Future perspectives and opportunities for the Institut Laue-Langevin

A STRATEGY FOR THE NEXT 10 YEARS

NEUTRONS FOR SCIENCE

NEUTRONS — SUBATOMIC PARTICLES USED TO STUDY THE STRUCTURE AND BEHAVIOUR OF ALL KINDS OF MATERIALS IN MICROSCOP

ENTAL AREAS EQUIPPED WITH A WIDE RANGE OF SOPHISTICATED INSTRUMENTS. SCIENTISTS FROM ALL OVER EUROPE AND THE REST OF THE WORLD

S AND HOUSEHOLD PRODUCTS, TO UNDERSTANDING BIOLOGICAL PROCESSES AT THE CELLULAR AND MOLECULAR LEVEL, AND TO ELUCIDATING THE UN

TAL PROCESSES THAT HELP TO EXPLAIN HOW OUR UNIVERSE CAME INTO BEING, WHY IT LOOKS THE WAY IT DOES TODAY AND HOW IT CAN SUSTAIN

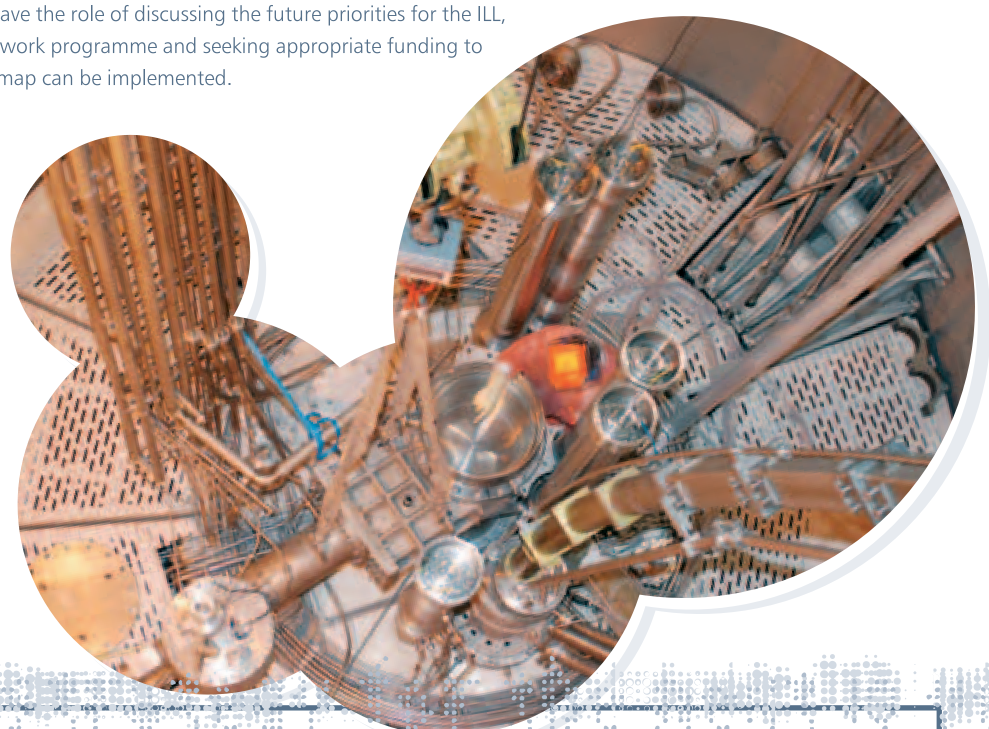
Future perspectives and opportunities for the Institut Laue-Langevin

A STRATEGY FOR THE NEXT 10 YEARS

A NOTE FROM THE ILL'S ASSOCIATES

It has been 5 years since the ILL produced a roadmap and it is timely that a revised document is produced. In addressing this issue, the management team for the past 5 years composed of Colin Carlile, Christian Vettier and Werner Press have, in consultation with the Associates, the Steering Committee, the Scientific Council and Users of the ILL, produced this *Perspectives and Opportunities* document.

Considerable time and effort has been spent over the past 24 months in considering the future opportunities that will keep the ILL at the forefront of neutron science for the next 15 years. These opportunities are presented in this document which we commend to you. We welcome your comments on the content and proposals – these will be passed on to the new management team that will take over the reins of the Institute during 2006 and 2007. They, with the Scientific Council, Steering Committee and Associates, will have the role of discussing the future priorities for the ILL, producing a detailed work programme and seeking appropriate funding to ensure that the Roadmap can be implemented.



NOTE TO THE READER

This document has appeared after 2 years of consultation and preparative study. It represents what would be possible at the ILL with optimum funding. The document is intended for many categories of reader and has purposely been presented in a sequence of layers. A brief overview is presented on page iv, an executive summary is included on page A.6, the work-plan with financial models is detailed in the narrower section A, and the 'traditional' Roadmap, which represents the foundation upon which the whole plan is based and provides essential background information on the Institute, is available in the wider section B. A CD on the inside back cover gives additional information on the ILL's facilities and operations. The whole document is available at: www.ill.fr/Perspectives

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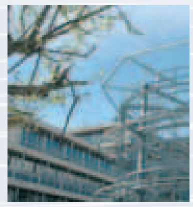
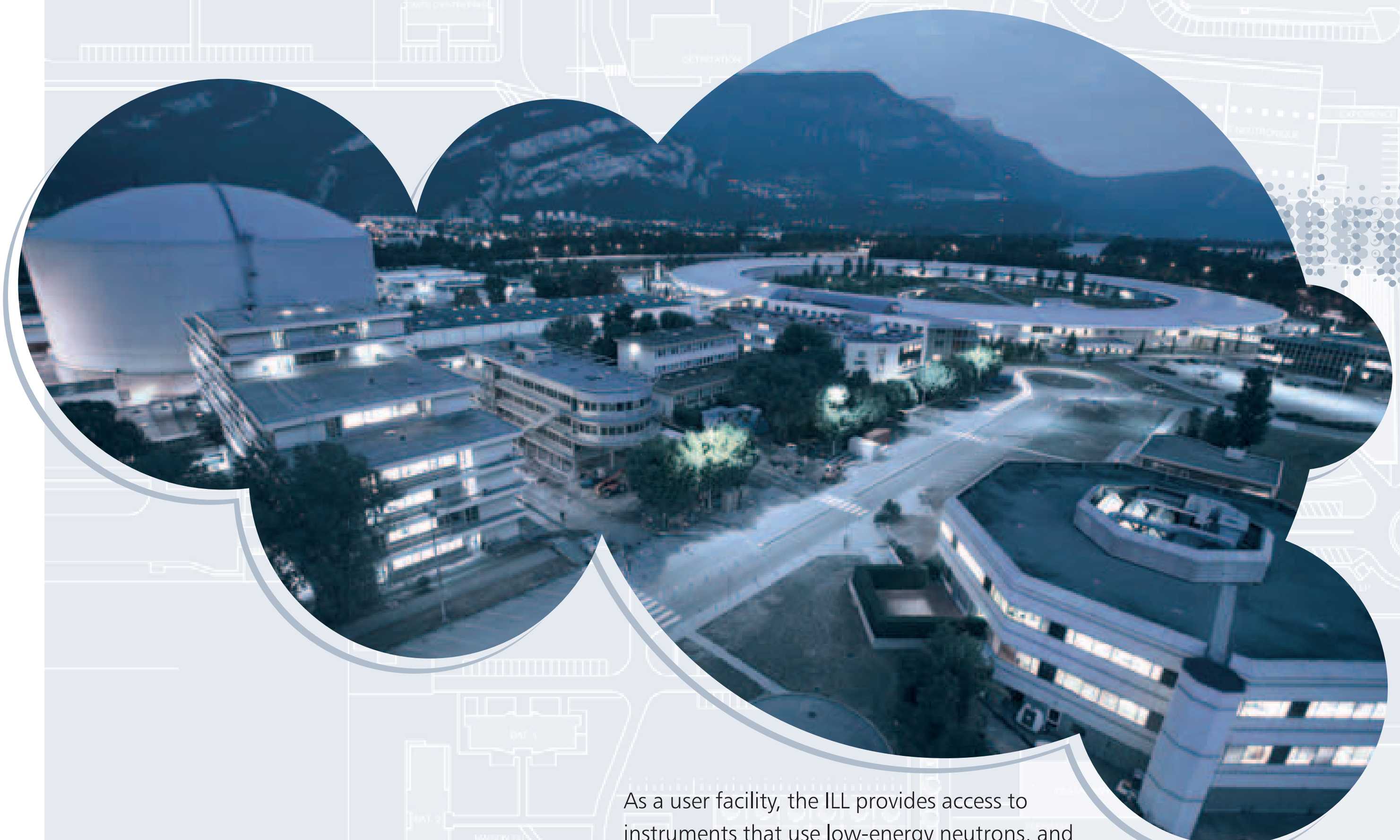
A PROPOSED 10-YEAR PROGRAMME

B THE INSTITUT LAUE-LANGEVIN



“The Institut Laue-Langevin (ILL) has firmly established itself as a pioneer in neutron science. Neutron beams are used to gain a deeper understanding of the materials of everyday life – from pharmaceuticals to materials for storing hydrogen, and also to probe the fundamental properties of nuclei and their constituent particles, leading to insights into why our Universe has evolved as it has. The ILL has occupied this leading position for 30 years. Making the invisible visible is our mission.”

Setting the scene



As a user facility, the ILL provides access to instruments that use low-energy neutrons, and which are of unequalled quality and breadth, to a community of many thousands of researchers throughout Europe and beyond. As a service institute for users, it has become a model for later facilities all over the world and represents a flagship of modern scientific research. It is recognised as an undoubted triumph for European cooperation.

Although the ILL enjoys a world-leading position today, it would be a deception to believe that it can remain so without constant innovation, and equally it would be a dereliction of

The three Directors of the ILL: from left to right, Christian Vettier, Colin Carlile and Werner Press

responsibility to the tax-payer not to invest appropriately in a facility conservatively valued at 2B€. There are few scientific areas in which Europe leads the world, and research using slow neutrons is undoubtedly one.

It is therefore timely to lay down a coherent plan showing the way forward for the Institute over the next decade – with a glimpse into the following decades. This is the aim of this document.

