were defined according to the fraction of their research program based on neutron scattering: Professional (75-100%), Very Frequent (50-75%), Frequent (25-50%), and Casual (0-25%). See figure references.



**Figure 16** U.S. neutron scattering users by field of research. See figure references.

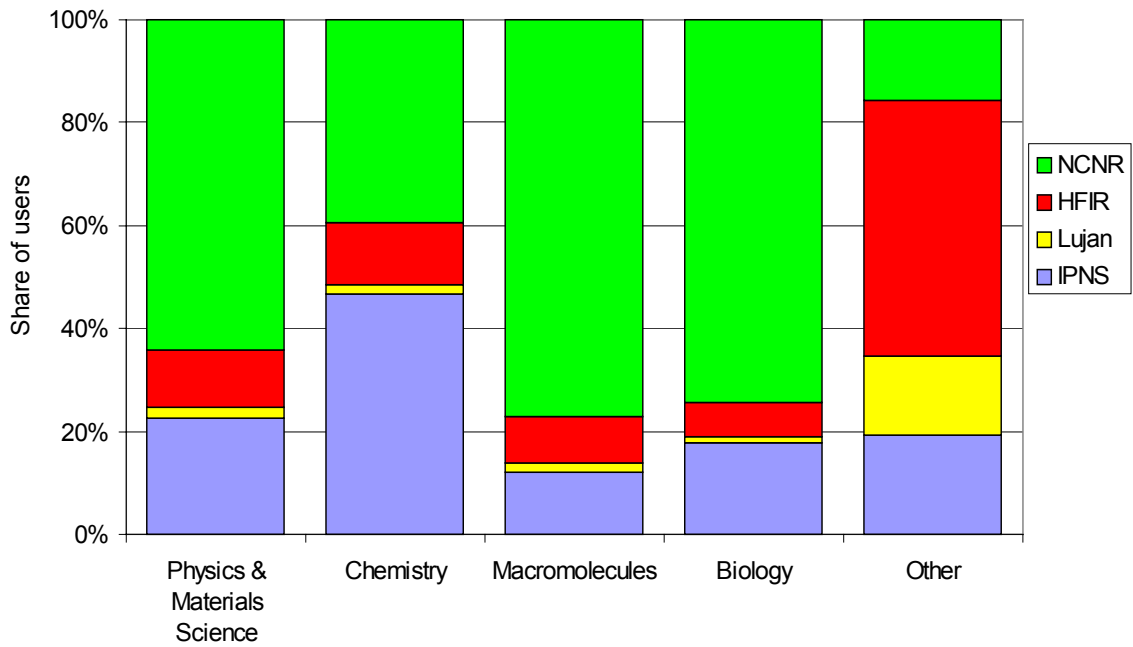


Figure 17 Share of users at U.S. neutron facilities by scientific field. See figure references.

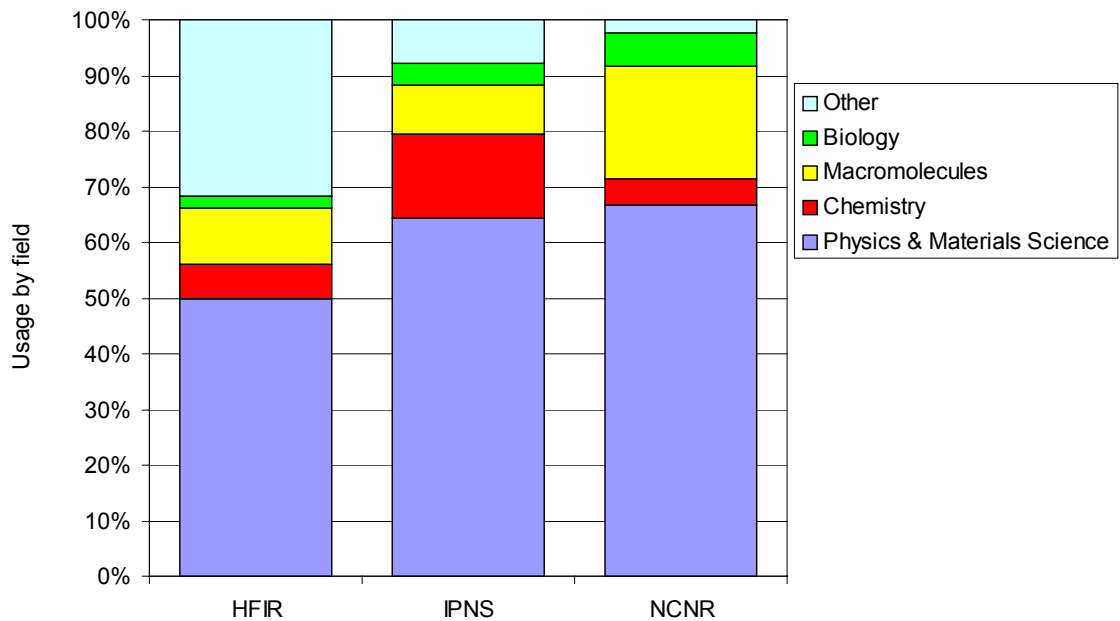
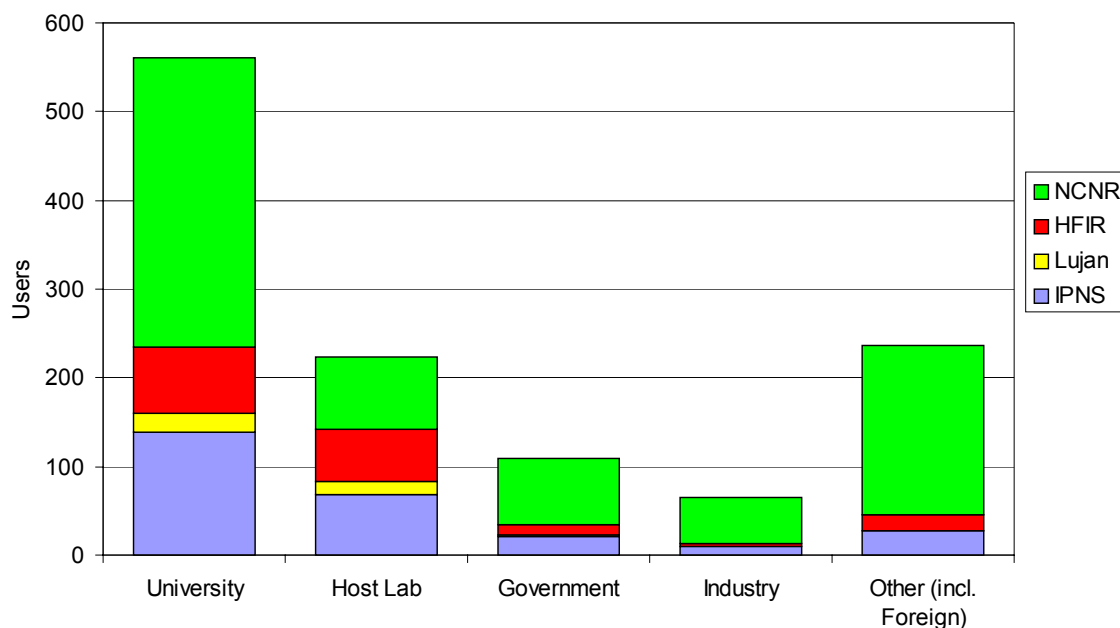


