COLD NEUTRON RESEARCH FACILITY BEGINS OPERATING AT NIST

Materials scientists, condensed matter physicists, analytical chemists and biologists are only part of a large and growing community of researchers who need access to subthermal, or "cold," neutrons and the various instruments that use these very-low-energy particles. For the past two decades, many US researchers have had to travel to Western Europe for that access, but now, with the opening of the new, $30-million Cold Neutron Research Facility at the National Institute of Standards and Technology in Gaithersburg, Maryland, intense beams of long-wavelength neutrons are available closer to home.

The guide hall at the Cold Neutron Research Facility at the National Institute of Standards and Technology in Gaithersburg, Maryland. Three of seven neutron guides, with neutron and gamma-ray shielding, have been built. Six of 15 experimental stations are now operating. Installation of a second 30-m small-angle neutron scattering spectrometer (the large cylindrical object at the front of the photo is its detector housing) and four other instruments will begin by the end of the year.

Neutrons: probing matter

The intrinsic properties of neutrons make them a valuable probe of matter. With average wavelengths comparable to interatomic spacings in solids and liquids, thermal neutrons (with energies of about 0.025 eV) are well suited for studying the interatomic structure of and collective excitations in condensed matter. Neutron scattering often complements x-ray scattering in structural investigations. But, as Sunil Sinha (of Exxon Research Corporation, which is helping to develop an instrument at CNRF) explains, "even at the most modern sources, neutron fluxes cannot compete with the enormous photon flux that comes pouring out of a synchrotron." That higher intensity often translates into superior spatial resolution.

Neutrons, nevertheless, have several advantages over x rays in the study of materials. X rays couple only weakly to spins whereas neutrons interact with unpaired electrons in magnetic materials. Thus elastic scattering of neutrons from these materials helps determine their magnetic structures; inelastic scattering reveals magnetic excitations. Neutrons are also far more penetrating than x rays of the same wavelength. The short-range, strong nuclear interactions through which neutrons interact with atoms vary irregularly with atomic mass, so that, unlike x rays, neutrons scatter from various light nuclei with high contrast. Furthermore, x rays produce damage in a sample, whereas neutrons are, as Sinha puts it, "a kinder, gentler probe."

Neutrons with wavelengths longer than about 4 Å—or energies less than about 5 meV—are referred to as subthermal, or cold neutrons. These lower-energy neutrons provide improved energy and momentum resolution over their thermal counterparts. Longer-wavelength particles can probe larger-scale structures: Cold neutrons can resolve mesoscopic structures (those on the order of a hundred to a few thousand angstroms) such as those of polymers, composites, fatigued metals, precipitates in metallic alloys, bioassemblies and thin-film interfaces. Cold neutrons can be polarized, permitting one to determine a material's three-dimensional magnetic structure and spin dynamics, and to separate nuclear from magnetic scattering.

Producing cold neutrons

Steady-state neutron beams are generally produced by fission in a nuclear reactor, whereas pulsed beams come from spallation neutron sources. Beams from a reactor have a distribution of wavelengths that is roughly Maxwellian, with a peak wavelength that depends on the temperature of the moderator that surrounds the fuel. Cold neutrons can be selected from the low-energy tail of the distribution, but the flux drops as $1/\lambda^4$. However, by shifting the whole spectrum to longer wavelengths one can dramatically increase the cold neutron flux, explains Frank Bates of the University of Minnesota, which has joined NIST in developing two experimental stations at the CNRF. This is

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achieved by replacing part of the core moderator with a cold moderator, or "cold source," such as liquid deuterium (at about 30 K) or D_2O ice (at about 40 K). Neutrons lose energy to the moderator through collisions, producing a shifted spectrum from which one can select lower-energy neutrons with a roughly ten-fold improvement in the flux.

Neutrons exhibit optical behavior such as refraction and total reflection. Thus one can use neutron guides—analogous to optical fibers—to conduct intense beams of neutrons from the reactor into a large experimental hall, dubbed a "guide hall," where background radiation is low. The longer the neutron's wavelength, the more readily it is transported along the guide, typically made of optically flat glass coated with a material (such as nickel) that has an index of refraction greatly different from 1. The tubes are evacuated to minimize scattering losses.

Much of the original interest in very-low-energy neutrons came from their importance as a nuclear and particle physics probe. In the 1950s and 1960s the US reactor facilities at Oak Ridge and Brookhaven National Laboratories and at NIST (then called the National Bureau of Standards) provided researchers with intense beams of neutrons, but through the 1970s and 1980s, the best source of high-flux cold neutron beams has been the Institut Laue–Langevin in Grenoble, France. Cold neutrons are available at several pulsed sources around the world, but reactors have been the best sources.

