Argonne's Pulsed Neutron Source Turned On

But only for a while. DOE has given the laboratory 2 years to find other federal sponsors for the new facility.

Argonne National Laboratory hosted an international symposium on neutron scattering in mid-August. Although none of those buttons with the little red hearts saying "I Love Neutrons" were passed out at the meeting, perhaps they should have been. Argonne's director Walter Massey opened the conference with the remark that the laboratory's new Intense Pulsed Neutron Source (IPNS-I) is producing neutron beams on schedule and that experiments at the facility will begin this winter, thanks in part to the support of the international neutron scattering community when the project was threatened with termination late last year. But the Department of Energy (DOE), which oversees the national laboratories, has served notice on Argonne that the only hope for survival of the IPNS-I past 1985 is the development of a large and vocal user community of physicists, chemists, biologists, and materials scientists that could pressure other agencies, such as the National Science Foundation (NSF) or the National Institutes of Health (NIH), to take up the slack when DOE support winds down. Because of the lengthy budget cycles, Argonne only has about 2 years to make this case.

The laboratory will actually have an extra burden because neutron scattering research in the United States has had more than a tinge of elitism. The use of neutrons to elicit structural and spectroscopic information from materials ranging from biological macromolecules to liquid helium superfluids grew up with the post-World War II availability of specialized research reactors that nowadays produce very high fluxes of neutrons. However, access to the largest research reactors at the Oak Ridge National Laboratory (100 megawatts) and the Brookhaven National Laboratory (recently upgraded to 60 megawatts) has generally been restricted to in-house scientists and to outsiders able to establish close ties with them. This situation arose in part because of a decision to emphasize "blue ribbon" science of the type coming from a researcher devoting a good part of a career to neutron scattering as opposed to a user-oriented operation where scientists who are not specialists could use the technique. The U.S. neutron scattering community is therefore not large and consequently not so influential, although there are also several smaller reactors in use.

At the opposite pole lies the Institut Laue-Langevin (ILL), a French-German-British facility in Grenoble, which has a more modern version of Brookhaven's reactor. Although it initially had to beat the bushes, in the words of one observer, to convince European neutron scatterers to come there, demand at the ILL is now so great that hardly anyone gets more than 2 weeks of beam time in any given 6-month period. Gerard Lander, who is on the staff at the ILL while on leave from Argonne, credits the cultivation of this mass of users for the institute's financial success; last year its budget was about twice that of the *entire* U.S. neutron scattering program and it is in the midst of a "second wind" modernization effort, with a "third wind" under consideration. And, while there have been some catcalls from the American side of the Atlantic about the quality of research at the ILL, a DOE-sponsored study of neutron scattering distributed last December—the one that called for termination of the IPNS-I project—pointedly noted that the majority of important advances were now coming from Europe. Before the ILL got up steam the reverse was true (*Science*, 16 January, p. 259).

Argonne, therefore, not only has to demonstrate the scientific productivity of its pulsed source, which has different characteristics than the steady-state reactors, but it also has to develop a user community in a land where researchers are generally uneducated as to the benefits of neutron scattering, a tall order to fill in a short time. "They're fighting for their lives," admits Donald Stevens of DOE's materials science division, which this year is funding the IPNS-I through a $6.5 million neutron scattering allocation to Argonne. By fiscal 1985, the laboratory will have only a little over $2 million (in constant dollars), and none will go to IPNS-I operations.

David Price, who is the director of the IPNS-I project, told *Science* that the ILL may have gone a little too far in the direction of democracy but that Argonne will be heading in the same direction. Fans of the Grenoble facility proudly point to the ease of applying for beam time; only a four-page form need be filled out. In February, Argonne sent out with its *IPNS Newsletter* a four-page proposal sheet. In June, a program committee headed by J. Michael Rowe of the National Bureau of Standards met to decide among 119 proposals received for the first 6-month running period that begins this October. For budgetary reasons IPNS-I will run in only 3 of the 6 months, and only 39 proposals were accepted, according to John Carpenter, the technical director of IPNS-I. Moreover, ten of the accepted proposals were for studies of radiation damage in metals and semiconductors. IPNS-I runs in two modes; in one, slow neutrons are produced for neutron scattering and, in the other, fast neutrons for radiation effects. About 25 percent of the time, the pulsed source will be in the latter mode.

