The Institut Laue Langevin

THE EUROPEAN NEUTRON SOURCE

THE ILL

THE INSTITUT LAUE-LANGEVIN (ILL) is an international centre for research in the field of neutron science and technology. Neutrons are used at the ILL to probe the structure and dynamics of a broad range of materials at molecular, atomic and nuclear level.

As the world's flagship centre for neutron science, the ILL provides scientists with a very high flux of neutrons feeding some 40 state-of-the-art instruments, which are constantly being developed and upgraded.

SERVING THE INTERNATIONAL SCIENTIFIC COMMUNITY...

As a service institute, the ILL makes its facilities and expertise available to visiting scientists from all over the world. Every year about 1400 researchers visit the ILL to perform experiments which have been selected through peer review by the Institute's Scientific Council and its subcommittees. Over the last three years, an average of around 640 experiments have been successfully completed.

... AND INDUSTRIAL R&D

The ILL is also the ideal partner for industrial R&D experts requiring fast and confidential access to highly specialised neutron instrumentation. Companies seeking a competitive edge in innovation can find all the resources they need at the ILL, including the invaluable support of the Institute's team of experienced scientists.

MAJOR CHANGES ARE UNDER WAY IN THE GLOBAL NEUTRON LANDSCAPE, and the ILL has a crucial role to play in this context. Building on its scientific and technological excellence, the Institute intends not only to maintain its world-leading position but also to sustain the pace of research across Europe by reinforcing and expanding the neutron user community.

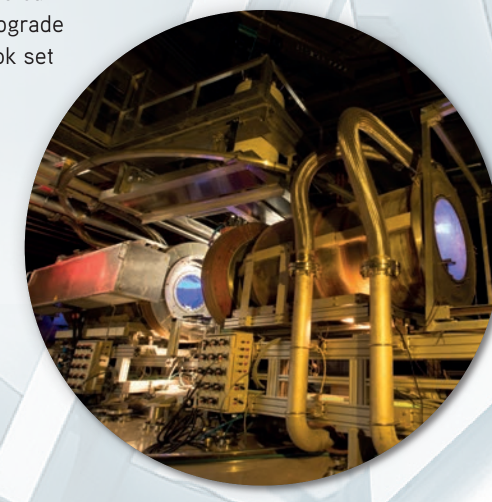
NEUTRONS FOR SOCIETY

For technological advances to be made, an understanding of materials at the molecular level is vital. Modern science possesses a host of methods for investigating the structure and dynamics of materials. Neutrons, however, are a particularly attractive tool, as they can penetrate deep into materials, making it possible to observe the movement of atoms and molecules.

Neutrons often provide crucial information which would be almost impossible to obtain any other way. Thanks to the versatility of neutrons, the scope of the research carried out at the ILL is very broad, embracing among other things condensed matter physics, chemistry, biology, materials and earth sciences, engineering, and nuclear and particle physics.

Much of this research impacts on society's major challenges, from sustainable sources of energy, improved healthcare and a cleaner environment, to new materials for the latest technologies.

The attractiveness of neutrons as a probe for investigating materials can be seen in the large-scale investments made in the construction and upgrade of neutron sources throughout the world. Such levels of investment look set to be maintained well into the future.



INTERNATIONAL SCIENTIFIC COOPERATION

The ILL is owned and operated by its three founder countries:

- France
- Germany
- The United Kingdom

As well as these three Associate member countries, 10 Scientific Member countries now participate in the ILL and contribute 20 % of its budget: Spain, Switzerland, Italy, Austria, the Czech Republic, Slovakia, Belgium, Sweden, Denmark and Poland.

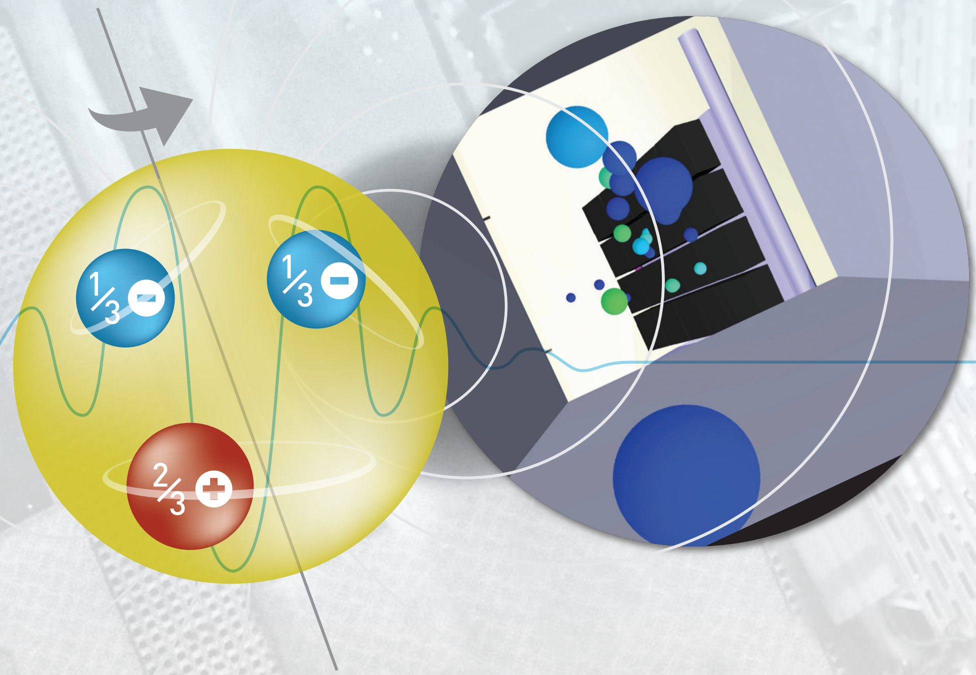
WHAT IS A NEUTRON?