The social and political balance in the world is changing at a startling pace. European decision-makers are tentatively edging towards the vision of a knowledge-based economy, declared at the beginning of the decade in Lisbon. A Europe-wide debate on investment in current and future European scientific infrastructures is being carried out, led by the European Strategy Forum for Research Infrastructures (ESFRI). New powerful neutron sources – yet to prove themselves capable of delivering their promise – are being built on other continents whilst Europe hesitates to decide on the construction of its own next-generation neutron facility.

Remaining a world-leader

In the meantime, the ILL has moved up a couple of gears – as witnessed by its innovative Millennium Instrument and Infrastructure Programme, put in place in January 2000 (p A.24). The result is that our suite of instruments can deliver eight times as much high-quality data today as it did in 1999, and much more will be offered in the future as developments continue. Our recent Seismic Refit Programme has secured the integrity of our nuclear installations, and has demonstrated that an almost indefinite lifetime for the Institute is a realistic goal – provided the scientific output remains first-class and highly relevant.

This *Perspectives and Opportunities* document identifies the technical initiatives that are possible and the investments that are needed during the next decade, together with the simultaneous increase in operational activities. The nuclear installations are to be kept at the cutting-edge year by year – and not once every decade as before. Safety and security are to be watchwords. The instrument suite, both public and private, is to be optimised and reconfigured. A combination of the users' needs in the short-to-medium term, and the innovative vision of the ILL's directors, scientists and engineers in the long term – advised by our Instrument Sub-committee and our Scientific Council – has and will continue to lead the development of instruments of unprecedented quality, and thus to prolonged scientific excellence.

The ILL is eager to take on this challenge. We foresee a productive future, working together with our neighbouring Institutes, our funders, our academic and industrial users, and our highly qualified and dedicated staff, together with the understanding and appreciation from the European man and woman in the street upon whom we depend for our existence.

We pledge to continue and reinforce the culture of innovative ideas that the ILL's founders pursued with such energy and vision. That energy and vision still exists today and – we firmly believe – so does the scientific need, political motivation and financial support to implement our considered plans for the future.

Colin Carlile
Director, Institut Laue Langevin, Grenoble September 2006

On behalf of the Management team
leading the ILL (2000-2006)

The principal ambitions

These are the principal ambitions of the ILL that guide the content of this *Perspectives and Opportunities* document

- TO GENERATE AND TO DELIVER NEUTRONS, RELIABLY AND SAFELY, TO THE ILL'S INSTRUMENTS, OPTIMISING AND ENHANCING THE PRODUCTION AND DELIVERY WHEREVER POSSIBLE, AND TAILORING THE NEUTRON SPECTRA TO THE FUTURE DEMANDS.
- TO MAINTAIN AND DEVELOP THE ILL'S INSTRUMENT SUITE AT THE CUTTING EDGE AND TO UPGRADE THE SUPPORT FACILITIES SO THAT THEY MAP ON TO THE EVOLVING NEEDS OF THE USER COMMUNITY.
- TO DEVELOP PARTNERSHIPS FOR SCIENCE AND TECHNOLOGY, MODELLED ON THE PARTNERSHIP FOR STRUCTURAL BIOLOGY, TO ATTRACT NEW COMMUNITIES OF USERS AND TO MAKE MORE EFFECTIVE USE OF THE ILL'S INSTRUMENTS, AND TO REGROUP ALL THE ILL'S ACTIVITIES IN DEVELOPING NEUTRON TECHNIQUES UNDER ONE ROOF – ANTS, THE PROPOSED ADVANCED NEUTRON TECHNOLOGIES CENTRE.
- TO ENHANCE SIGNIFICANTLY THE ASPECTS OF THE SITE, WHICH IS JOINTLY OCCUPIED BY THE ILL, THE ESRF (THE EUROPEAN SYNCHROTRON RADIATION FACILLITY) AND THE EMBL (THE EUROPEAN MOLECULAR BIOLOGY LABORATORY), TO CREATE A CLEARLY VISIBLE CENTRE OF EXCELLENCE FOR SCIENCE IN EUROPE.

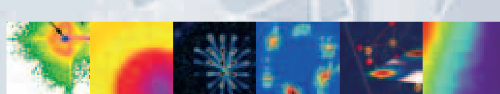
Timing

To be implemented over 10 years in two consecutive phases – **2007 to 2011** and **2012 to 2016**.

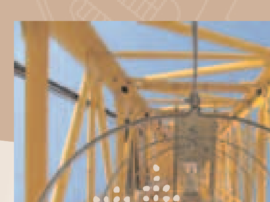
Costs

A capital investment of **160M€** over 10 years; with an additional **30M€** for the development of the common site in conjunction with the ESRF and funded by the national *Contrat de Projets Etat-Région* (CPER). When the programme is fully implemented in 2016, the operational budget of the Institute will have risen by about **5M€** per year.

A proposed 10-year programme



The aims and specific goals of the ILL



Our aim is to optimise the ILL's potential for scientific output from research by our user community, thereby maintaining our world-leading position in the field. The investment programmes will concentrate on our demonstrated scientific and technical strengths, and will be informed by the changing political, social and economic environment in Europe and worldwide.

Specific goals

The backbone of this document is the setting in place of four parallel 10-year investment programmes for the ILL. These build upon the ongoing Millennium Programme (p A.24) and use as input the recent Instrument Review, and the Refit Programme (p A.22).

The four investment programmes are:
(i) The renewal of key reactor components;
(ii) The provision of new moderators, instruments and techniques;
(iii) The creation of Partnerships for Science and Technology
(iv) The joint development of the common site shared by the ILL, the ESRF and the EMBL.

These programmes would be implemented in two phases, from 2007 to 2011 and from 2012 to 2016. The overall cost of these investments will be 160M€ for programmes (i) (ii) and (iii) with funding to be sought from our traditional funding bodies and the EU, and 30 M€ for (iv) with funding from regional French authorities. To conclude this document, a set of broad aims for the finance and governance of the Institute is presented. The operational costs of the Institute will rise by around 5M€ a year as a result of these investments after full implementation of the programme in 2016. This document assumes that the lifetime of the Institute will be at least until 2024 and probably beyond. The scientific and political framework in Europe and the neutron scenario within and beyond Europe have been taken into account in determining this plan.

PROGRAMME (i)

Renewal of key reactor components – 39 M€

Aims :

- Use the momentum of the Seismic Refit Programme (p A.22) to instigate the Key Reactor Components investment programme, central to which will be the rebuild of the detritiation facility. The Key Reactor Components Programme will be a continuous investment programme to ensure our neutron source is always state-of-the-art.
- Develop a new fuel element to enable us to provide a neutron source which operates at full-design power for four cycles per year, each of 56 days, thereby delivering 224 days of beam to about 40 instruments each year.

PROGRAMME (ii)

Development of new instruments and techniques: Phase I – 56 M€ and Phase II – 35 M€

Aims:

- Install new high-intensity thermal guides, a third cold source illuminating the currently under-used thermal guides, optimise the location of the cold-source instruments, and develop a high-density ultra-cold neutron source;
- Reconfigure the instrument suite in two 5-year phases, guided by the recent Instrument Review, the Scientific Council and the Millennium Symposium and focusing on the ILL's recognised strengths and the needs of the user community;
- Increase the number of public instruments stepwise from 25 to 30 by 2011;
- Increase the number of CRG instruments from 10 to a maximum of 15, according to demand;
- Instruments no longer fit for purpose will be closed down.

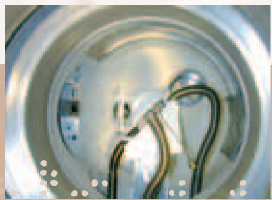
PROGRAMME (iii)

Creation of Partnerships for Science and Technology: Partnership for Soft Condensed Matter; Partnership for Materials Science and Engineering; the Advanced Neutron Technologies (ANTs) Centre; and the Partnership for High Magnetic Fields – 30M€

Aims:

- Capitalise upon the experience of the Partnership for Structural Biology (PSB) laboratory (p A.35) to create a 'Science and



Innovation cluster', serving the combined-site user community. Further such laboratories are envisaged in collaboration with the ESRF: a Partnership for Soft Condensed Matter (p A.35) and a Partnership for Materials Science and Engineering (p A.35) in order to attract new user communities and to improve the effectiveness of the experimental programme.

- Build an Advanced Neutron Technologies Centre, ANTs (p A.36), surrounded by private engineering companies as partners in developing and constructing novel components for new instruments. ANTs will facilitate the technology transfer of novel instrumentation, such as area detectors, polarisers and monochromators, to other neutron centres.
- Create a Partnership for High Magnetic Fields (p A.36) centred on a generator to produce magnetic fields of 35 tesla on the sample on purpose-built instruments at both the ILL and the ESRF. The ILL's financial contribution to the High Magnetic Field Laboratory would be 30M€, as would be the ESRF's. Finance for this facility would be sought elsewhere but is included in the 160 M€ total.

PROGRAMME (IV)

Joint development of the site – 30M€ (Contrat de Projets Etat-Région)

Aims:

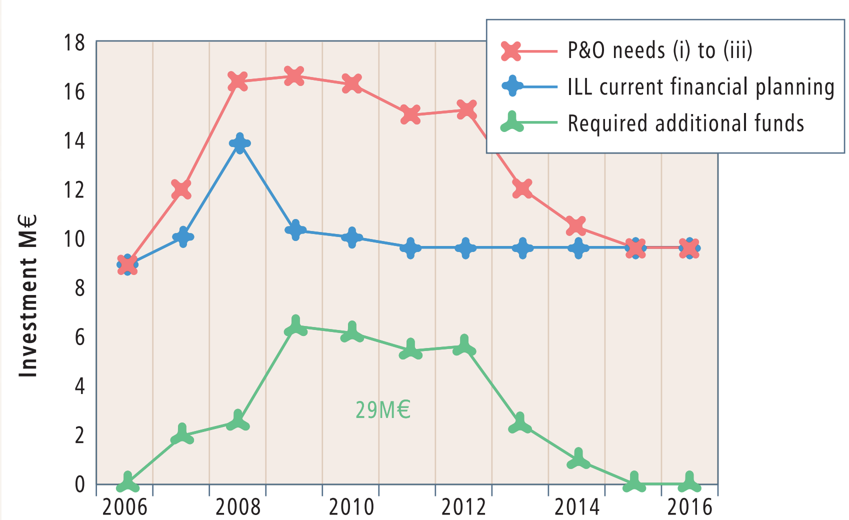
- Improve the international visibility and impact of our site by creating a new entrance which would incorporate a visitor centre as well as a conference and training complex;
- Implement a programme for building renovation, solar protection and environmental improvement with the goal of increasing intra-site connectivity, communication, effectiveness of work and instrument operation;
- Build a fourth guesthouse to increase the capacity from 220 to 320 researcher occupation;
- Reconfigure the common joint building including the library, adding a new restaurant to accommodate the increasing user community;
- Be an active partner in the setting up of a creche on the Polygone Scientifique.