Figure 18 Share of scientific field by users at each U.S. neutron facility. See figure references.



**Figure 19** Number of users by individual affiliation at U.S. neutron facilities. Foreign participation is mostly as part of multinational collaborations with U.S. participation. See figure references.

### *Findings – user demographics*

- European survey results indicate that, for the majority users, neutron scattering measurements represent 50% or less of their overall research program. Similar data were unavailable for the U.S. community, but substantial use by “non-experts” is also found at U.S. neutron facilities.
- U.S. neutron scattering usage is broadly multidisciplinary, with the “traditional” neutron scattering fields, physics and materials science, only accounting for 50-60% of all users (see also Figure 1).
- Science fields representing the “physical sciences” (all fields except biology) account for over 90% of all users at U.S. facilities.
- The mixture of fields at a particular facility reflects the capabilities at that facility. For example, the fraction of users in macromolecular and biological sciences at the NCNR is twice that at IPNS or HFIR due to the emphasis on cold neutron capability.
- University researchers are the largest segment of the U.S. neutron scattering user community (50%), followed by scientists from the host laboratory (30%). Foreign participation is significant, but is nearly always part of multinational collaborations that include U.S. researchers.



### ***Research output and outcomes***

The main purpose of neutron-based research facilities is to perform leading-edge research using the unique properties of neutrons. The IWG examined some available data on the outcomes of this research and on some of the research output, namely publications, from the U.S. neutron research facilities.

<b>Year</b>	<b>Name</b>	<b>Award</b>	<b>Research Area</b>
1957	Clifford Shull (MIT)	APS Buckley Prize	Neutron diffraction, magnetic structure
1963	Bertram Brockhouse (AECL)	APS Buckley Prize	Phonons, magnons
1973	John Axe, Gen Shirane (BNL)	ACA Warren Diffraction Award	Soft modes, phase transitions
1973	Gen Shirane (BNL)	APS Buckley Prize	Phonons, soft modes
1974	Paul Flory (Cal Tech)	Nobel Prize, Chemistry	Polymer structure
1978	Henri Benoit (Strasbourg)	APS High Polymer Prize	Neutrons, polymer structure
1982	Edwards (Cambridge), Pierre de Gennes (Col. Paris)	APS High Polymer Prize	Polymer structure, dynamics
1984	Charles Han (NIST)	APS Dillon Medal	Polymer structure
1986	Muthu Kumar (U. Mass)	APS Dillon Medal	Polymer structure, dynamics
1987	Robert Birgeneau (MIT)	APS Buckley Prize	Magnetism
1988	Robert Birgeneau (MIT), Paul Horn (IBM)	ACA Warren Diffraction Award	Low-dimensional systems
1988	Jean Guenet (Saclay)	APS Dillon Medal	Gel formation
1989	Frank Bates (AT&T)	APS Dillon Medal	Block copolymers
1990	Pierre de Gennes (Col. Paris)	Nobel Prize, Physics	Theory of polymers, liquid crystals
1990	James Jorgensen (ANL)	ACA Warren Diffraction Award	Structure of ceramic superconductors
1990	Dieter Richter (KFA), John Huang (Exxon)	Max Planck Research Prize	Dynamics of polymers and microemulsions
1991	Ken Schweitzer (Sandia)	APS Dillon Medal	Polymer RISM theory
1992	Glenn Fredrickson (UCSB)	APS Dillon Medal	Theory of microsphere polymer structure
1992	Phil Pincus (UCSB)	APS High Polymer Prize	Theory of complex fluids
1992	Alice Gast (Stanford)	Colburn Award (American Institute of Chemical Engineering)	Colloids and polymers
1994	Clifford Shull (MIT), Bertram Brockhouse (AECL)	Nobel Prize, Physics	Neutron scattering methods for structures and dynamics
1996	Frank Bates (U. Minn.)	APS High Polymer Prize	Structure of copolymers
1996	Nitash Balsara (N.Y. Polytech.)	APS Dillon Medal	Properties of polymer blends
1997	David Price (ANL)	ACA Warren Diffraction Award	Structure of disordered systems
1998	Eric Kaler (U. Delaware)	ACS Colloid & Surface Chemistry Award	Complex fluids
1998	Spiros Anastasiadis (U. Crete)	APS Dillon Prize	Structure and dynamics of polymer solutions, melts and films
1999	Anne Mayes (MIT)	APS Dillon Prize	Polymer self-organization
1999	Richard Stein (U. Mass)	MRS Von Hippel Award	Polymer structure
1999	Charles Han (NIST)	APS High Polymer Prize	Neutron scattering, polymer phase separation
2000	Lewis Fetters (Exxon)	APS High Polymer Prize	Polymer entanglement, miscibility and microphase separation
2000	Lewis Fetters (Exxon)	ACS Applied Polymer Science Award	Polymer science and applications
2000	Robert Birgeneau (MIT)	APS Lilienfeld Prize	Phase transitions

**Table 13 Major scientific awards for, or strongly influenced by, neutron scattering research. See table references.**

**Publications:** The IWG also looked at publications from the neutron facilities in FY 2000. To make comparisons, facilities were asked to estimate the number of journal articles published in FY 2000 in the area of neutron scattering research. The data show that a total of approximately 400 journal publications were published from all of the U.S. neutron facilities for research using neutron scattering. Approximately half of the U.S. publications were from the NCNR. The U.S. total is about the same as the number of publications from either the ILL or ISIS alone.