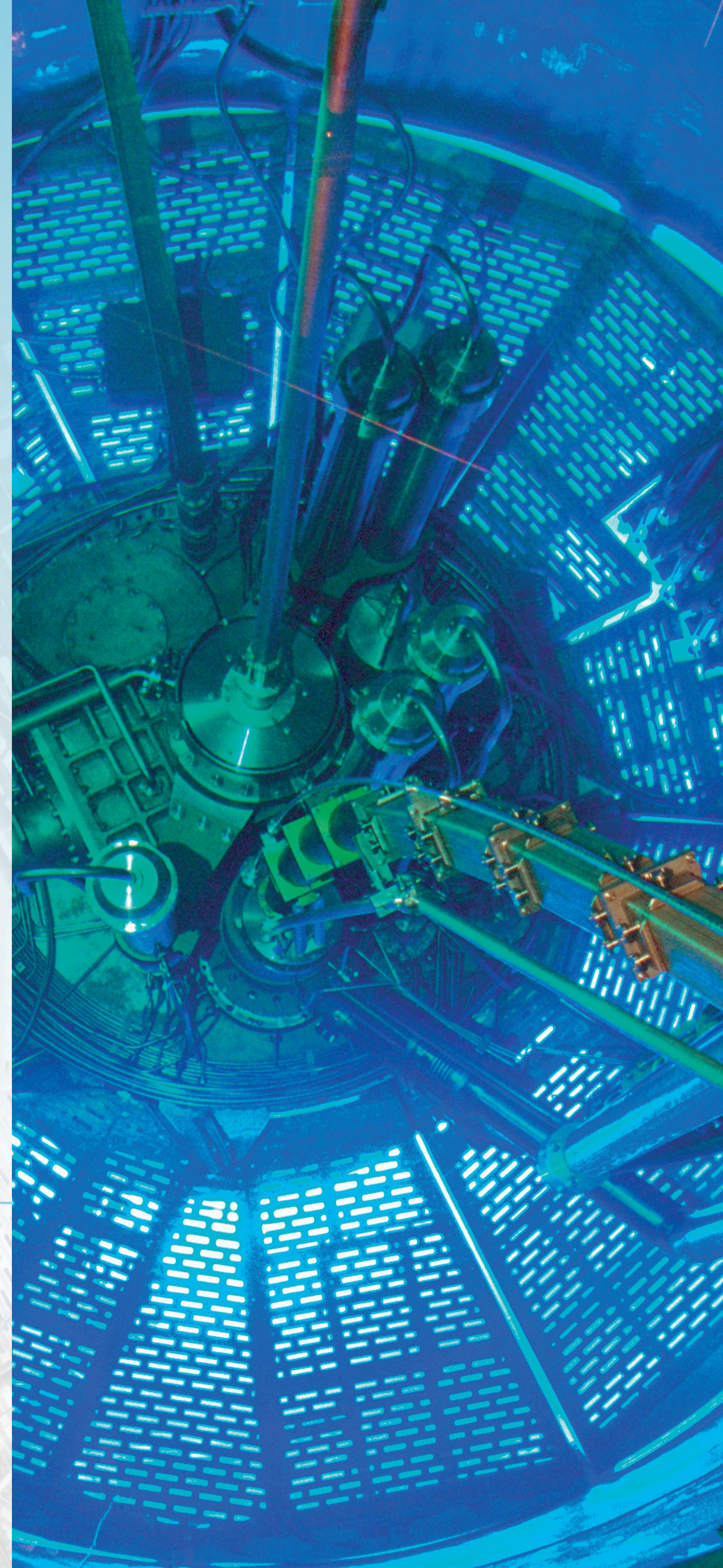
Neutrons are neutral elementary particles which have a property known as 'spin' and a mass similar to that of a proton. Their physical properties make them a powerful, non-destructive probe for the investigation of matter.

WHY NEUTRONS?

Neutrons reveal the structure and behaviour of materials at the atomic and molecular scale, information that is not accessible or is extremely difficult to access using other techniques.

- As their name suggests, neutrons are **electrically neutral**. They can therefore penetrate deep into matter without destroying it, allowing samples to be studied more than once.
- Neutrons have **wavelengths** which vary from 0.01 to 100 nanometres, depending on the temperature of their source. This makes them suitable for exploring the structure of various materials, ranging from those made of a single chemical element to polymers and large, complex biomolecules.
- Neutrons have a magnetic moment associated with their so-called spin (the smallest compass in the world). They can therefore be used to explore the magnetic behaviour of materials at the atomic level.
- Neutrons are **highly sensitive** to light atoms such as hydrogen, making them a powerful probe for the study of hydrogen storage materials, organic molecular materials, and biomolecular samples and polymers.
- Neutrons can distinguish between atoms that are close to or even next to each other on the periodic table. This allows ILL scientists to perform **isotopic substitution**, for instance swapping deuterium for hydrogen ('deuterium labelling') in order to highlight specific structural features.
- The possibility of producing beams of polarized neutrons (whose spins are parallel) allows scientists to pinpoint magnetic information much more precisely, making it easier to decipher complex magnetic structures.