Finance and governance

In addition, we intend to fine-tune the management of the ILL and broaden our financial base, by attracting investment from other Scientific Partners, the French regions and the European Union.

Specific aims include:

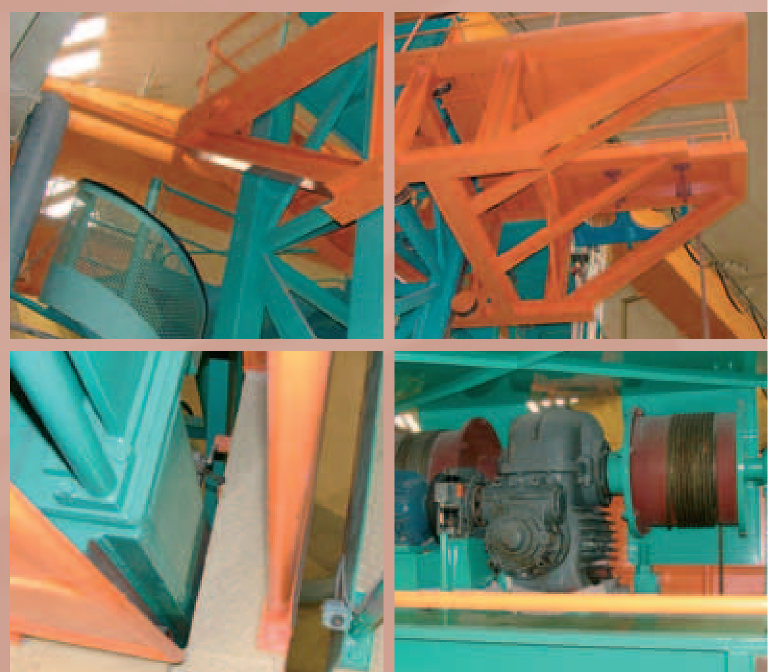
- Continue towards the full Europeanisation of the ILL, aiming for up to 20 national Scientific Partners by 2011 – currently there are 12;
- Aim for optimal funding of the Institute so as to employ its capital value efficiently. An annual budget of 85M€, including staff costs, operational costs and capital investment, would fulfil the needs of the initiatives proposed in sections (i) to (iii) in this document;
- Energetically pursue funding opportunities from our Associates, our Scientific Partners, both current and future, and the European Commission following our inclusion in the ESFRI (p. v) European Large Scale Facilities Roadmap. An effective site premium will be achieved through investment in infrastructure by the different levels of local French governments;
- Re-examine methods for the selection of experiments rendering the procedure more responsive and relevant to today's needs;
- Encourage access to industrial users either collaboratively or individually;
- Define and protect our intellectual property and facilitate knowledge transfer;
- Implement full Risk Management, continue to strengthen project-management skills and review all administrative support functions;
- Explore further joint ventures with the ESRF to create economies of scale by gathering a critical mass of expertise in certain functions;
- Attain an appropriate level of manpower;
- Validate our senior scientists via academic links and postdoctoral assistants;
- Encourage lifelong learning and individual development of our whole staff;
- Seek efficiency savings in order to create resources for investment and operations.



Future funding of the Perspectives and Opportunities Programme

The guiding principles

The plan that the ILL is proposing is based on the following principles



Science, innovation and investment

- To achieve wider scientific excellence by targeting different disciplines and attracting new communities of users.
- To design and build innovative instruments and to replace those no longer fulfilling expectations.
- To ensure the reliability and security of our nuclear facilities by a continuous programme of investment.
- To validate our scientific, technical and administrative staff.
- To train new generations of skilled scientists through our user programme.

Identity and partnership

- To maintain and improve upon our world-leading position in neutron science, instruments and techniques.
- To strengthen links with our sister laboratories, both national and international, and to local, regional, national and European policy-makers.
- To inform and influence the decision-makers of Europe.
- To secure funding for the implementation of our collective site-plan with the ESRF and the EMBL, emphasising our role as a future centre of excellence for European researchers.
- To actively enable the public appreciation of science.

The values we defend

- To be responsive to our user community, both current and potential.
- To emphasise the importance of safety and to further enhance our safety culture.
- To implement best practices in governance, mitigating risk and providing value for money.
- To encourage the individual development of each staff member.

Executive summary

The ILL, as a top-tier facility, has – rather remarkably – maintained its pre-eminent scientific position for 30 years, despite limited investment to maintain its infrastructure at the level required of an international laboratory. The urgent need for the Millennium Programme in 2000 and the Reactor Refit Programme in 2002, each having cost, by now, around 30M€, underlines the lack of a sustained investment programme. The plans described in this document represent these investments necessary to maintain the ILL fit for use and in its leading position for the next 10 years and beyond.

Key Reactor Components

We will maintain our nuclear facilities so that they are fit for purpose, operating continuously, ensuring that risk is mitigated. We will anticipate the future requirements of our 10-year safety reviews rather than just react to them. The detritiation facility, unique in Europe, will be reinforced totally, and will serve other neutron sources in Europe. The fuel element is to be upgraded to maintain 58-MW operation and to extend the cycle length to 56 days, thereby delivering 224 days per year of scientific use in four cycles. Economies will result from this initiative, together with greater effectiveness and convenience for users. A study of the factors influencing the longevity of the ILL's reactor is underway, and a costed programme for the eventual decommissioning of the site is being defined. Currently, there are no factors that indicate that the ILL's reactor, properly invested in, cannot continue operating safely, cost-effectively and reliably for as long as its scientific productivity remains outstanding.

Moderators and neutron delivery

The Institute's Scientific Council has identified that there are insufficient high-intensity cold and thermal beams to fulfill the priorities of the user community. Furthermore, many of the ILL's instruments are compromised by the fact that they are sited sequentially on each beamline. Equally well, the ultra-cold neutron (UCN) source will be outflanked by other facilities within 5 years. We are aiming, therefore, for less compromise. The ILL has identified the possibility of installing three more, very high intensity thermal guides, necessitating the closure of a public instrument no longer fit for purpose. A third cold source, of novel gradient concept, will feed cold and thermal beams of neutrons to the currently under-utilised guides on the east side of the main guide hall. Studies aimed at incorporating a high-density UCN source within the third cold source would allow the installation of the whole assembly in Phase II of the proposed instrument programme. Furthermore, a programme to manage the maintenance of the ILL's neutron guides and to mitigate the risk of unplanned downtime is being implemented.

The ILL Instrument Review

Launched in September 2004, a full-scale bottom-up review of the ILL's instrument suite has been carried out in conjunction with the user community and the Scientific Council and its Subcommittees. This has been informed by the evolving developments in neutron facilities in Europe and elsewhere, to ensure that the ILL will continue to occupy a leading position. The ILL's scientific and technical teams have formulated a programme comprising two consecutive 5-year phases which will involve closing unproductive instruments, and building state-of-the-art instruments in those areas where the ILL has an unbeatable capability, even when the new high-power spallation neutron sources are fully functioning (p A.18). We propose that the public instrument suite increases step-wise from the current total of 25 to 30 by 2011, as it was in 1990. There is demand also, from the new Scientific Partners now being attracted to join the ILL, for an increased number of Collaborating Research Group instruments (p B.17). There are currently 10, which the ILL has the capacity to lift to 15.

The Site Infrastructure Plan

Our sister laboratory on site, the ESRF, is also laying down a strategy plan for the future. It has, like the ILL, to adapt to advances in the provision of facilities and expanding research requirements for synchrotron radiation in Europe and elsewhere. Driven by the recognition that the shared ILL/ESRF site represents an unequalled international force in condensed-matter science, contributing towards Europe becoming the leading knowledge-based economy in the world, a goal laid down in Lisbon in 2000, we propose a significant upgrade in the visibility and capability of our site, which would be funded by the French Regions through the *Contrat de Projets Etat-Région* (CPER).

A new site entrance would bring together a new visitor-reception area, the stores receipt and dispatch area, a conference centre with a capacity for 400 delegates, a training centre for doctoral and postdoctoral students (including facilities for the broadening HERCULES courses, p B.20), and finally 'a public appreciation of science' drop-in exhibition space. The Conference Centre is urgently needed since scientific meetings with greater than 120 attendees cannot be contemplated on site, and even meetings of our users are impractical. A creche, built on the Polygone Scientifique, would serve all the neighbouring laboratories, and would help us to make the most of the under-used resource of women scientists, engineers, technicians and administrators. These developments are estimated to cost 30M€ and would be implemented from 2007 to 2011, in the first Phase of this *Perspectives and Opportunities* plan. Funding for the Site Infrastructure Plan is targeted at the French Regions and is not contained within the finance of the *Perspectives and Opportunities* landscape.

Interface laboratories

Increasingly, experiments using neutron and synchrotron beams are becoming more complex, involving, for example, simultaneous investigations with other probes, or dynamic experiments *in situ* on chemical reactions. We observe that simple experiments on stable samples prepared in researchers' home laboratories and brought to the ILL and the ESRF are no longer the norm. If the ILL is to be relevant to the needs of the present and future user community, and attractive to researchers working in the wider areas of applied science, we need to improve our sample-preparation facilities on site and reduce the mystique of neutron-scattering techniques. This can be done by setting up partnership laboratories in specific disciplines –

stepping stones for the user. We have already established a deuteration laboratory jointly with the EMBL which is now successfully integrated into the Partnership for Structural Biology. We have also established the FaME engineering laboratory together with the ESRF which would be incorporated into a future Partnership for Materials Science and Engineering (PMSE). We envisage eventually four Partnership laboratories (p A.34): the PSB and the PMSE, together with a Partnership for Soft Condensed Matter and one for High Magnetic Fields. These Partnerships will be developed with the ESRF and with other interested laboratories and universities throughout Europe.