Price and Carpenter pointed out that a major departure from the ILL style of doing things is the assignment of 25 percent of beam time to the exclusive use of research groups that develop and build instruments. There are 13 ports around the IPNS-I from which beams of slow neutrons emerge. Initially, seven of these will be used for scattering experiments and the other six for "special" experiments, such as those for the study of fundamental properties of the neutron itself. A topic of quite current interest, for example, is whether that particle has an electric dipole moment. At present, there are four neutron scattering instruments in place: a single crystal diffractometer, two powder diffractometers, and a low-resolution, medium-energy spectrometer. Three others are being built: a high-resolution spectrometer, a small-angle diffractometer, and a crystal analyzer spectrometer.

Why the fuss about Argonne's pulsed source? There are two reasons. The first is that most of the research reactors in use are getting on in age, and the question is what to replace them with. The technology is such that a marked improvement in performance in new reactors is unlikely because of heat transfer problems in the very small cores of high-flux machines, and the costs and political problems of building new reactors are thought to be immense even if the neu-

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tron intensity could be made to grow. The currently favored alternative is to use an intense beam of protons from a synchrotron or a linear accelerator to bombard a heavy metal target (IPNS-I has disk-shaped uranium targets). Nuclear transitions cause the emission of 20 or so neutrons per incoming proton when the bombarding energy is about 500 million electron volts (MeV). A moderator and reflector assembly "cools" the neutrons down to energies of 1 electron volt or less for neutron scattering.

The second reason is that the temporal and spectral characteristics of neutrons from the two types of sources differ. Reactors emit a steady stream of "thermal" neutrons having energies of 0.1 electron volt or less. These energies are convenient for the spectroscopic investigation of such phenomena as lattice vibrations in solids. Neutron wavelengths also nicely match unit cells in crystalline materials whose structures are to be de-

Spin Echo Neutron Spectroscopy

One of the distinct disadvantages of neutron scattering is that the intensity of the reactor- and accelerator-based sources is low, and there is no technology on the horizon that will appreciably improve this situation. Researchers therefore spend considerable time devising neutron optical systems that waste as few of these precious particles as possible. At the Symposium on Neutron Scattering, recently held at Argonne National Laboratory as a satellite meeting of the XIIth Congress and General Assembly of the International Union of Crystallography in Ottawa, Claude Zeyen of the Institut Laue-Langevin (ILL) in Grenoble, France, described a new way to do inelastic neutron spectroscopy. In conventional spectroscopy, there is always a trade-off between intensity and resolution. The new technique, spin echo spectroscopy, greatly enhances the resolution of inelastic neutron scattering (where a neutron changes its energy and momentum in passing through a sample) without sacrificing intensity. It may also make measurements feasible that were not so before.

A very productive application of inelastic scattering, for example, has been the investigation of lattice vibrations in crystalline solids, which come in continuous distributions or bands of energies. To map out this or any other complicated spectrum, neutron scatterers have used a triple-axis spectrometer. A crystal monochromator selects by Bragg diffraction a particular energy from the thermal distribution of energies in the incident neutron beam. A second crystal analyzer determines the energy of the neutrons after they are scattered by the sample. The difference between the energies of the incoming and outgoing neutron is the energy of the lattice vibration involved in the scattering process. By systematically varying the orientations of the monochromator, the sample, and the analyzer, investigators can make a complete map of lattice vibrations or other excitations as a function of their wavelength and direction of propagation.

The obvious problem, given that the neutron intensity is low to start with, is that the crystal monochromator and analyzer pass only a fraction of the particles incident upon them, and the fraction passed become[illegible]ller as the resolution required becomes higher. Abo[illegible]ecade ago, Ferenc Mezei of the ILL hit upon a different idea that overcomes the intensity limitation. Mezei's concept bears some resemblance to the Fourier transform methods that have revolutionized nuclear magnetic resonance and infrared spectroscopies in recent years. Neutrons in a broad band of energies are allowed to strike the sample, but before doing so they are first polarized so that the magnetic moments of all the particles are aligned.