THE NEUTRON SOURCE:
how are neutrons produced at the ILL

The ILL operates the most intense neutron source in the world, a single-element 58.3 MW nuclear reactor specially designed for high brightness.

The ILL's reactor is devoted exclusively to research; it normally operates round-the-clock for three or four 50-day cycles per year, supplying neutrons to a suite of around 40 high-performance instruments.

The neutrons are produced in the reactor by fission at very high energy (achieving speeds of 20 000 km/s). To be used for research, they must first be slowed down (thermalized) before they are guided to the scientific instruments. The ILL's reactor produces the most intense thermal neutron flux in the world – 1.5×10^{15} neutrons per second, per cm^2.

Thanks to this flux and to three other sources (one hot and two cold), scientists have access to a broad range of wavelengths and a vast field of investigation.

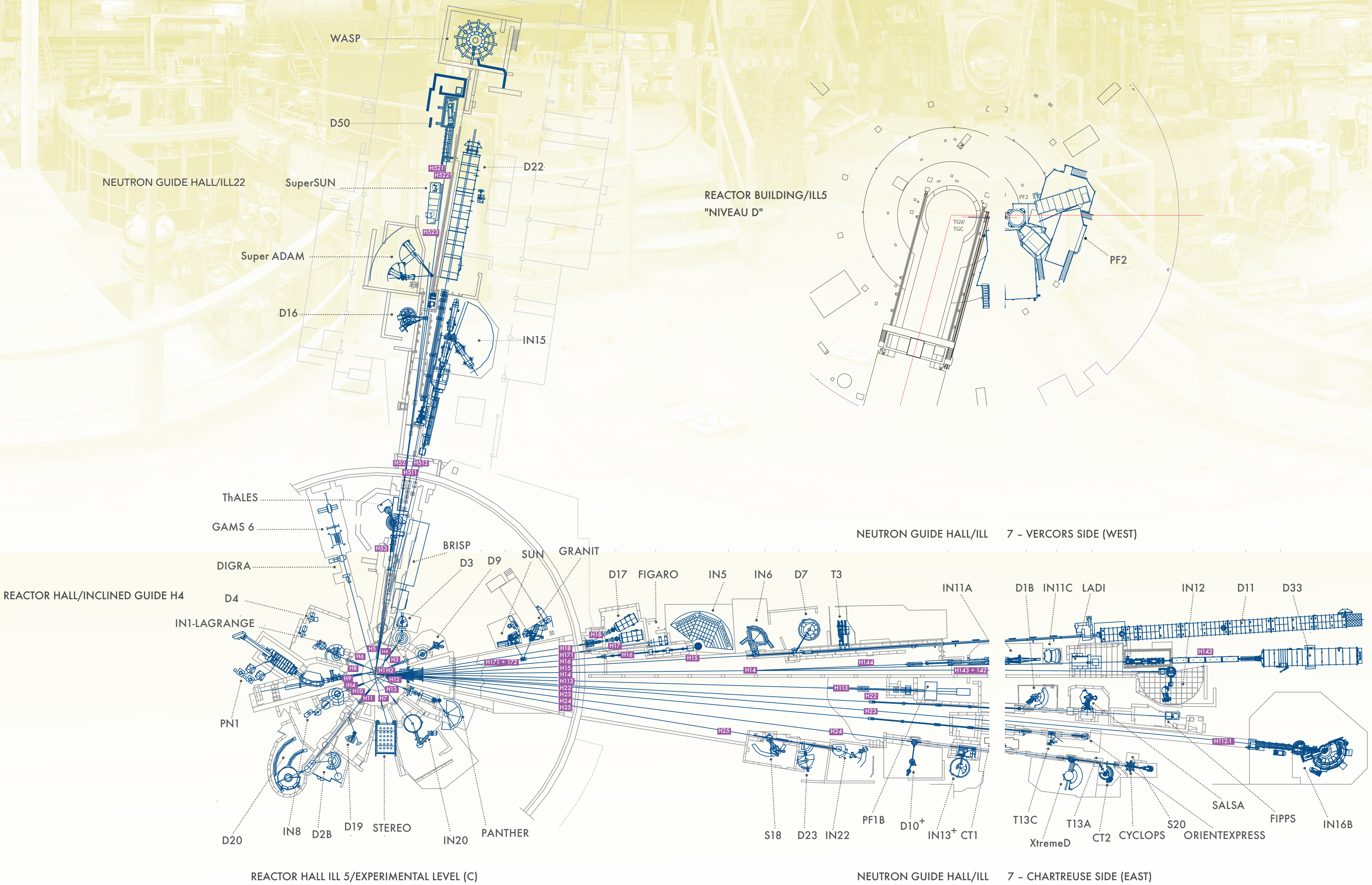
The ILL is an extremely safety- and security-conscious facility which operates in an open and transparent manner.