An Advanced Neutron Technologies centre, ANTs

The ILL has a well-deserved reputation for having developed much of the ancillary equipment used in neutron science, such as dilution fridges, detectors, polarisers and monochromators (p B.11). These have contributed to the improved power of neutron scattering overall, when increases in the intensity of the neutron sources themselves have not been possible. Over time, small individual laboratories devoted to developing a particular technology have appeared organically in at least 12 different isolated locations around the ILL. It is clearly more effective to locate all these facilities in a single building. This would be the Advanced Neutron Technologies centre, ANTs (p A.36).

The ANTs centre would welcome joint activities with other European neutron facilities. It would enable a critical mass of expertise to be assembled, so that all laboratories in the partnership could benefit mutually from access to the highest technology components – monochromators, detectors and polarisers, and so on.

The evolving scenario for neutron facilities

The realisation of the full potential of the existing neutron sources, both within and beyond Europe, is recognised politically and scientifically as being increasingly important (p B.8). The OECD Megascience Forum recommendations on neutron sources which advocate a high-intensity source in each region of the world and the full utilisation of the existing top-tier neutron sources around the globe have only partly been realised. The construction of the world's first purpose-built high-power spallation source, SNS, in Oak Ridge in the US has alerted the community of European neutron scatterers that their lead in the field will start to erode unless action is taken. The Paul Scherrer Institute in Switzerland, the second target station for ISIS in the UK, the new FRM-II reactor in Germany and other neutron facilities have begun to respond to this challenge, but uncertainty about the construction of the European Spallation Source still persists after two decades of studies.

The ILL's existing Millennium Programme (p A.24)

Inauguration of the D-Lab

Inauguration of the CIBB on 13 January 2006 was aimed towards realising the potential of instruments following the lean years for investment during and after the reactor was rebuilt in the early 1990s. The proposals contained in this *Perspectives and Opportunities* document, however, are a direct response to this changing political and scientific scenario, and they concentrate on those areas where the ILL excels. The American SNS facility is unlikely to reach its full design specification for at least a decade, and the time is ripe for the ILL and its funders to take action now to ensure that Europe's lead in this field is maintained.

Interacting with the user community

This Programme was launched at the ILL's Millennium Symposium meeting of its users in April 2006. It is only the second time that the ILL has run such a meeting, but it clearly must not be the last. Given the broad geographic spread of our user community, large face-to-face meetings can be justified only occasionally. In the intervening periods, more cost-effective ways of communicating must be sought. For this reason, the ILL's pioneering electronic User Club is to be extended in scope. We will introduce personalised user databases which will contain a retrievable history for every user, including not only proposals submitted, both successful and unsuccessful, but also files of preferred instrument configurations to be edited ahead of time and reloaded for forthcoming experiments. User feedback is very important and needs to be actively solicited. The User Forums, which ILL introduced 5 years ago, serve the purpose of providing comment when it is still fresh in the user's mind, as do the feedback forms, but these initiatives serve a specific goal and we need to go further. We are launching a specialised user blog to provoke discussion amongst our users and from which we can draw feedback to implement improvements in our service to users.

The D-Lab team in front of the new CIBB building

Broadening our appeal

We are targeting two specific areas here. First, there is the need to open up formal access to the ILL for other European nations so that the scientific community from the wider Europe can have right of access. This will enrich the scientific culture of the Institute and create a community that is stronger, more coherent, and more inclined to work together to realise the next generation neutron sources for Europe. The Netherlands, Poland and Slovakia, the remaining Nordic, Baltic and Balkan countries are candidates, as well as outlying European countries such as Ireland, Romania, Portugal and Greece. Secondly, there are still many scientific disciplines in which just a handful of pioneering researchers are using neutrons, or where there is today negligible application of neutron methods. Earth and planetary sciences, life sciences and cultural heritage are only three examples where we will promote the use of neutron methods (p B.5).

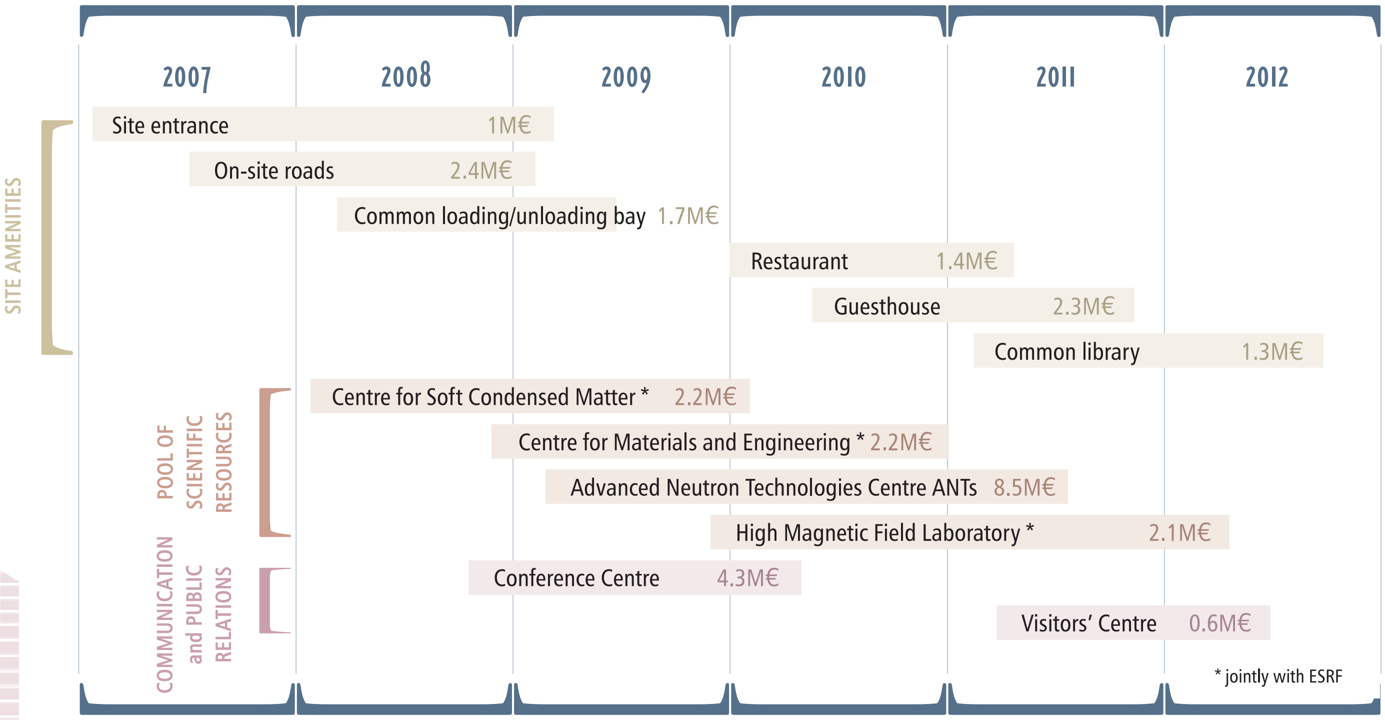
Governance of the Institute

In recent years, there has been a significant number of initiatives taken to modernise ILL's management practices. This will continue. The implementation of a professional risk-management approach has started, with the appointment of a risk manager and the definition of a risk register, to be reviewed and updated regularly. The use of electronic techniques to make management practices more effective is ongoing. The Budget Holders Toolkit is now fully functioning, as is the Human Resources Toolkit. Both are first points of call in managing finance and personnel. The use of electronic archiving and retrieval of contracts, key documents and drawings, is to being implemented, as is electronic recruitment and the optimum use of electronic libraries. The Medical Service is now furnished with a software management framework to make this large and important task – involving our whole site user community as well – more efficient and, of course, secure. This initiative enables the increasing demands for reporting – such as radiation doses, job risks files, and exposure levels to hazards such as noise and chemicals – as well as the legal need for enhanced record keeping, not to weigh too heavily on our resources.

Validating our staff

The ILL staff is committed to the future of the Institute. However, aspects of their management must be continually enhanced. Career structures for staff need particular attention in a single-use organisation like the ILL. Mobility is not as easy to

Timeline for the Site-Plan development



achieve as it is in larger organisations. However, we are planning to explore this in collaboration with our EIROforum partners (p A.11, p B.4). Training is a highly motivational tool, and helps each individual to realise their potential and to avoid the fading that can happen earlier or later in an individual's career, thus benefiting the Institute and staff-member alike. This equally well applies, of course, to our scientific staff and to our senior managers. We are beginning to set in place joint appointments with certain universities for those of our scientists who have a track record of collaboration with particular research teams. Not only does this academically validate the scientists themselves but it also allows us to reach out to undergraduates and put forward the benefits of neutron techniques for future generations. Researchers who have become Instrument Group Leaders have often had to sacrifice their research involvement to a significant degree. This is far from ideal and we are attempting to identify whether we can create the resources to attach a personal research fellow to each Instrument Group Leader so that their scientific life can continue to prosper.

Safety and security

Above all at the ILL, safety and security must be the highest priority. This has been emphasised in recent years by a strong push from the top to underline the importance of individual responsibility in this process. A culture change is underway. More staff resources have been devoted to these issues than previously. Training and refresher courses are now routine. Given the sensitive nature of our activities, any lapse in this area will be amplified out of all proportion in the public domain. Safety and security is being more deeply integrated into our culture such that it becomes second nature and therefore is not seen as a barrier but as an enabler to our work programme. Constant reviews of our safety procedures are being implemented, both internally and externally, including the very valuable *Exercices de Crise* which are organised regularly by the French authorities.

Public appreciation of our work

A weakness at the ILL has been the limited resources that could be set aside for public relations. We have never had, until recently, a press officer, having been able to assign resources only to scientific PR. Clearly the climate in society at large and on the political scene itself is changing, and the ILL, like any other top-flight scientific organisation, needs to promote itself in many different arenas, and to many different audiences. The scientific popular brochures are a successful example here and we will continue to produce these. Our efforts in this direction are being helped enormously by our partnership in EIROforum where we can pool resources, maximise our impact, share important

The Director Generals of Europe's major laboratories, EIROforum, meet Commissioner Potočnik in Brussels in April 2005

contact points and learn best practices, and at the same time optimise and enhance our visibility. The proposal to incorporate a 'public appreciation of science' drop-in centre within the new entrance structure will help to demystify our work to the local public, which is important for our long-term acceptance.