### ***Recent research highlights***

The IWG collected from the steward agencies a small selection of research highlights performed over the past five years at U.S. neutron facilities. This collection is representative, but not all-inclusive, of the breadth and quality of recent neutron scattering research in the United States. Some of the research highlights include:

- Neutron scattering studies of spin dynamics and nanoscale polaron formation in new *colossal magnetoresistive materials*, which have important applications in magnetic data storage and sensor technology.
- Fundamental breakthroughs in the understanding of quantum mechanical behavior of low dimensional and frustrated magnet systems.
- Neutron reflectivity measurements have greatly advanced the understanding of polymer thin films, adsorbed polymer layers and membranes under a variety of conditions critical to applications in coatings, adhesion and composite lamination.
- Neutron studies have been used to probe the role of “stripes” (i.e. magnetic structure) in the behavior of high temperature superconductors.
- SANS has revealed the types of structural changes occurring at the nano-scale that can cause embrittlement of power reactor vessels.
- Direct determination by neutron inelastic scattering of molecular interactions, which are the basis for the design of, advanced polymer materials.
- Advances in the understanding of the behavior of molecules and atoms in nanoporous materials using inelastic neutron techniques. These materials have important applications for chemical separation and environmental clean up technology.
- Neutron and synchrotron x-ray powder diffraction studies have greatly advanced the ability to tailor new zeolyte molecular sieves used for chemical separations.
- Neutron residual stress measurements now validate the finite element analysis techniques used for optimizing production of industrial products.

### ***Findings – research output and outcomes***

- Reviews of neutron scattering (see References section at the end of this report) all conclude that neutron scattering provides essential research tools needed for leading edge research.
- The number of major scientific awards attributable to neutron scattering research is substantial and increasing.
- The total number of U.S. publications in FY 2000 was approximately 400. This is about the same as the number of publications from either the ILL or ISIS over the same period. Half of the U.S. publications are from the NCNR.
- A quick review of recent research highlights using neutron scattering shows high-impact research, consistent with the conclusions from earlier reports.

## ***Conclusions***

The assessment by the IWG of the condition of U.S. neutron scattering facilities provides convincing evidence that there is a substantial need for improving both the number and quality of neutron scattering instruments, and in broadening the access to them by the U.S. research community. The SNS stands out as the most significant opportunity to increase both the quantity and quality of neutron scattering capability at a U.S. source. The completion of the SNS construction project will still leave the majority of potential beamlines undeveloped and thus the full SNS capability under-utilized. Given the large investments being made to develop the SNS source, the most cost effective approach is to completely instrument the source so that it can realize its full potential. Doing so would yield a neutron scattering capability unmatched in the world. The four operating U.S. sources are essentially at capacity with regard to the number of instruments, but a significant fraction of those instruments need upgrades or replacement to be competitive with capability available elsewhere. The IWG found that most facilities have major instrument upgrade or replacement efforts underway that, if successfully completed, should substantially improve the overall quality of neutron scattering capability in the United States.

The other significant challenge is to expand access to these neutron instruments for U.S. researchers. Clearly, this goal is related to the quality of the neutron scattering instruments and will be impacted by the activities described above. However, a vigorous user program that brings part-time neutron scattering researchers to the facility also depends upon: 1) adequate research facility staff; 2) instrument ownership modes that do not increase the time controlled through collaborative access; and 3) a commitment to an independent, merit-based general user program. The historical success of the ILL and ISIS facilities that are committed to this mode of operation, and the evidence presented in this report on the similar success at the NCNR show the benefits of this type of operation.

## Recommendations and Priorities

In consideration of these findings and conclusions, the IWG believes that the highest priority goals for the U.S. neutron scattering facilities are:

- To seek ways to fully exploit the best present neutron source facilities and the SNS;
- To broaden access to these facilities for the benefit of the broadest possible scientific community;
- To improve coordination between agencies, facilities and stakeholders so that the overall U.S. neutron capability is fully optimized; and
- To foster the advances in neutron source technology and neutron methods needed to develop advanced neutron techniques and develop future neutron scattering capability.

In support of these goals, the IWG makes the following general recommendations:

### ***Recommendation 1:***

**The IWG recommends that the highest priority for federal investments in neutron scattering is to fully exploit the best U.S. neutron source capabilities – including the SNS – for the benefit of the broadest possible scientific community.** Specifically, these investments should aim to:

- Fully develop at least 85% of available beam lines with neutron instrumentation that exceeds or is at least competitive with international best-in-class instruments;
- Maximize the amount of beam time made available to the broad scientific community through an independent, peer-review based general user program;
- Provide resources to fully staff and support the high productivity operation of the neutron scattering instruments;
- Provide support for research using neutron scattering techniques.

### ***Discussion:***

The IWG believes that the high priority and significant resources devoted to developing and operating the nation's neutron *sources* have not been matched with the commitment and resources to fully instrument and staff those sources so that they achieve the highest level of scientific productivity and serve the broadest possible scientific user community. The assessment data clearly demonstrate the major gains in per instrument productivity that can result from state-of-the-art neutron instrumentation and the resources to operate a robust user program. However, even the remarkable gains at the NCNR are now being limited because the growth in users has outstripped the size of the research facility staff.

The specific goals for this investment strategy reflect the findings from the IWG assessment:

- A facility should strive for 100% leading or competitive class instrumentation. However, the IWG believes that the recommended level of 85% or better takes into account the flexibility needed by a facility for a reasonable program of instrument replacement and upgrade.
- The IWG recognizes a legitimate need for collaborative access to specialized capability, but believes that the goal should be to maximize general user access to the instruments with broad scientific appeal.
- The IWG believes that a robust general user program requires significant staffing resources and a strong in-house science program at the facility. The assessment data demonstrate that the traditional staffing benchmark level of 3-4 scientific, engineering

and technical support staff per instruments is too low to sustain the maximum number of users. The appropriate staffing level appears to be closer to 5 for the present generation of best-in-class instruments. This is a useful starting point for the SNS, *but it may not be sufficient for the high productivity expected for the SNS instrument suite.*

***Recommendation 2:***

**The IWG recommends that the steward agency for each of the major neutron facilities form partnerships with other federal agencies to meet the objectives of**

**Recommendation 1. These partnerships should be based on the following principles:**

- They must support the role of the steward agency;
- They must promote the role of the facility staff to manage and operate the instruments;
- They must provide adequate resources to develop instruments and to operate them in a robust user program;
- They must meet the needs of the U.S. research community and support the specific program objectives of the participating agencies;
- The scope and terms of the partnership should be mutually agreed upon by the partners and then clearly stated to all stakeholders;
- Participating agencies should use joint mechanisms to select and review projects in the partnership.

