Seeking to bridge Europe's impending neutron gap

Europe's primacy in neutron scattering depends on maintaining a network of local and international facilities.

PERRY NORDENG

THE EUROPEAN SPALLATION SOURCE under construction in Sweden is set to start up in a few years.

Even as Europe's neutron-scattering community looks forward to the startup of the world's most powerful neutron source—the European Spallation Source (ESS) in Lund, Sweden—it faces a decrease in total beam time due to the shutdown of several reactor-based facilities.

The dearth won't be felt for a few more years, when two medium-flux research reactors shut down in 2019. Together, those reactors, in Berlin and in Saclay, near Paris, have about 40 instruments, run 200 to 300 days a year, and serve some 15% of Europe's users. The €1.8 billion ($2 billion) ESS is scheduled to produce its first neutrons around the same time, but it won't open for experiments until 2023 at the earliest (see PHYSICS TODAY, March 2010, page 24). Even when the 5 MW, pulsed ESS comes on line, it won't offer as many instruments as the Berlin and Saclay reactors combined.

With beam time not yet curtailed and a flagship facility in the works, mobilizing the neutron-scattering community to minimize the upcoming neutron gap is proving tough, says Christiane Alba-Simionesco, chair of the European Neutron Scattering Association and director of the Laboratoire Léon Brillouin, where the Saclay reactor—known as Orphée—is located. Mitigating measures could include extending the lives of reactors, upgrading existing facilities by building new beamlines and instruments, and developing new alternative sources. But getting cash-strapped governments to pony up for the field on top of their investments in the ESS is a hard sell.

Across Europe, says Alba-Simionesco, neutron scientists urgently need to lobby policymakers and funders. "The timing is already desperate." Without a supporting network of small and medium-sized neutron sources, she says, the ESS could be a "financial and scientific disaster."

Shifting neutrons

Europe's neutron-scattering community has thrived on a mix of neutron sources, from small university reactors, to national medium-flux reactors and spallation sources that serve larger communities, to one international source, the high-flux 58 MW reactor at the Institut Laue–Langevin (ILL) in Grenoble, France. "Europe has always been strong in research with neutrons because of the distributed network of facilities," says Thomas Brückel, director of neutron science at Germany's Jülich Center for Neutron Science and a scientific director at the Heinz Maier-Leibnitz Zentrum, home to the FRM II reactor outside of Munich. At present, Europe has upwards of 6000 neutron users, compared with the US's 1500 or so.

With energies comparable to thermal energies in condensed matter, neutrons are often the best probe of atomic and molecular structure and dynamics. Hot neutrons, with shorter wavelengths, are useful for studying liquids, amorphous solids, and crystals; cold neutrons, with longer wavelengths, are good for probing complex soft matter and biological samples; and ultracold neutrons, which can be trapped, are used for measuring lifetimes, electric dipole moments, and other properties of neutrons themselves. Because neutrons are deeply penetrating, detect magnetism, couple to hydrogen, and are nondestructive, they are used in fields ranging from archaeology to engineering. Notable applications include the experimental confirmation of antiferromagnetism and polymer chain reptation, the determination of crystal structure and magnetic dynamics in high-temperature superconductors and other complex oxides, and strain measurements in bulk materials.

In contrast to synchrotron users, who typically have lab access to x rays, notes Brückel, neutron users often cannot get hands-on experience in university labs, which makes it harder for students to become familiar with neutron scattering and analysis. "You need some access to a smaller facility," he says. "User recruitment is regional." The dense distribution of neutron sources of different sizes "was the success of Europe in the past."

But Europe's neutron facility landscape is shifting. After the Berlin and Saclay reactors close, only three major national user facilities will remain: the 10-year-old, 20 MW FRM II reactor and two accelerator-based sources—ISIS, a 200 kW pulsed spallation source near Oxford, UK, and the Swiss Spallation Neutron Source (SINQ), a roughly 1 MW continuous source near Zürich. The Czech Republic has a 10 MW research reactor; Hungary does also, although it is slated to close in 2023. In addition, a handful of smaller reactors (1–3 MW) are still running, but they are decades old. Several other reactors have closed in recent years, including in Risø, Denmark, in 2000; in Jülich in 2006; and in Geestacht, Germany, in 2010.

In the wake of the 2011 Fukushima nuclear accident in Japan, some countries vowed to cease operating nuclear reactors, and it's widely accepted that no new research reactors will be built in Europe. (See PHYSICS TODAY, November 2011, page 20.)

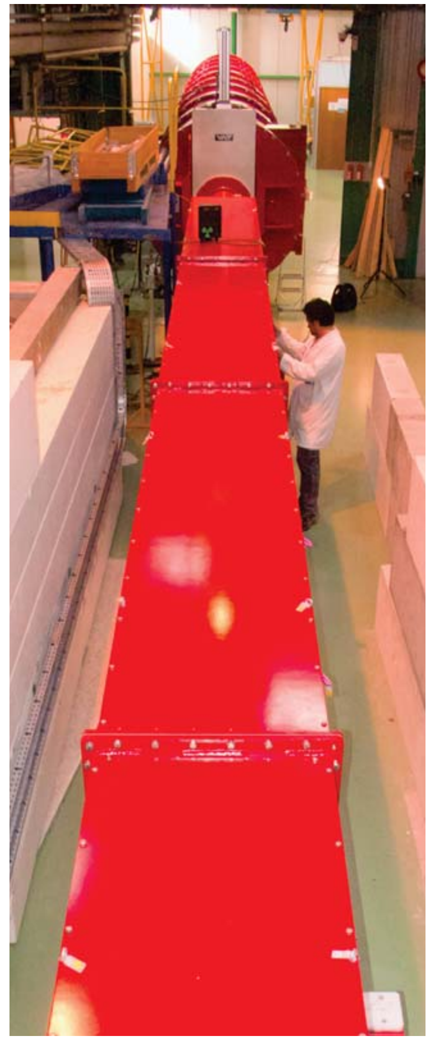
"In parallel and partnership"