EIROforum

An initiative which has broadened the ILL's scope in recent years, has been the EIROforum partnership with the six other large European experimental science laboratories. The alliance now functions at many levels within the seven laboratories – ILL, ESRF, EMBL, CERN (European Organisation for Nuclear Research), ESA (European Space Agency), ESO (European Southern Observatory) and JET (Joint European Torus) – and is paying dividends in many areas. The sharing of operational experience and the exchange of information, particularly on science policy, both nationally and in Europe, is one obvious area. The ability to pool efforts at representative events ensures cost effective visibility. EIROforum's Outreach and Education Group has launched the exciting Europe-wide series of *Science on Stage* teaching festivals, which have had the unexpected effect of making the ILL more visible to national research ministries, which have then been more inclined to negotiate scientific partnership with the ILL. Best practices in human resources is also a lively topic, and a critique of the Researchers' Charter and Code of Conduct is being addressed in concert, rather than in isolation. Common initiatives in instrumentation are also facilitated by EIROforum. All these activities have engendered a politically-aware, more outward-looking attitude in the Institute, and they will be enhanced and continued.

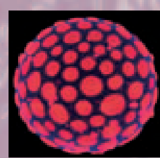
Timescales and costs

The capital cost of the proposals in this *Perspectives and Opportunities* document is estimated at 160M€ over the years from 2007 to 2016. Within our current projected budget envelope for this decade, about 100M€ of this sum can already be identified. We are optimistic that modest resources could be released as a result of our inclusion on the ESRFI Large Scale Facilities Roadmap for Europe, and indirectly via various national review recommendations of our Associates. Being on the ESFRI Roadmap will, of course, open up other doors. The attraction of further Scientific Partners will also help towards resourcing this landscape, as would the increased level of participation of current Scientific Partners. Finance for the joint site-infrastructure costs, estimated at 30M€, is being sought through the French *Contrat de Projets Etat-Région* (CPER). Annual operational costs are likely to rise by about 5M€ when the complete plan is implemented.

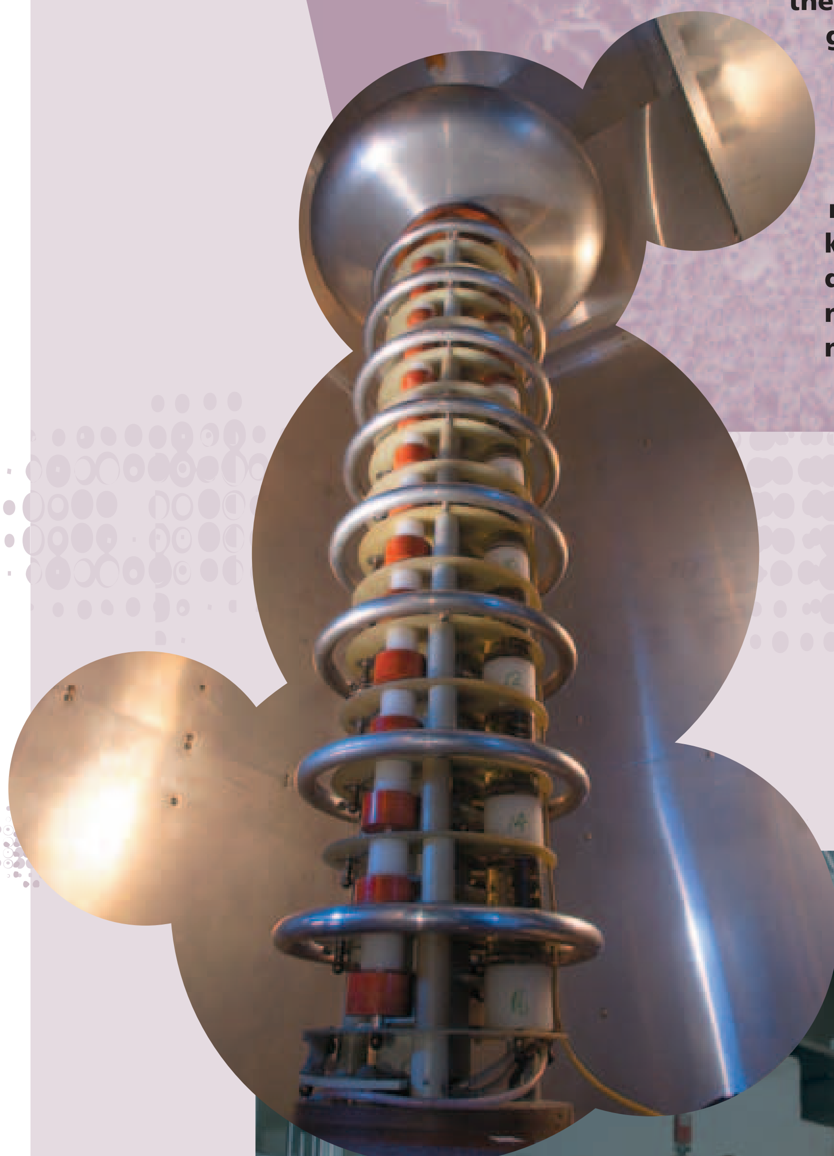
It is clear, however, that whilst the vision laid out here can be realised only by a concerted and dedicated effort by all parties, the scientific paybacks in years to come will far outweigh the effort and investment required.

Layout of the new ILL/ESRF/EMBL site

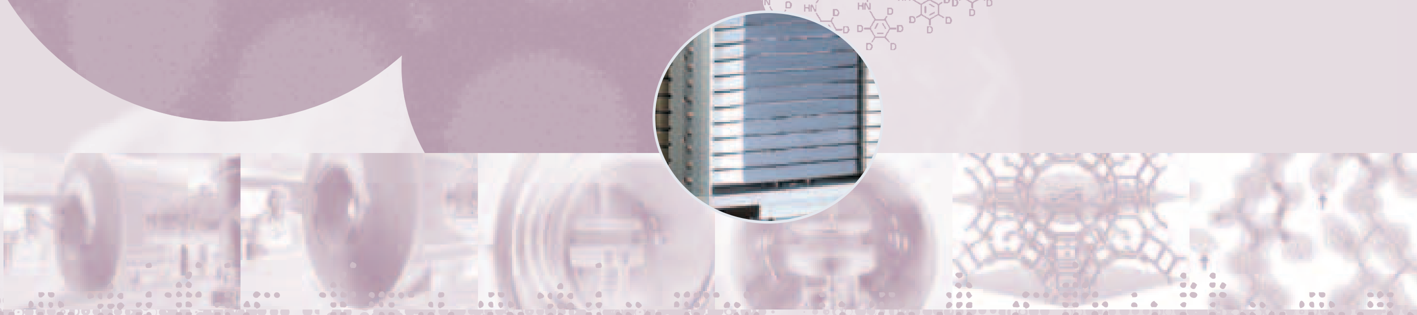
New scientific



Forty years ago, when the production of neutron beams for research into condensed matter was still an emerging technology, many of today's dominant questions in science – how did the building blocks of the Universe come into being, or how do genes control the basic processes of life – were just being formulated. Since then, developments in neutron scattering techniques have progressed hand in hand with the rapid advances in scientific knowledge, leading the way more deeply into traditional areas such as magnetism, molecular chemistry, materials science and biology.



frontiers and challenges



Thanks to an ongoing programme of technical innovation, the scope of problems that neutrons can tackle today has broadened dramatically, providing new kinds of information not available from other analytical methods. Neutron beams are now a key tool in emerging areas of science, and their fields of application, along with user demand, continue to expand.

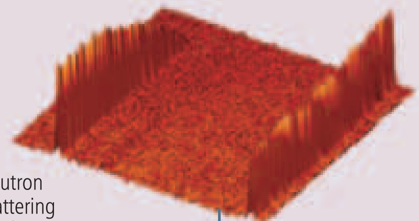
The fundamentals of Nature

At the fundamental level, scientists are benefiting from instruments able to offer neutron beams with tailored properties at increased intensity to understand quantum processes in complex materials. For example, beams of polarised neutrons are helping to unravel phenomena such as high-temperature superconductivity and ever more exotic magnetic behaviour – for applications in the next generation of communication and data-storage devices. New, improved polarised neutron techniques will take this work further, which ILL – already pre-eminent in this field – will capitalise upon.

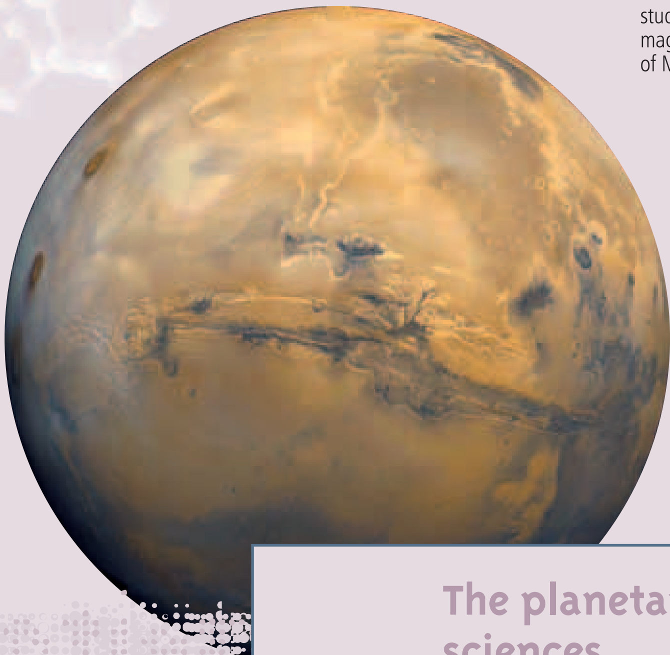
Unique experiments with ultra-cold neutrons are elucidating the relationship between fundamental forces, taking our understanding of Nature to a deeper level. Ultra-precise studies facilitated by more intense sources using new techniques may provide clues as to how the fundamental forces of nature such as gravity came into being.