***Discussion:***

The size of neutron facilities and the breadth of their use have increasingly required cost sharing to support the continued development and operation of the *research* facilities. The *Cooperative Stewardship*<sup>3</sup> report provides a helpful framework for cost sharing mechanisms that allow for diverse sources of support without undermining the stable operation of the central source facility. Specifically, the *Cooperative Stewardship* report found that:

- Growth in the use and size of major user facilities has given rise to funding stresses at the facilities to support robust user operations;
- Early U.S. management models (and European models) based on dispersed stewardship and funding, have been shown to be unsatisfactory for user facilities because of the diffusion of responsibility and the instability of funding;
- User fee-based cost sharing mechanisms would undermine merit based access to major facilities and would destabilize the funding for operation and maintenance;
- The preferred funding and management model is single agency stewardship of the core facility (called source facility in this report), and the use of partnerships for the research facility.

The IWG fully endorses these findings and believes that the need for partnerships extends to large neutron sources. Furthermore, the IWG believes that that the goals for the U.S. neutron facilities given in Recommendation 1 can be best met through partnerships between the federal agencies that support the many scientific and engineering areas that use neutron scattering methods. The “small science at a large facility” character of neutron scattering research means that investments in neutron source capability are truly investments in a national measurement infrastructure that has broad appeal beyond the mission focus areas of the steward agencies. The IWG believes that with proper care, interagency partnerships can be an effective method to provide adequate stable resources to develop and operate high-quality neutron scattering instruments, while ensuring the broadest possible access to those instruments by the U.S. scientific community

***Recommendation 3:***

**The IWG recommends a series of actions to improve coordination between participating agencies, facility managers, and user organizations in order to maximize the overall effectiveness of the nation's neutron resources. These actions include:**

- Continued interagency coordination through OSTP for the development and use of neutron scattering capability in the United States;
- The establishment of some regular venue for the management of the nation's neutron facilities to foster inter-facility cooperation, mutual planning and strategic planning for the neutron field, and to improve collaboration, and communication between the facilities;
- The steward agencies, in coordination with neutron facility management, should take steps to foster improved communication and coordination among the user communities (through their representative organizations) of the neutron facilities.

***Discussion:***

As neutron source capability is limited within the U.S., the IWG focused on ways to ensure that this precious resource is wisely exploited. Improved coordination at all levels is needed to make certain that instrument development meets the national needs of the U.S. neutron scattering community, is well matched to the source performance, and minimizes unnecessary duplication of capability. The IWG found that there were few formal mechanisms to organize or coordinate efforts at the U.S. neutron facilities. Because of the limitations in the U.S. neutron scattering infrastructure, it is imperative to improve the effectiveness of these facilities by closer coordination at a variety of levels:

- Interagency coordination, along the lines of this IWG, should continue so that stakeholder agencies can have a regular forum to evaluate the effectiveness of their investments in neutron scattering programs;
- Inter-facility coordination should be formally established so that senior managers of the U.S. neutron facilities have a regular venue to discuss operations schedules, instrument and source improvements, options to develop new and needed capability and to explore ways to eliminate barriers to neutron facility use by the broader scientific community.
- Coordination should be established between the facility-based user groups and national user organizations such as the Neutron Scattering Society of America. The diverse scientific fields served by neutron scattering methods should have some common forum for providing their input to facilities and to agencies, but also for promoting the kinds of interdisciplinary contacts that often fuel new developments.

***Recommendation 4:***

**The IWG recommends that participating federal agencies promote and coordinate efforts to advance neutron scattering methods and neutron source technology needed for the future. Specifically, this includes promoting:**

- Upgrades and enhancements to neutron scattering instruments;
- Research and development in neutron source (including moderator) technology;
- Efforts to develop new and improved neutron scattering methods; and
- Efforts to expand the application of neutron scattering to new areas of science.

***Discussion:***

The IWG assessment projected an increased demand for future neutron scattering capability. U.S. researchers will face this increased demand with a very limited neutron measurement capability (both sources and instruments). The future health of the neutron scattering program in the United States requires a continuous effort to improve the present capability and to develop tomorrow's capability. The IWG believes that the steward and partner agencies should focus efforts in these areas and ensure that they receive appropriate resources. Traditionally, the specialized expertise to advance neutron source and scattering methods has resided within the neutron facilities. The IWG believes that this core competency of the science and technical staff at the facilities should be enhanced. The IWG also notes that universities have a critical role developing new talent in neutron techniques and believes that university-based efforts must also be supported. The IWG noted the comparatively better organized efforts in Europe and Japan for research and development in neutron techniques. It is important to ensure a robust effort in this area for the United States as well.

***Implementation of recommendations at U.S. neutron facilities: Priorities***

***Spallation Neutron Source***

The SNS project represents the most significant enhancement of neutron source capability in the United States at this time. As such, it also represents the largest opportunity to significantly enhance U.S. neutron scattering capability through investments in a robust instrument suite and strong scientific and technical support to operate those instruments. As stated in the 2000 BESAC Subpanel on Neutron Scattering report<sup>10</sup>:

*The Spallation Neutron Source will, when operational, be a world leader in neutron science, and a focal point of neutron scattering in the U.S. More than an order of magnitude gain in intensity over existing pulsed neutron sources, combined with an innovative and robust initial instrument suite (emphasis added), will provide entirely new possibilities for forefront research, and will re-establish this country as a leader in neutron scattering. It is the highest priority for the neutron community...*

Meeting this opportunity will require a commitment to fully achieve the goals in Recommendation 1 for the SNS soon after commencement of routine source operations. Consequently, the IWG considers the needs of the SNS research facility to be the highest priority within the U.S. neutron program:

***Implementation Priority 1:***

**The Department of Energy, the National Science Foundation, and other interested agencies, should immediately establish a framework for an interagency partnership to provide funding resources to develop and operate a robust suite of instruments, approximately 75% of full instrumentation, to address a broad spectrum of neutron scattering measurements at the SNS. To be timely, the framework for instrument development should be affected within the next six months.**

***Status:***

The President's FY03 budget request to Congress includes a program within DOE's Office of Basic Energy Sciences (DOE/BES) for support of instrumentation and associated R&D for x-ray and neutron science at a level of approximately \$15M beginning in FY2003, with at least \$5M of this funding allocated for new instruments and instrument upgrades at the SNS. Furthermore, DOE/BES intends to provide operating support for most new instruments built for the physical sciences regardless of the support of capitalization. This will provide stable support for these instruments and will maximize access for the broad user community. DOE/BES will also support research using these instruments appropriate to its mission.