THE ILL INSTRUMENT SUITE

Once the neutrons produced by the reactor have been slowed to lower energies, they are guided to a suite of around 40 instruments installed in experimental halls.
On their way to the instruments, the neutrons travel through a series of optical and mechanical devices, many of which were developed at the ILL, designed to adapt the beams of particles to different experiments and optimise their analytical potential. These devices include:

- **Neutron guides,** which are based on so-called supermirrors and transport the neutrons to the scientific instruments over distances of up to 100 m
- **Collimators, choppers, velocity selectors and monochromators,** which select neutrons according to their direction of travel (propagation) or their energy.

The ILL instrument suite is continuously renewed and upgraded, ensuring that in future the Institute continues to play its dominant role in neutron research worldwide. Each instrument is designed to probe the properties of matter in the finest detail.



THE MODERNISATION PROGRAMMES: MILLENNIUM AND ENDURANCE

In 2000, the ILL introduced a sustainable strategy - **the Millennium Programme (2001 - 2018)** - for the continual improvement of its scientific and technical infrastructures:

- Total investment: 78 M€
  - 12 new scientific instruments
  - 16 upgraded instruments
  - Average detection rate improved by a factor of 25 at the end of the programme.

A follow-up programme, known as Endurance, was launched in 2016 with the aim of consolidating and building on these results.

In a first phase, running from 2016 - 2018, Endurance consisted of:

- For a total investment 22 M€
  - 7 new or upgraded instruments
  - one upgraded thermal neutron guide (H24)
  - enhancements to support infrastructures such as sample environment and software for data treatment.

In order to sustain this momentum, we have now defined the scope and strategy of a second phase of Endurance, Endurance 2, to run between the years 2019 - 2023.

Endurance 2 will deliver:

- For a financial package of 36 M€
  - a total of 20 new or upgraded scientific instruments
  - a possible two additional CRG instruments (externally operated)
  - substantial detector developments.

THE MILLENNIUM PROGRAMME IN FIGURES

78 M€

18 years

Average gain of 25

ENDURANCE
Setting the pace

SCIENTIFIC HIGHLIGHTS

EXAMPLES OF SCIENCE PERFORMED AT THE ILL

MAGNETISM & SUPERCONDUCTIVITY

Electrons are key actors in energy transportation and data processing, with their movements inherently related to magnetism. Neutrons allow scientists to 'see' the magnetic field distribution created by electrons inside a wide range of materials. Neutron scattering is the only technique able to produce such detailed magnetic landscapes and is therefore an invaluable technique for experimental and theoretical work in this area.

EXCITATIONS IN A QUANTUM MAGNET: WHEN SPINS RESIST ORDER...

A quantum spin liquid (QSL) is a fascinating exotic state. Theorists have been investigating the properties of QSLs for decades, but their existence in real systems is debated. Unlike classical magnetic systems, the spins (the direction of the electron's angular momentum) do not order and organise into a non-magnetic state at lower temperatures. However, once agitated, the QSL system can create magnetic excitations, or so-called spinons. ILL's cold neutron spectrometers, ThALES and IN5, are perfectly placed to measure these spinon excitations and are therefore playing a key role in the hunt for spin liquid candidates, as demonstrated by recent studies.

QSLs are particularly intriguing, as their spins mutually interact with each other but do not form an ordered structure. This is because the spins are quantum objects and are connected in the QSL via 'entanglement' – a phenomenon which merges spatially separated spins. For instance, if we assume that the information of the spin is either 'up' or 'down', when we observe one spin in the 'up' state, the entangled spin will immediately be in the 'down' state, and vice versa. However, according to quantum mechanics, it is impossible to predict which set of measurements will be observed. Confused? Don't worry! Even Einstein thought entanglement was spooky. As QSLs demonstrate an unusually high degree of entanglement between all spins, they are the subject of many investigations not only in a host of areas of condensed matter physics, but also in quantum information science.

MAGNETISM – THE CLUE TO THE GLUE IN UNCONVENTIONAL SUPERCONDUCTORS

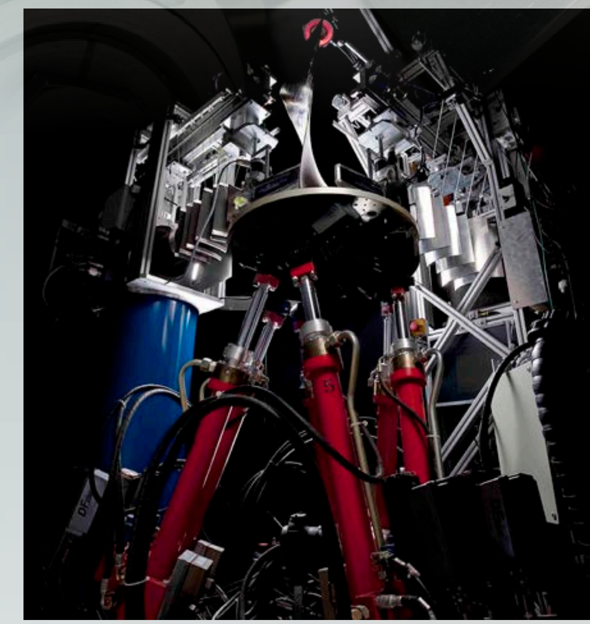
A great deal of energy is lost, in the form of heat, when an electric current moves at room temperature, due to the resistance of the wires. One of the most widely investigated problems in physics today is how to create compounds, so-called superconductors, which can overcome this challenge in conditions of ambient temperature and pressure. In superconducting materials, the resistance drops dramatically below a certain material-dependent critical temperature, which for all known materials is much lower than room temperature. At these temperatures, the electrons in superconducting materials couple to each other, forming so-called Cooper pairs, and superimpose to a common macroscopic quantum state – preventing the usual interactions within the host lattice and in turn the resistance.