After being polarized, the neutron beam passes through a fixed magnetic field, which causes the magnetic moments to precess at a fixed rate independent of the neutron's velocity. The number of precessions then depends directly on the time the particle spends in the field, that is, on its velocity. Because the beam as a whole has a broad distribution of velocities, it gradually becomes unpolarized before it leaves the region of high magnetic field and subsequently is scattered by the sample. On the other side of the sample, the application of a second magnetic field in the direction opposite to the original reverses the precessions. The beam that finally emerges is repolarized (the echo) when the second field is adjusted to take account of any changes in the neutrons' velocities due to the scattering process.

Mezei, John Hayter, and others at the ILL spent several years perfecting an instrument of this type, and somewhat more than a year ago it was made available to the general user community there. As developed, the instrument is suitable only for small energy and momentum transfers, so-called quasi-elastic scattering. To extract the details of the scattering process, the magnitude of the reversed magnetic field is scanned and the polarization is measured as the field changes. The instrument's performance has been spectacular, with energy resolutions of a fraction of a microelectron volt for neutrons having millielectron volt energies when used in the study of the motion of macromolecules in solutions.

About 4 years ago, Mezei proposed combining the spin echo instrument with a triple-axis spectrometer in order to do high-resolution inelastic scattering. It is this idea that Zeyen has recently succeeded in putting into practice. For starters, the triple-axis spectrometer is operated in a low-resolution mode so that the neutron intensity is not reduced nearly so much as in normal inelastic spectroscopy. Zeyen also combined the neutron polarizers with the crystal monochromator and analyzer of the triple-axis spectrometer. This was accomplished with the use of special ternary magnetic crystals (Heusler alloys), which are magnetized by an external field so that the only neutrons diffracted are those that have their magnetic moments in the required direction. The curved crystals also focus the beam.

Zeyen said the spin echo–triple-axis spectrometer is still in the feasibility testing stage. In preliminary investigations of quasi-elastic scattering, an energy resolution of about 0.3 microelectron volt was obtained. In the future, he said, it may be possible to carry out some kinds of investigations that conventional triple-axis spectrometers cannot handle. One would be the detailed study of the line shapes in the intensity profiles of neutrons inelastically scattered by lattice vibrations. This ability would open the way to learning details of interactions between lattice vibrations and electrons in solids, for example.—A.L.R.

termined by diffraction methods. Even longer wavelength neutrons from cryogenically cooled moderators (cold sources) have proved useful for the study of biological molecules by small-angle scattering, at the ILL in particular.

The neutrons from pulsed, spallation sources (as they are now called) come in short bursts from less than a microsecond to considerably longer. The pulsed emission of neutrons opens the way to time-of-flight detection schemes in which the energy of a scattered neutron can be determined from its arrival time at a detector. With the appropriate electronics, for example, a single detector can simultaneously accept scattered neutrons of all energies rather than having to count separately those of each energy interval in a scanning spectrometer. In addition, the energies of neutrons from a spallation source extend up to 0.5 to 1 electron volt—so-called epithermal neutrons. These can be used to observe higher energy excitations (electronic transitions, for example) than normally possible. The assertion is that, just as cold sources have revolutionized neutron scattering by opening up investigations not previously possible, so too will the advent of pulsed beams and higher neutron energies.

Among reactors, the upgraded Brookhaven and the ILL facilities produce the highest neutron fluxes, about 1.5×10^{15} thermal neutrons per square centimeter per second. No planned pulsed source can match this intensity when the flux is averaged over time, although the peak flux in a pulse can far exceed it. But comparing the two types of sources in this way is a somewhat meaningless exercise. As Colin Windsor of the British Atomic Energy Research Establishment's Harwell laboratory argued at the neutron scattering symposium, the most relevant figure of merit is the counts per second in a detector in a specific experimental configuration. Pulsed and steady-state sources shine most brightly in different sorts of experiments.