The National Science Foundation is also developing plans to institute a program for instrument development at major user facilities, including neutron and x-ray sources. This program will accept proposals on a competitive basis for the cost to develop or upgrade instruments at major facilities. Negotiations are underway between these two agencies to explore ways to coordinate their activities through a joint partnership to develop instrumentation at the SNS.

***NIST Center for Neutron Research***

The NCNR is the highest performing and most used neutron facility in the United States at this time, and will remain in that position at least until the SNS is operational and robustly instrumented. With high quality instrumentation, especially for cold neutron techniques, and a robust user program, the NCNR facility serves the majority of U.S. neutron scattering users. Recent activities at the NCNR have aimed to further enhance instrument capability and to expand access to these instruments. Highlights include:

- Upgrade of the liquid hydrogen cold source to double cold neutron intensity;
- Funded upgrade of thermal neutron scattering instruments;
- New NIST/NSF/John's Hopkins University partnership to develop high intensity cold neutron triple axis capability;
- New NIST/NIH partnership to develop dedicated capability for low-Q diffraction of protein membranes;
- Expansion of the NIST/NSF Center for High Resolution Neutron Scattering (CHRNS). The Center provides enhanced support for a selected suite of instruments and results in an increased fraction of instrument time available through the general user program. A more complete description of the CHRNS is found in the Appendix. The 2001 expansion doubled the number of instruments in the Center.

In spite of these improvements, the IWG assessment finds that the NCNR is still under funded to fully exploit its measurement capability for the general user community. At this time, only about 60% of the available beam time is access through the general user program and available staffing and research support limit this fraction. Furthermore, the present NRC license for the reactor expires in May, 2004 requiring a timely license renewal application for a 20-year extension.



### ***Implementation Priority 2:***

**The IWG recommends that NIST and the Department of Commerce along with their partners, including the National Science Foundation, continue to fully support: 1) the source operations of the NCNR; 2) the improvements in source and instrument capability; and 3) the increased levels of support for both the NIST research program the general science community.**

**In addition, because of the essential role of this facility to the nation's neutron measurement infrastructure, the IWG recommends that NIST and the Department of Commerce fully support all activities related to the license renewal for the NIST reactor by the Nuclear Regulatory Commission.**

### ***Status:***

The President's FY 2003 budget request to Congress includes a \$6M increase for the NCNR to enhance in-house research activities and to increase staffing support. These resources will allow the NCNR to bring more beam time into the general user program as the instrument upgrades described above are completed. This should result in a 30% increase in the number of users at the NCNR making it comparable to the present capacity of ISIS. In addition, the NCNR is actively fostering instrument development partnerships with agencies and institutions when it is an appropriate mechanism for the development of a particular instrument capability. The Department of Commerce and NIST fully support all preparations for a timely license renewal application to the NRC.

### ***The High Flux Isotope Reactor***

The HFIR is in the midst of a major project to enhance its neutron scattering capability.

Major elements of this project include:

- Modification of the beryllium reflector geometry to allow larger diameter beam tubes;
- Installation of a super-critical hydrogen cold source in beam tube HB-4;
- Construction of a cold neutron guide tube network and associated guide hall facility;
- Development of four new cold neutron spectrometers. New capability includes two SANS instruments, one reflectometer and one cold neutron triple axis spectrometry; and
- Major upgrades to thermal neutron scattering instruments.

The IWG believes that the successful completion of this upgrade project and the subsequent operation of the HFIR instruments in a vigorous general user program is essential for the health of the U.S. neutron scattering program and therefore, a high priority for the Department of Energy and Oak Ridge National Laboratory. The HFIR will, when complete, offer complementary capability to the SNS and "will join the NIST reactor as a major facility on the world scene, and become an essential component of the U.S. neutron scattering capability."<sup>10</sup>

A 1998 BESAC report on the High Flux Isotope Reactor Upgrade and User Program<sup>10</sup> made several specific recommendations to Oak Ridge National Laboratory regarding the HFIR:

1. Develop a plan to address long-term reliability of the HFIR;
2. Develop a coherent vision of the expected outcome of the ongoing upgrades and develop and implement a management plan to reach that goal;

3. Develop a viable plan to develop a high quality user program at the upgraded HFIR that is tightly coordinated with the user program at the SNS; and
4. Develop a staffing plan that broadens the existing science program.

As stated in the report<sup>10</sup>: “Access to neutron facilities remains an important national issue. Access to the HFIR remains based on a collaborative philosophy and continuation of that approach cannot be justified with the upgrade investment.” The IWG concurs with this conclusion.

### ***Implementation Priority 3:***

<p><b>The IWG recommends that the Department of Energy should fully support the cold source and instrument upgrade project at the HFIR and ensure that the instruments are operated to support a robust general user program .</b></p>
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### ***Status:***

The President’s FY 2003 budget request to Congress includes funding to support the upgrade program and to continue fabrication of new instruments. The operating budget of the facility will be adjusted in FY 2003 and beyond to support a growing user program as instruments are reinstalled at the reactor following the year-long outage to replace the beryllium reflector.