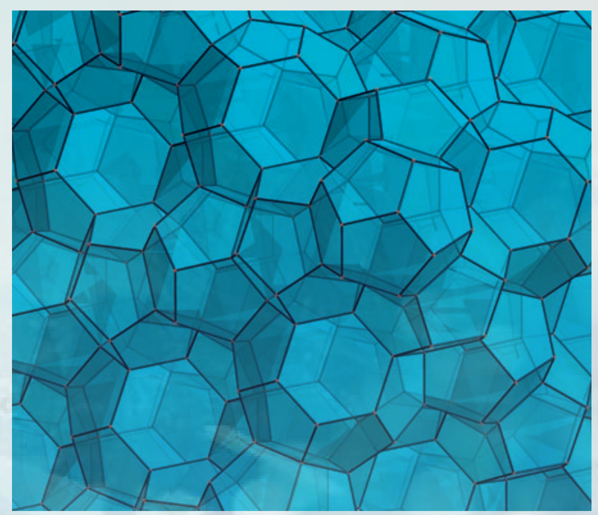
Since the late 1980s, several new superconducting families have been discovered, some of which display promising technical properties, including a higher critical temperature. The microscopic origin of superconductivity in these materials – the glue holding together the Cooper pairs – is still unknown and they have come to be referred to as 'unconventional' superconductors. Magnetic excitations, as measured by neutron scattering at the ILL, seem to correlate with the superconducting properties, and it is therefore believed that the pairing mechanism is of magnetic origin. A conclusive theory describing 'unconventional' superconductivity could bring us closer to the possibility of producing room-temperature superconductors, paving the way for potential new applications ranging from body scanners and ultra-fast computing chips to the high-efficiency transmission of electricity.

ADVANCED MATERIALS & TECHNOLOGIES

CRASH-TOLERANT VEHICLES

Ultra-high-strength steels, such as press-hardened boron, are used across a wide variety of industries, in particular car manufacturing, where they offer high strength and a weight-saving potential, allowing for stronger but lighter cars with improved passenger safety. In the automotive industry, a major joining method for boron steel components is resistance spot welding (there are several thousand of these welds on a single car!). This process exposes the boron steel sheet directly underneath to very high temperatures, creating a heat-affected zone where the surrounding material contracts and its microstructures are altered. This can in turn shorten the material's lifetime. Because of their high penetration power and ability to extract information in a non-destructive way, neutrons are virtually the only probe available to help us understand the exact effects on welding spots. The results obtained by scientists at the ILL are of particular importance not only to industries which already use boron steel, namely the car and farming industries, but also more widely to developers in the metallurgy industry, who can use the data for modelling and destructive simulations.





NEW ICE FORM FOR ENERGY STORAGE AND PRODUCTION

Gas clathrate hydrates are ice-like solids in which gas molecules or atoms are trapped inside crystalline frameworks formed by water molecules. They have attracted attention over the last decade for their potential as a fuel resource, as they naturally form in large quantities within marine sediments or below continental permafrost. At the molecular scale, gas clathrate hydrates are characterised by polyhedral water cages of different shapes and sizes, which can combine to form various crystalline structures. During the formation or decomposition of a clathrate structure, the gas molecules move from cage to cage. During experiments conducted at very high pressure (800 times atmospheric pressure), scientists at the ILL recently measured for the first time the diffusion of methane on the picosecond time scale and Å length scale. Their study revealed that the translational diffusion of methane is remarkably fast, a finding that will help tackle some of the energy and environmental issues facing our planet, such as methane recovery from marine hydrate sediments and carbon dioxide capture. The results of this work may also be used in the future to construct models of the methane clathrate hydrate layers embedded in the cryosphere of the gaseous planets of our solar system.

SCIENTIFIC HIGHLIGHTS

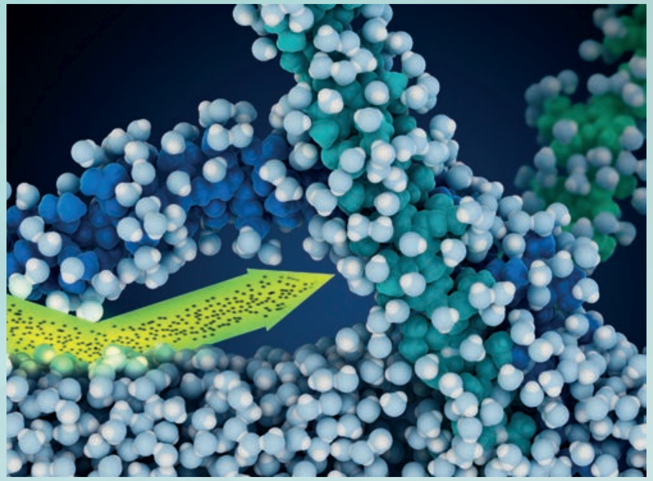
EXAMPLES OF SCIENCE PERFORMED AT THE ILL

LIFE SCIENCE

SMART NANOGELS

Gels are materials that are present in many everyday products, such as shampoos, sunscreens and food gelatin to name but a few. They are formed by mixtures in which large amounts of liquid, usually water, are confined within a flexible network of polymer chains or colloidal particles. Among the different types of gels, all with different properties and applications, nanogels are sub-micrometer-sized cross-linked polymer particles that can carry or incorporate macromolecules in their network structure. This is a property with many interesting applications, including for pharmaceuticals, and drug delivery in particular.