The complexity of the everyday world

Neutrons are proving to be one of the most powerful probes of everyday matter, which in many cases exhibit intricate or irregular structures, or can contain mixed phases or simply impurities – for example, washing-up liquids, cosmetics, paints and other consumer goods. Neutrons are now applied to areas as diverse as oil prospecting and archaeology. Experiments can be carried out under extreme conditions of pressure, temperature or magnetic field that simulate situations in a realistic context. The behaviour of polymers in the process of being extruded or sheared can be observed in real time, which is important in optimising production methods. Complex materials used in energy-producing devices such as fuel cells are now of key interest to society as we seek supplies of energy to sustain us in the 21st century, which are both environmentally friendly and cheap. The most complex systems are, however, still to be found in biology, and the ILL is now a leader in applying neutron techniques to the life sciences thanks to the opening of the Partnership for Structural Biology within the new Carl-Ivar Brändén building (p A.35) in January 2006.



Neutron scattering has been used to study the magnetism of Mars



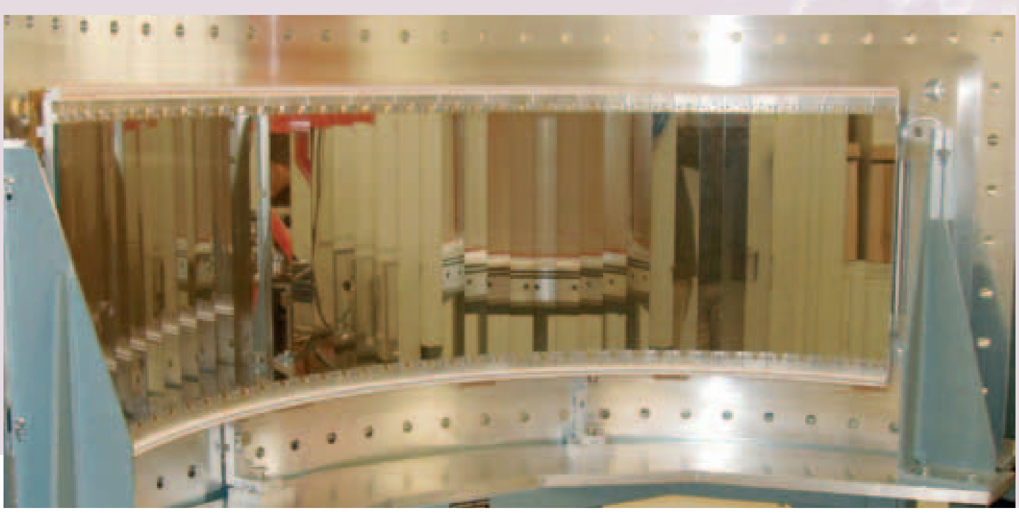
1

The planetary sciences

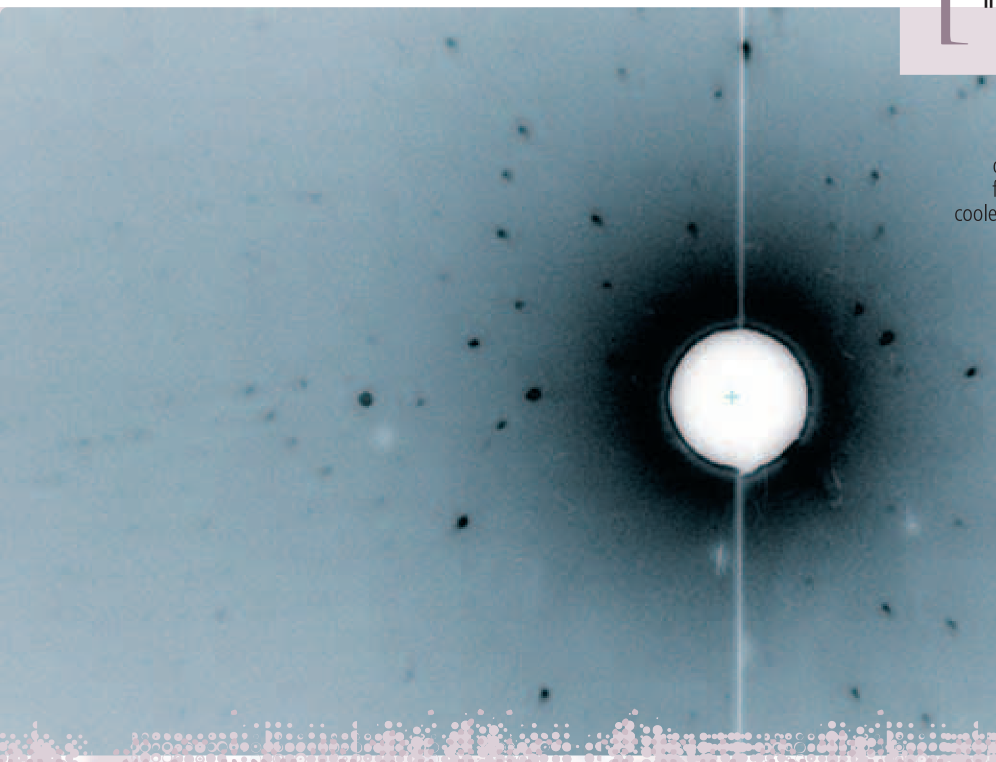
Understanding the interior of the Earth (and that of other planets in the Solar System) is a huge challenge, but is necessary to gain a deeper insight into hazards such as volcanic eruptions and earthquakes. Neutrons play a key role: because of their high penetrating power, they can detect details of rock composition and structures in massive samples, or can address questions related to the behaviour of magma at high temperatures and pressures. The methods used include neutron diffraction, along with neutron imaging and tomography.

Neutron methods are employed to investigate the microscopic crystallites comprising rocks, and the structure of frozen materials – not only on Earth but also on other planets, moons and comets in the Solar System. The data obtained can then be used as input to help define the goals of future planetary space missions. Studies of the crystallite texture and porosity of rocks reveal many of the processes underlying geological evolution: the formation and movement of rocks, the flow of fluid through rocks, and the freeze/thaw cycles of water in rocks. Experiments using magnetic neutron diffraction have now put forward an explanation for the disappearance of magnetism on Mars caused by the impact of huge meteorites on the Martian surface.

More recently, the ILL is collaborating in a programme to investigate the interior of Jupiter and its moons, Io and Ganymede. Powder diffraction instruments such as D20, D2b and the neutron tomography instrument have already produced remarkable data. Conditions prevailing in planetary interiors can be studied by analysing minerals at high temperatures and pressures in the laboratory. Neutron experiments can be routinely carried out at pressures of 5 to 8 gigapascals, which is about half that of the Earth's upper mantle. The ILL is planning to construct a new instrument – DRACULA – dedicated to small samples under extreme conditions of pressure and temperatures.



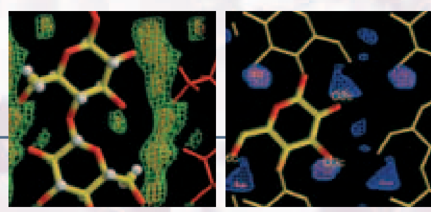
DRACULA will measure samples under extreme pressures and temperatures using the latest ILL detector technology



A neutron Laue diffraction pattern from a large cryo-cooled concanavalin A crystal at 15 K

Crystals of Gamma B crystallin observed with a microscope in the Deuteration Laboratory

2



The health sciences

Fields related to human health – medicine, biotechnology and food science – have been transformed by recent advances in molecular and cell biology, and in genetics. Neutron methods are playing a central role in this revolution because they can trace the location and dynamics of hydrogen atoms embedded in biomolecular assemblies over a wide range of length scales – macromolecules, cells, membranes and artificial structures. Such studies allow scientists to better address the important health challenges of our age such as designing effective drug-delivery agents, improving foods, tackling the problems of ageing, and devising new tools such as biosensors for medical diagnosis. Equally important, materials for implantation – ranging from teeth to joints – can be studied, feeding back into the initial definition process of such bio-compatible materials.

One important issue in neutron science is obtaining crystals of biological samples that are large enough for diffraction studies. A new approach for diffraction which involves polarising the protons (the hydrogen nuclei) in the sample will, when successfully developed and implemented, take neutrons into a totally different regime – allowing high-signal, low-background measurements to be carried out on very small crystals. Such studies will be truly complementary to using synchrotron sources such as the ESRF.

All these studies, however, require intense neutron beams not only for small-angle neutron scattering and reflectometry experiments but also for diffraction measurements (p B.5). The ILL is proposing instruments that will provide the necessary neutron flux to carry out such experiments. A new horizontal surface reflectometer FIGARO is currently being built to study the functioning of cell membranes – how drug molecules can be transported across these membranes and how cell walls can be protected against viral attack. New small-angle neutron scattering instruments will allow us to elucidate the formation of the proteinaceous structures called amyloids which are implicated in age-related disorders such as Alzheimer's disease.

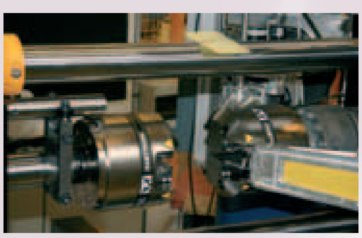
In the field of food science, more accurate structural studies of enzymes, which control many digestive processes, require the use of diffractometers which provide higher resolution, such as the new Laue diffractometer LADI-3 currently under construction.

All of the ILL's reflectometry instruments can be used to investigate, for example, biosensors – membranes grown on artificial surfaces having a soft polymer cushion as a seed layer. The technological challenges here can be addressed with neutron methods being developed at the ILL.

3

The engineering sciences

Modern construction schemes are evolving to become more efficient, less energy-consuming and more environmentally benign. Transport also has to meet important challenges such as high capacity, high energy-efficiency, high safety standards and low environmental impact. Neutron diffraction and radiography are ideal tools for designing and evaluating the materials for new buildings and engine components. Internal stresses in key parts, such as turbine blades, aircraft wings, irradiated components of fission or fusion reactors, railway wheels or tracks, are determined with ILL instruments and compared with the results of numerical simulations and fatigue tests.



Neutron strain-imaging equipment for examining stresses in engineering components

The resistance of construction materials to water corrosion or absorption, as well as the effectiveness and durability of lubrication, can be probed by exploiting the sensitivity of neutrons to hydrogen atoms in water, solvents and oils: neutron tomography experiments (p B.31) reveal the details of how fluids move through micro-channels in materials, from plants to sandstone, and can also gain access to the time-scales involved. The penetration of drugs through skin, administrated by patches, can also be addressed.