### ***The Intense Pulsed Neutron Facility***

The IPNS has been one of the most successful DOE neutron sources, operating with consistent, high reliability; developing new moderator and instrument capability; and operating a well-run general user program. Currently the IPNS has several modest instrument improvement efforts underway that will improve capability on selected instruments. In addition, Argonne National Laboratory is the lead lab within the SNS project for development of instruments at the SNS. The IPNS staff plays a key leadership role in the development of SNS instrument and moderator capability. A recent BESAC panel examined the neutron scattering programs at IPNS and at the Lujan Center at LANSCE. This panel found that<sup>6</sup> the IPNS “*is an extremely reliable source with a talented and experience staff. However, the facilities (source and some instruments) are in need of improvements to make them more competitive and to maintain reliability.*”

The IWG decided not to make the IPNS one of the implementation priorities at this time. The long-term future of the IPNS must be assessed with a clear-headed appraisal of how it can contribute when the SNS is operational. The IPNS has been a great success, and continues to outperform the other DOE neutron facilities in many respects. However, it will not be able to provide competitive capability in comparison to the SNS. The IWG believes that any recommendations regarding the future of this facility should wait until the SNS is functioning as an effective neutron scattering facility.

### ***The Los Alamos Neutron Scattering Center***

The IWG assessment makes clear a troubling history of poor source performance at LANSCE that has crippled attempts to foster a strong neutron scattering program. The BESAC review of IPNS and LANSCE<sup>6</sup> reached a similar conclusion and recommended changes in the governance and management of this facility. In response, Los Alamos and DOE management have articulated a new governance model for LANSCE, made changes in the LANSCE leadership and instituted reviews of various aspects of the LANSCE program. The IWG was pleased with the

aggressive response on the part of LANSCE and the Department to address the problems at this facility, and early signs point to improvements in restoring reliable source operations.

The IWG believes that the success of LANSCE – a diverse multi-program effort – depends on strong leadership by Los Alamos and by the agency steward, the National Nuclear Security Administration (NNSA) at DOE. A major effort to define the role of this facility within Los Alamos National Laboratory and within the NNSA is underway. Because of this ongoing process, the IWG decided not to make any specific recommendation regarding LANSCE at this time. Based on the ability of LANSCE to convincingly demonstrate that it can reliably operate the neutron source, it may be possible at a future date to re-examine the role that LANSCE should play in the U.S. neutron infrastructure, particularly for the broader, general scientific community.

## Appendix: NSF-NIST Center for High Resolution Neutron Scattering

The Center for High Resolution Neutron Scattering (CHRNS) is an interagency partnership between the National Science Foundation and NIST which aims to:

- Develop and operate state-of-the-art neutron scattering instrumentation for use by the general science community;
- Promote effective use of those instruments by having identifiable staff whose primary function is to assist users;
- Conduct research and development that advances the capability of the CHRNS facility;
- Contributes to the development of human resources through education and outreach efforts.

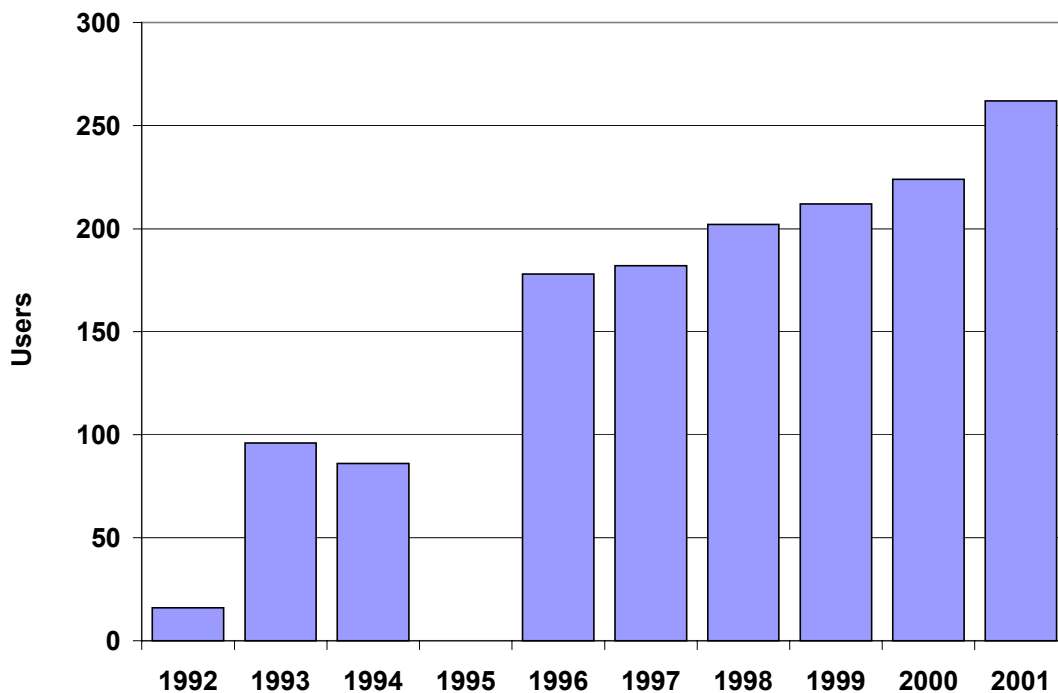
Under a series of cooperative agreements, NSF and NIST agree to share resources under CHRNS to develop and operate “best-in-class” neutron scattering instruments at the NCNR with an agreed upon fraction of the beam time made available through the general user program and scheduled by an independent Program Advisory Committee based on outside peer review of beam time proposals. The current list of CHRNS instruments and the fraction of time made available to the general user program is:

Instrument type (name)	Fraction of time in general user program	Year entered CHRNS
30m small angle scattering (SANS)	75%	1992
Spin polarized, cold neutron triple axis (SPINS)	67%	1993
Ultra high resolution sans (USANS)	67%	2000
High flux backscattering spectrometer (HFBR)	67%	2001
Neutron spin echo spectrometer (NSE)	67%	2001
Disk chopper spectrometer (DCS)	67%	2001
9m small angle scattering (SANS)	50%	2003

**Table 14 Instruments included in the NIST/NSF Center for High Resolution Neutron Scattering.**

### ***Program Highlights:***

- CHRNS instruments supported over 260 neutron scattering users in FY00: more neutron scattering users through CHRNS than through any other U.S. neutron facility (excluding the NCNR).
- Research on CHRNS instruments in FY00 resulted in over 85 publications in refereed scientific journals.
- The CHRNS sponsors an annual summer school and supports other outreach efforts.
- This program allows expanded access to NIST facilities through instrument improvements, resources to fully staff instruments for general user access.
- CHRNS effectively serves users from general science community, especially at universities (see Figure 22).



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Figure 20 Number of neutron users through the CHRNS program at the NCNR. See figure references.