The Fukushima disaster also led to safety measures being taken to the tune of €27 million to protect the ILL reactor in the event of a flood or an earthquake. Tightened safety requirements have also driven up the cost of highly enriched uranium fuel elements; this year the ILL will run 160 days, three-quarters of what it would have run had fuel costs remained stable, says director William Stirling. Next year the reactor will undergo a decadal safety evaluation, and then the partners—France, Germany, and the UK, plus 11 smaller countries that collectively have a one-quarter share of the ILL's €95 million budget—will decide whether to extend the ILL's lifetime beyond the current 2023 contract.

Keeping the ILL open beyond 2023, says Stirling, "needs political will and some money." Already, he says, some smaller member countries are finding it difficult to keep up with their ILL dues as they invest in the ESS. "Their scientific communities want them to maintain the availability of the ILL. But some are just not paying, which is not good," he says.

"Closing the ILL too early would be a disaster for European and world science," Stirling says. "The best would be for the ESS and ILL to work in parallel and partnership for a number of years." The worst, he adds, would be if a poor safety evaluation were to kill the chances of extending the facility's lifetime. The French community would be hardest hit, according to Alba-Simionesco. If both ILL and the Saclay reactor close, and no new sources are arranged, France's capacity will decrease to 5% of what it is now, she says. "It's dramatic for both the science community and industry. We are losing a unique probe. And if we have no users, then there will be no reason to contribute to the ESS."

GREGORY CHABOUSSANT AND SYLVAIN DÉSERT



A NEW SEVERAL-MILLION-EURO SPECTROMETER, inaugurated last month, will help neutron researchers squeeze as much science as they can from the Orphée reactor outside Paris before it shuts down in 2019.

The medium-flux and smaller centers are planning to help fill the inevitable gap in neutron beams. They will extend hours, add instruments, and otherwise broaden their availability. The 2 MW Delft reactor "cannot compete with the 10 MW Berlin reactor or the 14 MW Orphée," says Catherine Pappas of the Technical University of Delft in the Netherlands. "But there may be two or three applications where we can contribute" to making up for lost beam time. The FRM II will pick up some slack; SINQ has a beamline funded and run by a group from Denmark and is open to more such arrangements; and ISIS is increasing its capacity and international collaborations and considering a major upgrade.

The development and use of specialized techniques could be vulnerable. Says Pappas: "If you have a limited number of beamlines, you can't sustain things like diffraction with a polarized neutron beam or high resolution inelastic spectroscopy. If the availability shrinks, the knowledge may disappear."

Compact challenges

With the writing on the wall for research reactors, many in the neutron-scattering community are pinning their longer-term hopes on the compact accelerator-driven neutron source (CANS) approach. Accelerator-based spallation sources require protons with energies approaching 1 GeV, which produce copious neutrons in a cascade of collisions in the nuclei of a heavy-metal target. The resulting neutrons are slowed down in moderators to below eV energies. With CANS, the idea is to start off with lower-energy particles, in the MeV range: using protons or deuterons on light-metal targets or using electrons on heavier nuclei. Neutrons are liberated through various processes with far lower efficiency than via spallation but also with less residual radioactivity.

The lower energies require less shielding and, since parts can be closer together without incurring heat and radiation damage, allow for a more compact facility. They also mean lower total neutron fluxes. Still, says Brückel, "we are confident that compact accelerators can achieve flux at the instrument comparable to existing sources like ISIS or medium-flux reactors. We are aiming to outperform the Berlin reactor by a large margin, especially for small samples." That will mean upping the flux by several orders of magnitude above existing CANS facilities, such as the Low Energy Neutron Source at Indiana University in Bloomington or the CANS network in Japan that is used mainly in training, development, and industry. Teams at Saclay and Jülich and at other labs around Europe are working on CANS designs; they hope to have prototypes ready in the next five or so years and working facilities by 2030.

Two main technical challenges need to be overcome for CANS to effectively replace today's medium-flux reactors as neutron sources, says Brückel. One is to increase the incident particle flux on the target without melting it, so that the resulting neutron flux gets a corresponding boost. The second is to make small moderators that not only slow the neutrons but also direct them to the experimental site. Typically, neutrons fly out in all directions; guiding them would prevent loss and increase the usable flux. Every piece gives a small gain factor, says Brückel. "But multiply them and you get a good gain factor."

The beefed-up CANS concept is gaining traction, but is yet to be proved. Although it's too early to make credible cost estimates, it's clear that they shouldn't exceed about €300 million—below the ballpark cost of a synchrotron light source, which most countries have. Brückel also hopes to develop a less-powerful, mini CANS for around €10 million, which universities could afford.

Toni Feder

Safeguarding nuclear material may be losing urgency

Since 2014 just one nation has rid itself of all weapons-usable materials.

No improvements have been made in the past two years to on-site physical protections, insider threat prevention, security during transport, control and accounting practices, and incident response measures assessed by the Nuclear Threat Initiative (NTI). The nonprofit organization released its third biennial report card in January in advance of the fourth—and likely last—Nuclear Security Summit to be convened in Washington, DC, later this month.

The NTI ranks the 24 nations possessing at least 1 kg of weapons-usable nuclear material by how well they secure it. For the third time, Australia, a