Researchers are developing increasingly advanced materials for highly specialised tasks, from robotic arms and artificial muscles, to photosensitive devices at the molecular scale. The ILL's neutron scattering instruments constitute powerful tools for optimising the performance of materials via systematic studies of their properties, and observing how these materials behave in real time, particularly during processing. As the emerging nanotechnologies increasingly exploit bio-materials to create devices on an ever smaller scale, advanced neutron methods will be more and more in demand.

Increasingly, neutron methods which aim at imaging large objects, or mapping subtle metallurgical features, are coming to the fore. Neutron-transmission techniques, combined with finely pixellated, high-count rate, large-area detectors can reveal the smallest defects in large-scale engineering components. The technique of neutron tomography is rapidly becoming the method of choice for tracing the interiors of structures containing light elements, not easily seen with X-rays. This is possible today thanks to the rapid advances in computing power, thereby enabling previously unwieldy mathematical algorithms to yield instant 3D images. Improved detectors, combined with dedicated large cross-section beams, will enable a rapid growth in these kinds of neutron application.

High-resolution powder diffraction is used to analyse polycrystalline materials

Materials for energy production, transmission and conservation

The search for cleaner and more efficient methods of generating and conserving energy is becoming ever more urgent. New materials and methods of storing energy from sustainable sources are vital, as well as methods of minimising energy consumption in industry, in transport and at home. Worldwide research encompasses new sources of clean energy – devices to deliver power remotely – (the hydrogen-based economy, fuel cells and both classical and high-performance batteries) and new methods of conserving energy by optimising industrial processes, improving vehicle efficiency, and reducing heat loss in buildings.

Neutron diffractometers provide the means to study many of the underlying phenomena *in situ*. small-angle neutron scattering measurements (p B.5) can follow changes in the structure of novel lighter, stronger materials for engines (superalloys, ceramics and polymers) in real time during heat treatment or manufacture. Advances in the design of new engines can be made by imaging the defects within such structures using 3D neutron tomography in real time; such programmes benefit from the ILL's high-flux neutron beams, with their intrinsic high stability and high spatial resolution. The behaviour of lubricants in real conditions, or the combustion of fuels, can also be studied with small-angle neutron scattering and tomography experiments.

4

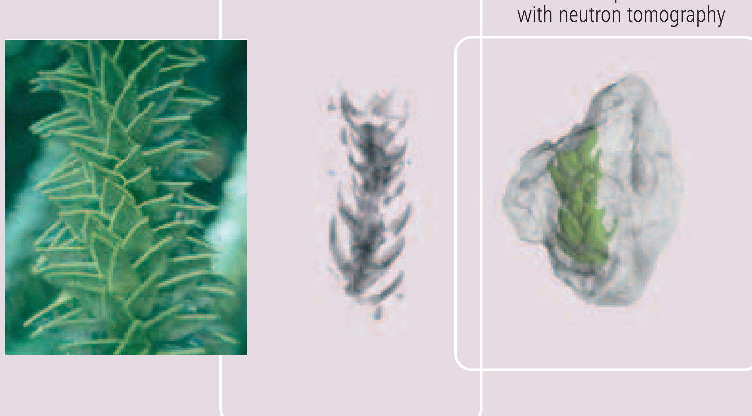
Our cultural heritage

One of the most fascinating and newest applications of neutrons is in archaeology and palaeontology. Neutrons can delve inside an artefact or beneath the surface of a painting without damaging it, and establish its structure at the microscopic scale, thus providing crucial information needed for conservation or restoration. An object's interior can be imaged using neutron tomography and its composition analysed through neutron-induced gamma activation; details of its microstructure can be observed via diffraction experiments.

Neutron absorption and tomographic techniques currently achieve an impressive spatial resolution around 50 micrometres. The texture in high-tech components, often linked to the local tensile strength of a material, can be determined with small-angle neutron tomography (p B.31). New opportunities in this field will emerge when the proposed small-angle tomography instrument is built on the third cold neutron source at the ILL. Geological fossils, stones and human artefacts are currently studied with ILL instruments, and further programmes requiring better contrast and higher resolution will develop in the future as elements of the *Perspectives and Opportunities* plans are put in place. In particular, conservation programmes for buildings and sculptures will exploit the peculiar neutron sensitivity to hydrogen in water and other solvents to investigate the effects of porosity and the migration of water, with the aim of developing surface or volumetric treatments to prevent erosion.

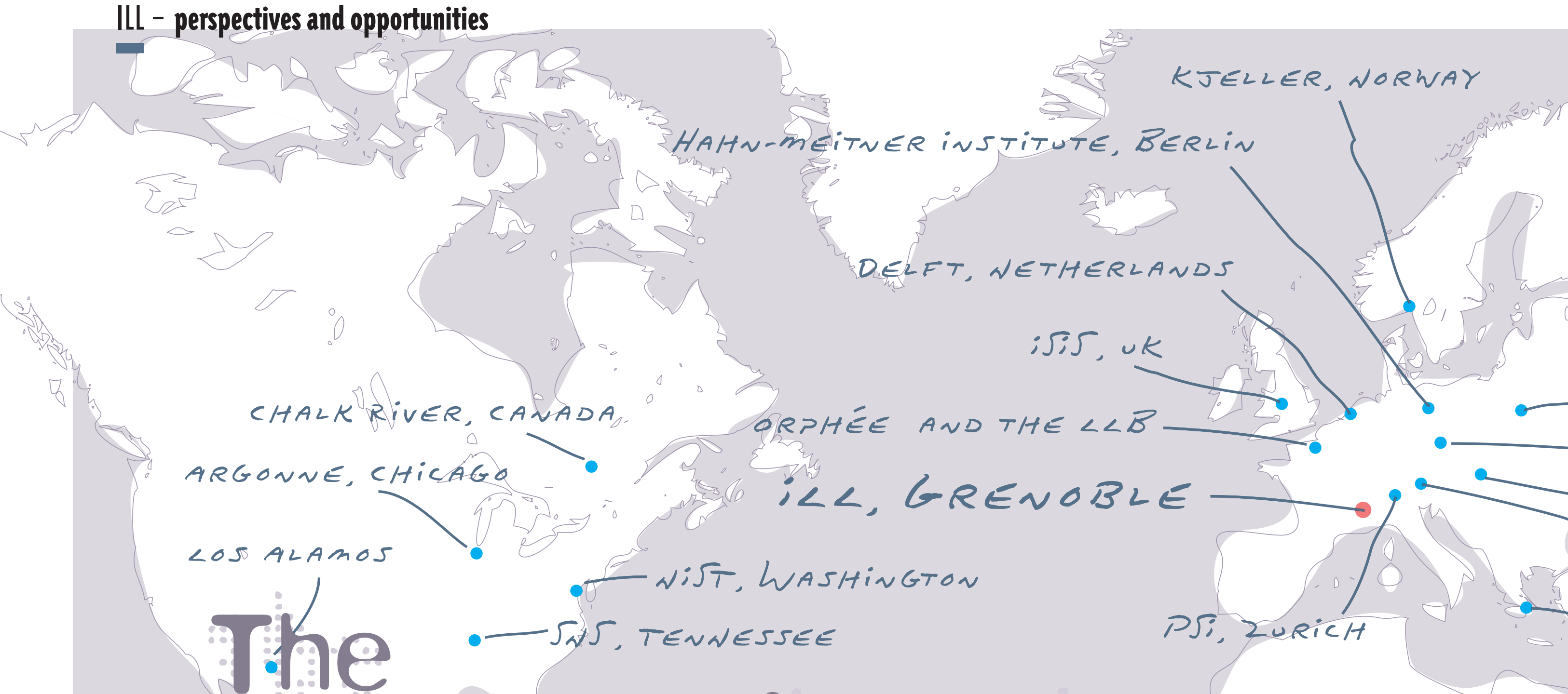
By identifying the microstructure and the crystal type of materials used in ancient artefacts such as ceramics, metal tools and ornaments, or fossils, it is possible to discover where they came from and gain an understanding of the technology used to make them. Future dedicated instruments at the ILL will offer the highly focused and intense neutron beams required to carry out such research programmes.

We have highlighted here but a few emerging applications of neutron scattering. As the technique becomes more powerful, more widely-known and more user-friendly, and boosted by the partnerships in the course of being set up (p A.34), new applications will continue to appear.



A fossilised plant as seen with neutron tomography

Future applications



The neutron landscape

For more than 30 years, the ILL has set the standard whereby all other neutron sources worldwide are judged. This is still the situation today. But will it be so in 10 years' time – or even in 5 years? For the first time, the ILL has serious competitors and if we are to remain in a world-leading position we have to constantly re-invent ourselves.

The European position

A snapshot of scientific output from work done at neutron facilities around the world, as measured through publications in the highest impact journals, reveals that the ILL leads its nearest rivals – the NIST Center for Neutron Research in the US, the pulsed spallation neutron source ISIS in the UK and the Laboratoire Léon-Brillouin (LLB) reactor facility near Paris – by a factor of two. The story was the same 5 years ago and interestingly, on the same measure, the output of our sister facility, the ESRF, is similarly world-leading.