Neutron reflectivity studies are providing important missing information on how nanogels behave at interfaces. This in turn may lead to the smart design of novel materials for specific applications, as well as to the development of more patient- and user-friendly drug administration routes than those currently used.

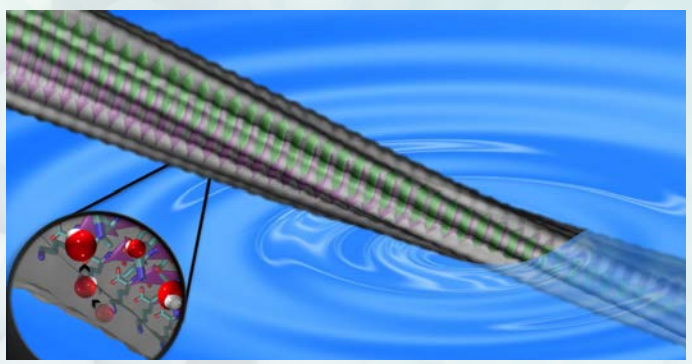


ALZHEIMER'S DISEASE MARKERS

One of the pathological hallmarks of Alzheimer's disease is the formation of amyloid fibres by tau proteins. These pathological fibres develop early on in Alzheimer's disease and understanding the mechanism by which tau aggregates is integral to understanding the disease's development and progression.

At the ILL, scientists have shown that water mobility is increased on the surface of these tau fibres, suggesting a potential avenue for the identification of Alzheimer's disease markers. Protein deuteration was used to mask as far as possible the neutron scattering signal of the proteins themselves in order to focus instead on the signal from the water molecules on the protein surfaces.

This study perfectly illustrates the benefits of using neutrons in probing the dynamics of biological samples. This spectroscopic technique made it possible to measure the mobility of water molecules on tau surfaces with high accuracy.



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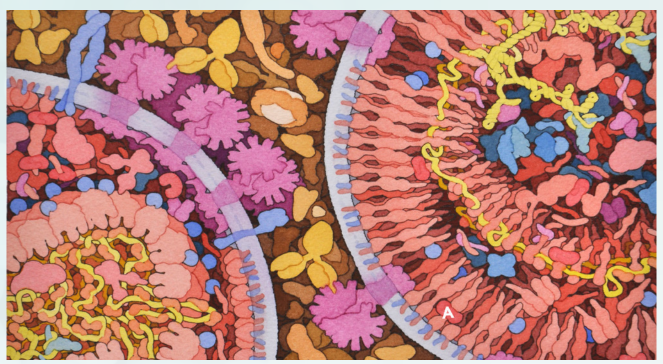
HIV DRUGS

HIV, the virus that causes AIDS, has become one of the world's most serious health and development challenges. Currently, there are approximately 37 million people living with HIV and tens of millions of people have died of AIDS-related causes since the beginning of the epidemic in 1981. HIV treatment includes medications to prevent and treat the many opportunistic infections that can occur when the immune system is compromised by HIV, as well as the use of antiretroviral therapy (ART) to attack the virus itself, with the aim of halting the development of AIDS.

HIV-1 protease is an enzyme responsible for the maturation of virus particles into infectious HIV virions, which ultimately leads to the development of AIDS. Without effective HIV-1 protease activity, HIV virions remain non-infectious. Given its fundamental role in HIV replication, the disruption of HIV-1 protease activity is a key target for successful ART drugs.

Scientists have used neutron crystallography to determine the structures of HIV-1 protease/drug complexes, providing vital information to help design new, more effective ART drugs.



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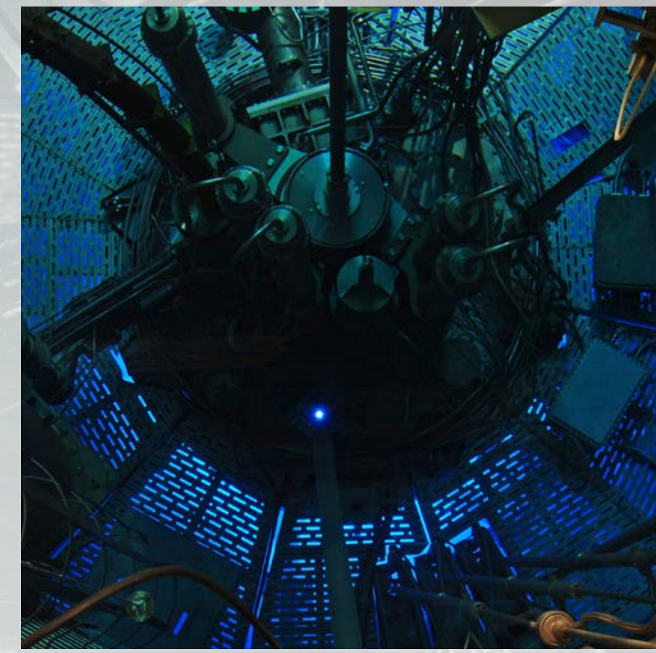
RADIOISOTOPE PRODUCTION FOR CANCER THERAPY

The high neutron flux of the ILL's research reactor is helping to further R&D into new, more targeted cancer therapies that cause less collateral damage to healthy tissue.