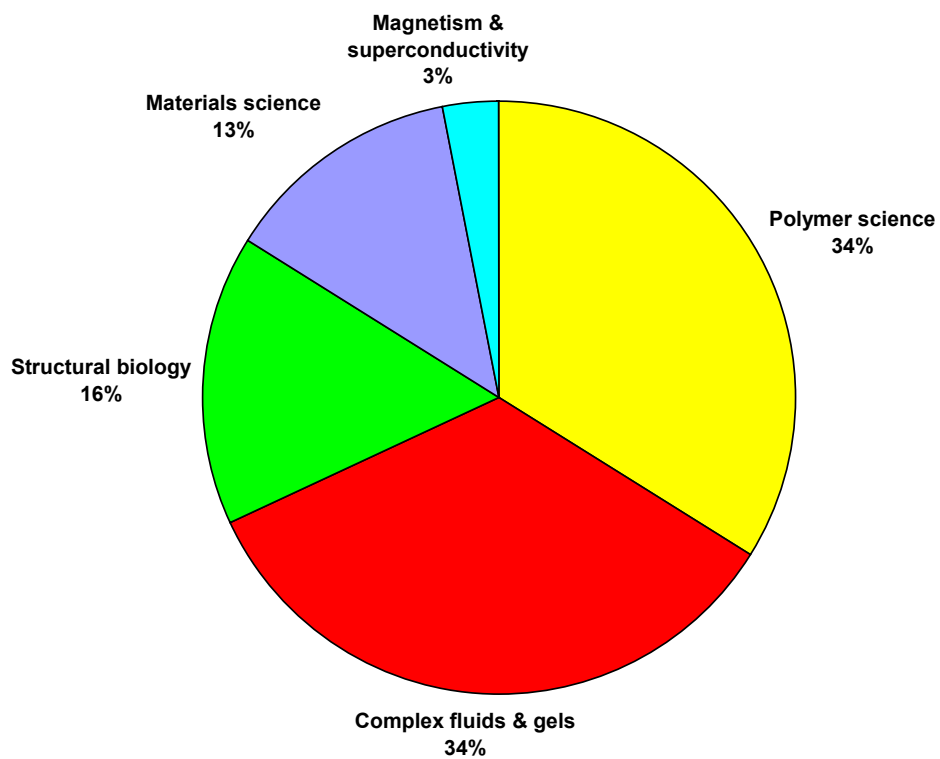


Figure 21 Share of CHRNS users by scientific field of research for FY00. See figure references.

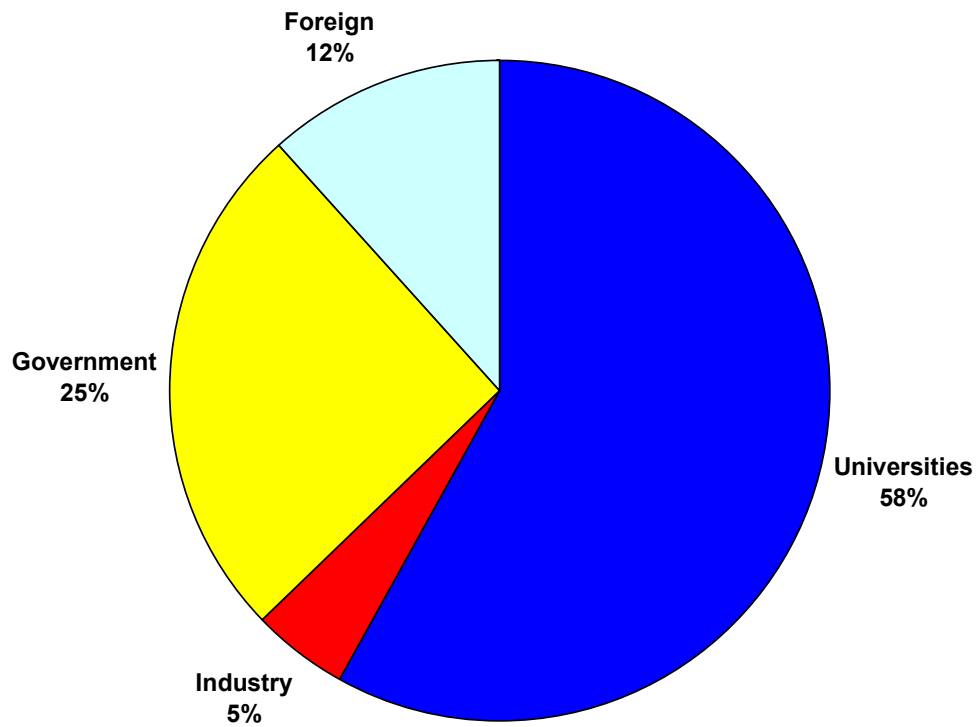


Figure 22 Share of CHNRS users by affiliation in FY00. See figure references.

## Table References

Table 1. Source: Adapted from the *Report of the Basic Energy Sciences Advisory Committee on Neutron Source Facility Upgrades and the Technical Specifications for the Spallation Neutron Source*<sup>11</sup> with updates provided by IWG members.

Table 2. Source: Adapted from *A Twenty Years Forward Look at Neutron Scattering Facilities in the OECD Countries and Russia*<sup>7</sup>, with updates provided by IWG members.

Table 3. Source: Adapted from *Research Infrastructures: Neutron Sources*<sup>12</sup> and updated by J. Rush, NIST.

Table 4. Source: DOE/BES compilation of annual facility survey results, courtesy R. Astheimer, DOE. Instrument numbers modified to reflect neutron scattering instruments only courtesy of J. Roberto, Oak Ridge National Laboratory.

Table 5. Source: DOE/BES compilation of annual facility survey results, courtesy R. Astheimer, DOE.

Table 6. DOE/BES compilation of annual facility survey results, courtesy R. Astheimer, DOE. Instrument numbers modified to reflect neutron scattering instruments only courtesy of R. Teller, Argonne National Laboratory.

Table 7. DOE/BES compilation of annual facility survey results, courtesy R. Astheimer, DOE. Instrument numbers modified to reflect neutron scattering instruments only courtesy of P. Lisowski, Los Alamos National Laboratory.

Table 8. Source: NIST, courtesy of J. M. Rowe.