Formally founded in 1967 by France and the Federal Republic of Germany, and operational in 1972 (the UK joined in 1974), ILL rapidly became the world's premier neutron research facility. With its relatively high-power reactor (57 MW), large flux of neutrons (maximum 1.5×10^{15} $cm^{-2}s^{-1}$), 25-K liquid-deuterium cold moderator and wide range of instruments (currently 30–40 instruments at 20 beam lines), ILL was during the 1970s and into the 1980s the catalyst for a growing neutron scattering community as well as a center for the development of neutron instruments and techniques.

In the meantime, for the lack of a competitive facility, cold-neutron research in the US suffered. Some see the funding policies of that time as short sighted. Says Norman Ramsey (Harvard), who has since the early 1950s been searching for the neutron electric dipole moment, most recently at ILL, "it was clearly a mistake not to fund the cold moderators" during the 1960s and 1970s.

In 1984 the NRC's Major Materials Facilities Committee, chaired by Frederick Seitz and Dean E. Eastman, examined proposals for major materials research facilities (for example, those providing synchrotron radiation, neutrons or high magnetic fields) with initial costs of $5–10 million or more. The committee considered new facilities as well as new capabilities at existing facilities. In the latter category, proposals for cold neutron facilities received the highest priority for immediate funding. The committee's 1984 report stressed the need to enable US scientists to be competitive in cold neutron research during the next decade. Governments in Western Europe had invested over $150 million in cold neutron research, and Japan was about to build a new reactor with a cold neutron guide hall. (The 20-MW JRR-3 reactor, which produces a maximum thermal neutron flux of 2×10^{14} $cm^{-2}sec^{-1}$, opened this year at JAERI in Tokai, Japan.)

NIST's Cold Neutron Facility

The Cold Neutron Research Facility, headed by J. Michael Rowe, Chief of NIST's reactor division, was finally funded in 1987 and opened its doors this past June. CNRF is located at the 20-MW NIST research reactor, which began continuous operation in 1969. With some foresight, the designers of the original reactor allowed space for the addition of a cryogenic moderator, which is only now being exploited.

The CNRF cold source, installed in August 1987 and made operational in October of that year, is a 36-cm-diameter, 22-cm-long block of D_2O ice (with 8% H_2O added) cooled to 30–40 K by recirculating helium gas. The cold source broadens the wavelength distribution of the neutron beam and shifts its peak wavelength from 1.6 to 2.5 Å. The cold neutron flux from the cold source is about 10^9 $cm^{-2}s^{-1}$ in the guides. An H_2 cold source, currently under construction, is expected to increase this flux by a factor of two.

Seven neutron guides, three of which are now completely installed, (see the photo on page 17) will transport neutrons from the cold source to the guide hall, and one additional port will be available for use inside the reactor hall. The guides will support 15 experimental stations, of which six are now operating.

NIST will develop 10 experimental stations for use by the research science community. Additional help in financing the facility comes from participating research teams made up of groups from industry, academe and government. These teams are expected to develop the remaining five instruments. In return, each team is entitled to 75% of the available time on its instrument.

The National Science Foundation has joined with NIST to help fund the Center for High Resolution Neutron Scattering at CNRF. The center aims to provide users with maximum access to two instruments that are in high demand: a 30-meter small-angle neutron scattering spectrometer, and a spin-polarized inelastic neutron scattering spectrometer. The former will be useful in studying structures of 1 to 100 nm in a large variety of materials, while the latter can measure spin-dependent cross sections as well as collective excitations and atomic and molecular motions in ordered materials. Another participating research team, made up of groups from Exxon Engineering and Research Corporation, the University of Minnesota and NIST, will operate a second 30-m small-angle neutron scattering instrument. And the University of Minnesota and IBM are joining NIST in the development of a cold neutron reflectometer for studies of surfaces and interfaces.

Looking to the future

Even as CNRF opens its doors, plans are being developed for a new-generation research reactor—one that will include, among other things, a very high intensity source of cold neutrons. US research reactors, built in the heyday of the 1960s, are aging. Even the ILL reactor is currently shut down for an indefinite period—at least one to two years—so that engineers may replace a baffle in its cooling system that shows "unusual traces," or cracks. "We are all a bit worried," confides Bernd Maier, scientific secretary at ILL, "but we are confident that the problem is repairable."

The Department of Energy has plans to build at Oak Ridge the Advanced Neutron Source, a facility designed to provide a neutron flux 5–10 times higher than that of any steady-state source ever built. The high flux will, for one, allow the study of time-dependent, nonequilibrium phenomena, such as occur during some manufacturing processes. And because the High Flux Reactor at Oak Ridge is likely to be shut down within the next 10 years, the Advanced Neutron Source, Bates warns, will also be urgently needed as an isotope production and materials irradiation facility.

—ELLEN J. ZEMAN■