Radiopharmaceuticals (made up of a radioactive isotope attached to a bioconjugate that delivers the isotope to the cancer cells) are one of the best ways to diagnose and treat tumours. The progress in developing better targeting bioconjugates calls for isotopes with short-range radiation that damages the tumours but leaves the surrounding healthy tissues unharmed.

The production of innovative isotopes requires neutron sources with a high neutron flux. ILL is one such source and has already successfully demonstrated that it can produce radioisotopes such as tungsten-188 (a radionuclide generator of rhenium-188), lutetium-177, terbium-161 and scandium-47, which are important ingredients in developing new treatments for improving the quality of cancer therapy and patient care.

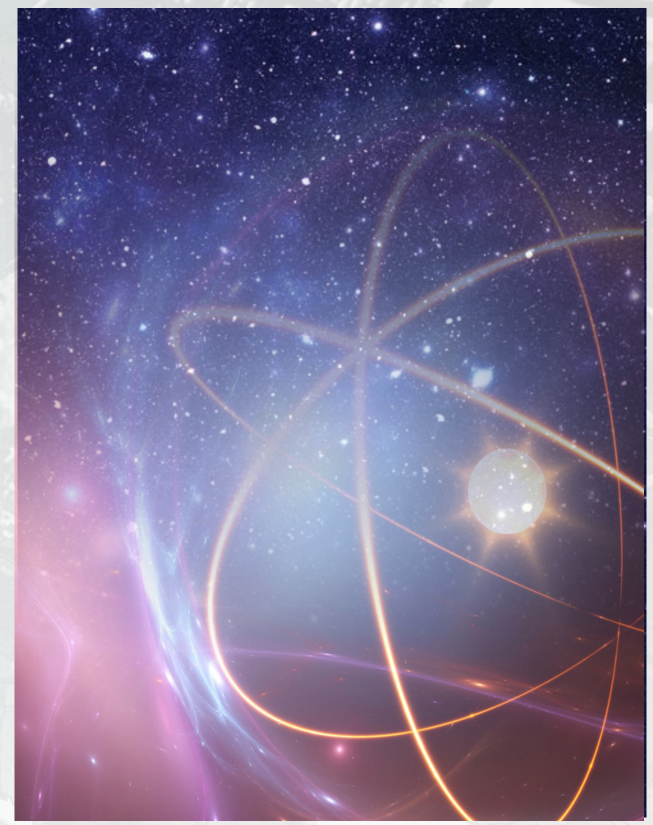
An automated irradiation system is currently under development which will allow the ILL to upscale the production of radioisotopes considerably enabling it to supply more hospitals more frequently.



NUCLEAR AND PARTICLE PHYSICS

Our views about the building blocks of Nature – fundamental particles and forces – have evolved dramatically over the past few decades. We now have models that attempt to unify the forces and particles, and describe how they came into existence in the very early Universe. To test these models, particle physicists have designed experiments over a wide range of energies.

In the sub-eV range, the cold and ultra-cold neutrons produced at the ILL can tell us a great deal about the 'symmetry' characteristics of particles and their interactions – perhaps helping to explain, for example, how the Universe came to contain mostly matter and not antimatter, even though both were created in equal amounts. Neutrons at the ILL are also used to investigate the structure and behaviour of nuclei by generating excited nuclear states. Although atomic nuclei have a finite number of constituents – neutrons and protons – they display extremely diverse modes of excitations associated with both single-particle and collective behaviour, and can be regarded as miniature laboratories for studying complex, strongly interacting systems. The ILL is also able to create exotic nuclei with high numbers of neutrons to explore how elements are made in the stars.



THE EPN SCIENCE CAMPUS: A UNIQUE RESEARCH HUB

The ILL is the historical nucleus of the European Photon and Neutron Science Campus. The site also hosts the European Synchrotron Radiation Facility (ESRF), an outstation of the European Molecular Biology Laboratory (EMBL) and the *Institut de Biologie Structurale* (IBS).

This constellation of facilities providing complementary instrumentation and know-how has served as a model for similar initiatives across the world. The synergy generated by the diverse strengths of the four partners has produced a number of major scientific and technological successes, such as the inauguration in 2017 of a Cryo-electron microscope platform, CryoEM.

NETWORKING & PARTNERSHIP

If Europe wishes to maintain its leading position in research with large-scale facilities, it must make optimum use of its resources. European research institutes have for a long time been combining their efforts to do just this, with European funding programmes playing a key role.