NOTE: NIST tracks *research participants* instead of users, as defined by DOE/BES. *Users*, as defined in this report, includes all researchers who actually come to the facility at least once in a given year to perform neutron scattering research (excludes casual visitors, but includes facility research staff). *Users* are only counted once per year per facility, even if they make multiple visits over the year. *Research participants*, as defined by NIST, includes all *users* plus all research collaborators that participate in the research, but who do not come to the facility. To make comparisons, NIST provided both *research participant* data and *user data* for FY00. The ratio of neutron scattering users to all research participants at the NCNR that year was 0.43. This factor was multiplied by the historical *research participant* data provided by NIST and rounded to the nearest whole number to estimate the number of users reported in this table.

Table 9. Source: columns 1 and 2 are compiled from Table 11. The total beamtime scheduled through the general user program committee was provided courtesy of J. M. Rowe (NCNR), and R. Teller (IPNS).

Table 10. Source: DOE/BES and NIST representatives to the IWG.

Table 11. Source: DOE/BES and NIST through the directors of the neutron facilities: HFIR data courtesy of J. Roberto, IPNS data courtesy of R. Teller, LANSCE data courtesy of P. Lisowski, and NCNR data courtesy of J. M. Rowe.

NOTES:

1. Instrument names and types are shown as reported by the facilities.
2. “Year” refers to the year since the instrument was first commissioned or since its most recent major upgrade, whichever is earlier.
3. “World Class?” refers to whether the instrument is considered by the facility management to be competitive (“Y” or yes) or not (“N” or no) with similar best-in-class instruments available worldwide. Condition is shown as reported by the facilities.
4. “Ownership” refers to whether the capital costs to develop and/or operate the instrument came from the facility or from an instrument development partnership team.
5. “Access mode” refers to whether the majority of beam time is scheduled by the instrument owners (collaborative) or through an independent access committee (general). This distinction does not rely on whether or not merit review of formal proposals is used.

Table 12. Source: DOE/BES and NIST through the directors of the neutron facilities: HFIR data courtesy of J. Roberto, IPNS data courtesy of R. Teller, LANSCE data courtesy of P. Lisowski, and NCNR data courtesy of J. M. Rowe.

Table 13. Source: Adapted from *Neutron Sources for America’s Future: Report of the Basic Energy Sciences Advisory Committee Panel on Neutron Sources*<sup>1</sup> and *Cooperative Stewardship: Managing the Nation’s Multidisciplinary User Facilities for Research with Synchrotron Radiation, Neutrons, and High Magnetic Fields*<sup>3</sup> with updates courtesy of J. Rush (NIST) and H. Kerch (DOE/BES).

NOTES: Award descriptions:

1. The Nobel Prize (Physics and Chemistry) is one of the highest international honors in science. The award is made to those who have made the most important discoveries or inventions in physics or chemistry.
2. The Max Planck Research Prize is an international award bestowed by the Max Planck Society in recognition of outstanding scientific achievement.
3. The APS Buckley Prize (Oliver E. Buckley Condensed Matter Prize) is given by the American Physical Society in recognition of outstanding theoretical or experimental contributions to condensed matter physics.
4. The APS High Polymer Prize (now Polymer Physics Prize) is given by the American Physical Society in recognition of outstanding accomplishment and excellence of contributions in polymer physics research.
5. The APS Dillon Medal (John H. Dillon Medal) is awarded by the American Physical Society in recognition of outstanding research accomplishments by young polymer physicists who have demonstrated exceptional research promise early in their careers.
6. The APS Lilienfeld Prize (Julius Edgar Lilienfeld Prize) is awarded by the American Physical Society in recognition of a most outstanding contribution to physics.
7. The ACS Applied Polymer Science Award is awarded by the American Chemical Society in recognition of outstanding achievement in the science or technology of plastics, coatings, polymer composites, adhesives and related fields.
8. The ACS Colloid and Surface Chemistry Award is awarded by the American Chemical Society in recognition of outstanding scientific contributions to colloid chemistry in North America.
9. The ACA Warren Diffraction Award (Bertram Eugene Warren Diffraction Physics Award) is awarded by the American Crystallographic Association in recognition of an



important recent contribution to the physics of solids or liquids using x-ray, neutron, or electron diffraction techniques.

10. The MRS Von Hippel Award is the highest award given by the Materials Research Society.

Table 13. Source: NIST/NSF Center for High Resolution Neutron Scattering, courtesy of C. Glinka, director.

## Figure References

Figure 1. Source: DOE/BES and NIST.

Figures 2-7. Source: Data in Tables 4-9.

Figure 8. Source: Data on U.S. facilities compiled from Tables 4-9. Data from the ILL courtesy of C. Carlile, Director. Data from ISIS courtesy of A. Taylor, Director. Ratio of users per instrument based on 1250 users at ILL and 1080 users at ISIS in 2000. Instrument totals for these facilities are shown in Table 3.

Figure 9. Source: Data from Table 11.

Figure 10. Source: Data from Table 3.

Figure 11. Source: Data from Table 11.

Figure 12. Source: For U.S. neutron sources, data is from DOE/BES and NIST through the directors of the neutron facilities: HFIR data courtesy of J. Roberto, IPNS data courtesy of R. Teller, LANSCE data courtesy of P. Lisowski, and NCNR data courtesy of J. M. Rowe. Data from the ILL courtesy of C. Carlile, Director. Data from ISIS courtesy of A. Taylor, Director.

Figure 13. Source: Figure 12 and Table 11.

Figure 14. Source: Figure 12 and Tables 4-9.

Figure 15. Source: Adapted from *Survey of the Neutron Scattering Community and Facilities in Europe*<sup>13</sup>, European Neutron Scattering Association (ENSA), August 1998. Available on-line at:

Figures 16-19. Source: Data is from DOE/BES and NIST through the directors of the neutron facilities: HFIR data courtesy of J. Roberto, IPNS data courtesy of R. Teller, LANSCE data courtesy of P. Lisowski, and NCNR data courtesy of J. M. Rowe.

NOTE: Because data is collected by user, it does not necessarily reflect the make-up of multinational research teams participating on a particular experiment. Data available from the NCNR IN 2000 indicate that fewer than 3% users were affiliated with foreign institutions and participating in research teams without U.S. researchers. This indicates that most foreign research users are members of multi-national teams with U.S. participation.

Figures 20-22. Source: NIST/NSF Center for High Resolution Neutron Scattering, courtesy of C. Glinka, Director.

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Robert Marianelli

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