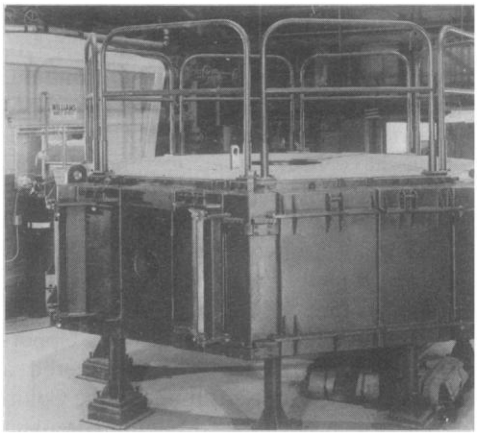
All the new neutron sources under construction or study are accelerator based. The most ambitious is a West German project described in a report jointly issued by the usually competitive Kernforschungsanlage Jülich and the Kernforschungszentrum Karlsruhe. Tentatively priced at 680 million Deutschmarks, the facility would center around a 600-meter-long, 1100-MeV proton linear accelerator and would produce an average thermal neutron flux of 7×10^{14} neutrons/cm^2-sec. At the peak of very long 500-microsecond pulses, the instantaneous flux would rise to 1.3×10^{16}. In an optional configuration with a proton storage ring added, the machine could reach 10^{17} neutrons/cm^2-sec in much shorter pulses. This spring a government-sponsored study of German "big science" projects came in with a recommendation to put the Spallations-Neutronenquelle (SNQ) project on hold. To get on-line with a new source more quickly, German scientists have started talking up a more modest pulsed source that would be similar to a British facility now under construction.

The Science and Engineering Research Council's (SERC's) Rutherford Laboratory 3 years ago closed down a proton synchrotron used for high energy physics studies. But, phoenix-like, rising from its ashes and using parts of the defunct accelerator is a Spallation Neutron Source (SNS) that will occupy the same site. Based on an 800-MeV proton synchrotron, the SNS will spit out neutrons at a peak rate of 5×10^{15} neutrons/cm^2-sec. But the pulses, which come at the rate of 50 per second, are less than a microsecond long, so the average flux is considerably lower. The SERC's unusual pattern of level funding will stretch out the construction period from the initially hoped for 1982 date for the first neutrons to 1984 and operation at full intensity to 1986, according to George Stirling of Rutherford.

In the United States, the Los Alamos National Laboratory has an intense, 800-MeV proton linear accelerator that is used for nuclear physics and medical research. Part of the beam is also extracted for production of neutrons, but the pulse characteristics are not ideal for neutron scattering. Consequently, a proton storage ring is being built with a 1986 completion date that will sharpen up the pulses and reduce their frequency. The new source will have 12 pulses per second of less than a microsecond duration having a peak intensity of 10^{16} neutrons/cm^2-sec. Curiously, the facility is mainly being paid for by DOE's military application office, which has indicated its intention of leaving the source free for basic research most of the time. It was this prospect of a highly "cost effective" pulsed neutron source that led DOE's neutron scattering study panel to recommend dropping Argonne's IPNS-I if an increase in the department's research budget was not forthcoming.

The IPNS-I, as the I indicates, was conceived as one in a series of progressively more powerful machines, and itself is of modest performance. Because of budget limitations, the intensity is even lower than planned with 30 pulses per second of peak intensity 3×10^{14} neutrons/cm^2-sec, just ahead of a Japanese spallation source that opened last year in Japan's Tsukuba "Science City." Nonetheless, the IPNS-I will be the most powerful machine of its kind until the SNS and Los Alamos facilities come to full power. Argonne scientists have maintained that an early test of the scientific utility of pulsed sources is essential.

The first neutrons into the neutron scattering area of IPNS-I came on 4 August, exactly a year after DOE's study panel visited Argonne prior to recommending termination of the project. In any case, it was probably never possible politically to close down the machine immediately. Said DOE's Stevens, "It would have been unproductive to shut it off before it even operated." But Stevens added that DOE cannot afford to fund four major neutron scattering centers and that, when Los Alamos gets rolling, the intention is to support that pulsed source and the two reactors at Oak Ridge and Brookhaven, as recommended by the panel.



Powder diffractometer

Shown before installation on the IPNS-I, the diffractometer has a ring of neutron detectors inside. The sample is inserted through the opening in the top. Neutrons enter through the opening in the side.

So, neutron scattering eyes are turning toward other agencies, including NIH—if enough biologists get turned on to the technique—and NSF. The science foundation often seems to play the role of a balance wheel by supporting areas of research that other agencies drop or forgo. It got into the synchrotron radiation business almost a decade ago when the Air Force Office of Scientific Research decided to cease funding the University of Wisconsin's Synchrotron Radiation Center. DOE has made it perfectly clear that something like this must happen in neutron scattering as well.

—Arthur L. Robinson