Experiments requiring extensive support with sample preparation and the processing of experimental data are particularly challenging. The ILL is making concerted efforts to provide the necessary resources via partnerships with other research centres and universities, including:

- the Partnership for Structural Biology (PSB), which in particular offers users access to a specialised deuteration laboratory for biological samples (D-Lab)
- the Materials Science Support Laboratory
- the Partnership for Soft Condensed Matter (PSCM).

THE ILL AND GRENOBLE

Grenoble, with its many excellent research institutions and universities, offers ideal conditions for fruitful scientific and academic collaborations. Despite its strong international focus, the ILL relies on this local stimulus for its exceptional performance. The GIANT partnership is forging dynamic new links between education, research and industry aimed at fostering the technological breakthroughs that will be the economic drivers of the future.

The ILL also has strong links with its local university, the Université Grenoble Alpes. As well as holding a number of chairs at the university, the Institute co-supervises several PhD students and organises numerous placements and summer schools.

In addition to scientific excellence, Grenoble offers ideal surroundings and infrastructure for foreign staff and visitors, who in turn enrich the cultural and economic life of the city.

GENERAL ORGANISATION

The ILL is a private French company, governed by an Intergovernmental Convention.

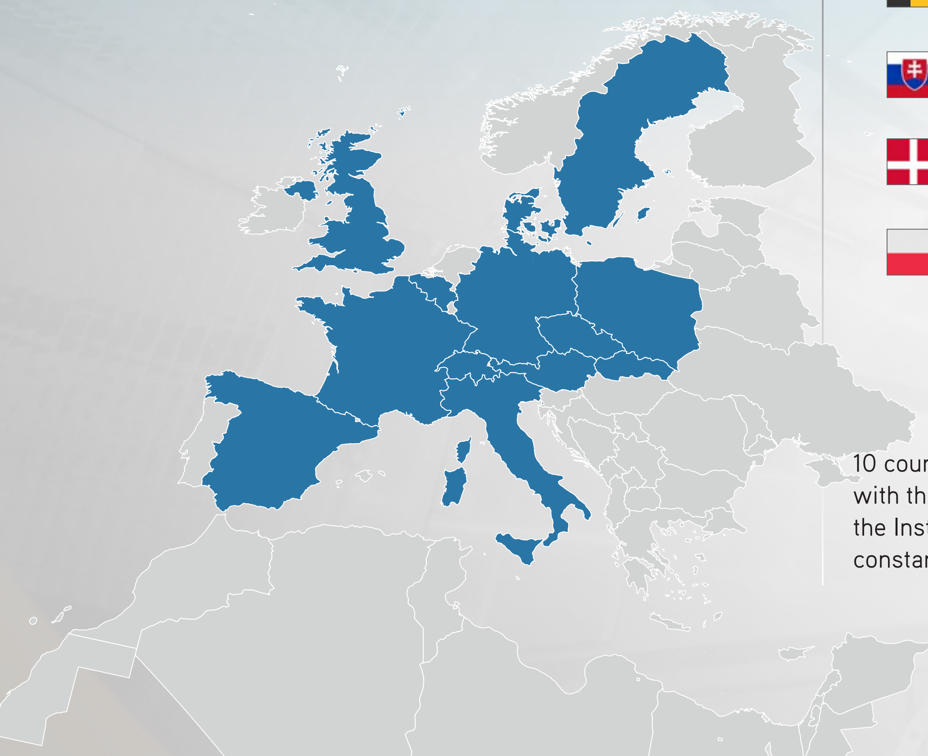
The three Associate members appoint a Steering Committee, which, in consultation with ILL Management, defines the broad strategy for the Institute and sets its budget.

THE ASSOCIATE MEMBERS

France
- Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA)
- Centre National de la Recherche Scientifique (CNRS)

Germany
- Forschungszentrum Jülich GmbH (FZJ)

UK
- United Kingdom Research & Innovation (UKRI)



THE SCIENTIFIC MEMBERS (2018)

Spain: Ministerio de Ciencia, Innovación y Universidades

Switzerland: State Secretariat for Education and Research

Austria: Austrian Academy of Science

Italy: Consiglio Nazionale delle Ricerche (CNR)

Czech Republic: Charles University of Prague

Sweden: Swedish Research Council

Belgium: Belgian Federal Science Policy Office (BELSPO)

Slovakia: Comenius University in Bratislava

Denmark: Danish agency for science, technology and innovation

Poland : "Neutrony dla Polskiej Nauki" (NDPN) Consortium of Polish scientific and research institutions, coordinated by the Henryk Niewodniczański Institute of Nuclear Physics, Kraków

10 countries had signed Scientific Membership agreements with the ILL to allow their scientists privileged access to the Institute's facilities. The list of Scientific Members is constantly evolving.

FACTS & FIGURES (A three-year average)

BUDGET
90,1 M€

The ILL is financed by grants from its Associates (71 %) and contributions from its Scientific Members (21 %), as well as revenue from industrial contracts

STAFF
475

including 67 scientists and 36 thesis students

PROPOSALS
881

of which 594 received beamtime

EXPERIMENTS
641

on 28 ILL-funded instruments and 9 CRG instruments

VISITORS
1224

from 40 different countries

PUBLICATIONS
559

NEUTRONS
FOR SOCIETY

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FOR FURTHER INFORMATION, PLEASE CONTACT THE COMMUNICATION UNIT communication@ill.eu

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