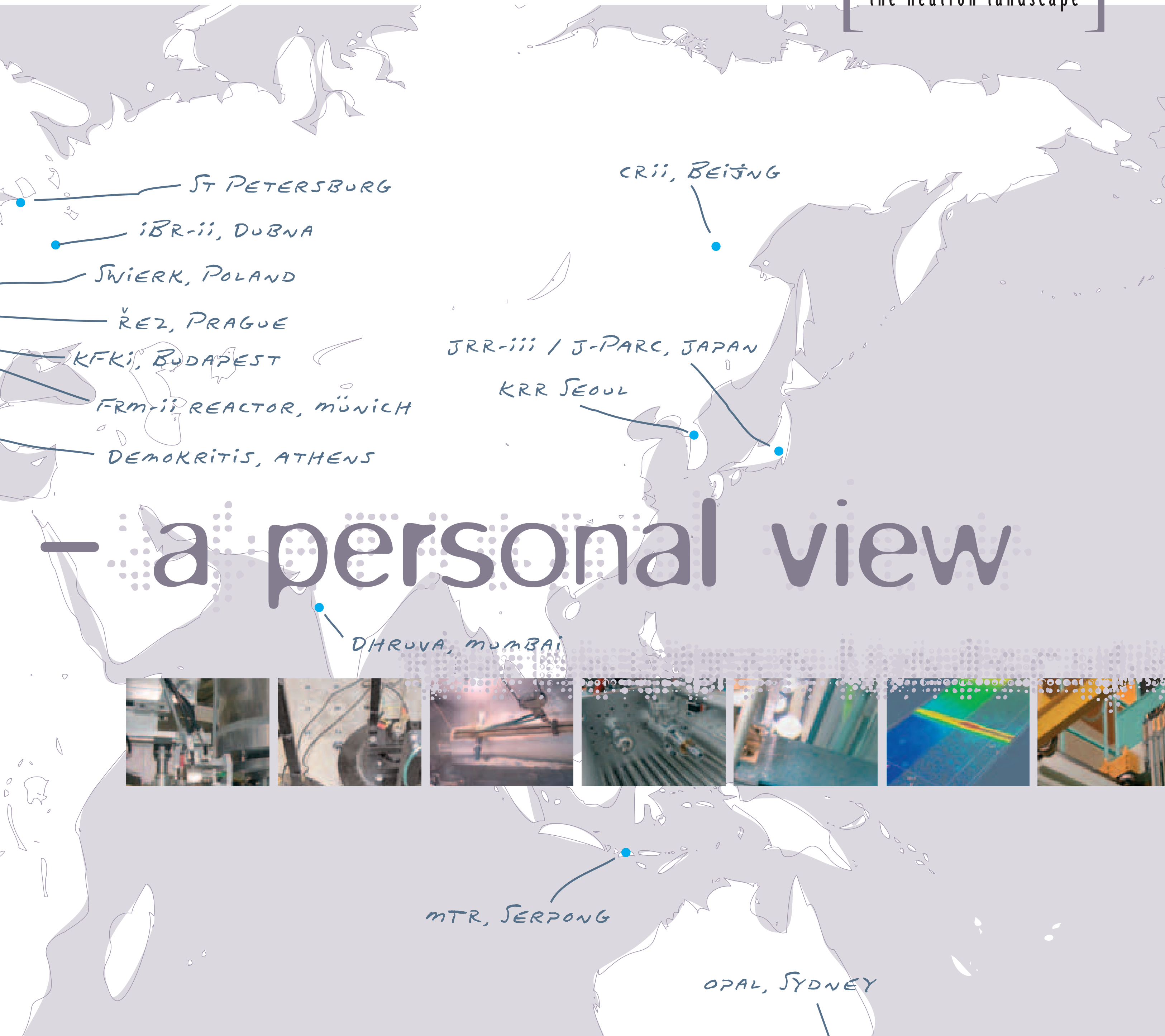
The reason why Europe leads the world in this area is however not simply because of the ILL, ISIS and the LLB, or because of the new FRM-II reactor in Munich and the Hahn-Meitner Institute reactor in Berlin, but because of the large network of neutron sources, small and large, located across Europe. Without facilities such as Delft in the Netherlands, Řež in the Czech Republic and Świerk, Europe's neutron landscape, and its wide user-community, would be significantly poorer. In the Americas and the region around the Indian and Pacific Oceans, there is not the distribution of neutron facilities to rival those in Europe, although there is a clear danger that our lead could be eroded in the near future.

The European user-community today is healthy – involving about 5000 active researchers – but the situation in the rest of the world is less sanguine – with maybe 1000 researchers each in the Americas and around the Pacific, and somewhat fewer on the Indian subcontinent.

But with the attraction of new sources outside Europe, ready to come on line soon, the situation is changing. We would expect to see a significant rise in the user community over the next 5 years in North America as the Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory in Tennessee (ORNL) begins to operate and, slightly later, a similar rise in the Pacific region, as the J-PARC facility, 100 kilometres north-east of Tokyo in Japan, and the Opal reactor near Sydney in Australia are fully commissioned and instrumented.

A sensitive issue, nevertheless, is the question of the day-to-day reliability of accelerator-driven neutron sources. Reactor sources are significantly more reliable than pulsed spallation sources but we expect to see distinct improvements here with the new purpose-built sources.

– a personal view

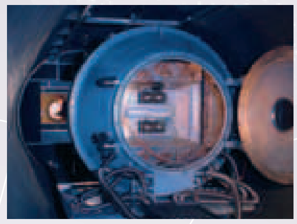


Turning to scientific applications, we are witnessing a broadening-out of disciplines – archaeology, planetary and environmental sciences, and so on (p A.14) – which are able to obtain unique information by taking advantage of neutron techniques. It must be emphasised, however, that the high-profile demonstration experiments carried out in these very attractive, emerging areas still need to be converted into really solid user bases.

Finally, when considering the situation which might exist within the next 2 or 3 years, the return of the ILL to full 224-day operation in 2008, following the completion of the Refit Programme, will provoke a significant rise in output. In terms of experiments carried out, user numbers, proposals and, somewhat later, high impact publications, the real effect of the Millennium Programme (p A.24) will begin to kick in and create a major impact.

The scenario in 2010

The most noteworthy event in the next 5 years will be the first years of operation of the SNS at Oak Ridge. Currently, it is not known whether the SNS can sustain full design power (1.4 MW) with its mercury target. A reasonable scenario would therefore be for the SNS to be operating relatively reliably at 500 kW in 2010, with seven to 10 instruments commissioned or being commissioned. At this performance, the source would be twice as powerful as that of ISIS, although with less than half the number of instruments operating. Scientific output would be rising and the user community would be growing, attracted by a brand-new facility



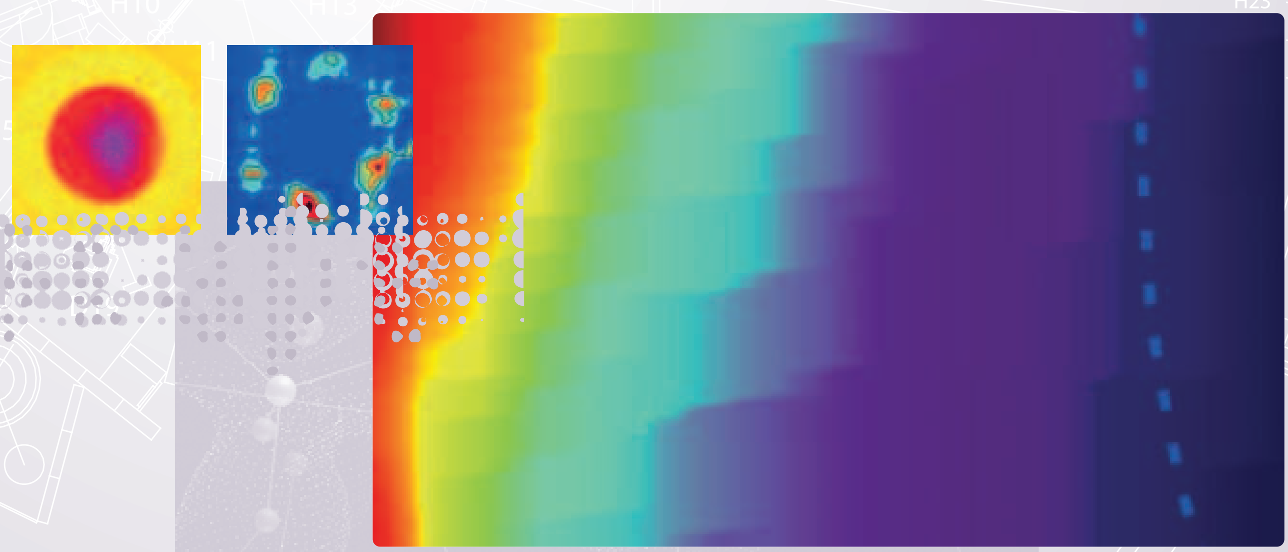
surrounded by well-appointed interface laboratories. It is unlikely that there will be extensive European use of the SNS, except by specialist teams who choose to build instruments there or to station scientists there permanently.

The early years of the SNS will certainly see many 'curiosity-driven' experiments undertaken by high-profile European users, but this is unlikely to be sustained because of the relative inaccessibility of the location. In the other direction, the use of the ILL by American researchers is likely to remain close to the current level since demand is high and use is capped, and furthermore, the ILL's instruments are complementary to those on the SNS.

The commissioning of the spallation neutron facility within the J-PARC accelerator complex will follow in 2008 but probably rather more slowly than the SNS, given the increased power per proton pulse which the target will have to withstand because of J-PARC's lower operational frequency. By 2010, J-PARC will probably be operating at the current power levels of ISIS (160 kW) with, say, five instruments operational. The European use of J-PARC is likely to be marginal and centred on technical developments or personal scientific collaborations. The bringing online of such a facility is, however, bound to have a significant impact on how neutron scattering is viewed worldwide. A similar story will apply to the Opal reactor in Australia which will be operating a full user programme by 2010, even though it will be furnished with a limited instrument suite.

In 2010, ISIS will be routinely operating its second target station, which concentrates upon cold-neutron instrumentation, with a power level of 30 to 40 kW and perhaps seven instruments functioning. The overall ISIS scientific output will increase thereafter, especially as power levels are lifted and the instrument suite is increased in number.

In 2010, the new FRM-II reactor in Munich will be running a full suite of instruments, strengthened both technically and scientifically by the transfer of instruments together with their long-term know-how from the Forschungszentrum Jülich. The scientific output should be rising towards the current level of the LLB Saclay in France. The presence of FRM-II will significantly strengthen the German user community and might, in the early years, affect the German use of the ILL, but by 2010 any perturbation will have recovered as the German community expands.



The ILL will not have stood still either. Investment in the Millennium Programme will have continued at least at current levels and, it is hoped, higher. The number of operational days will be 224 per year, and the total number of public instruments will have increased to 30 together with 15 CRG instruments. Between 2000 and 2010, a gain in instrument luminosity over the whole public instrument suite of at least a factor of 20 will have been achieved. From 2008 onwards, scientific output in terms of high impact journal papers should therefore start to increase.

In 2010, the situation with the proposed European Spallation Source will surely have crystallised. The most likely scenario is that the original concept for the facility – two targets with different characteristics – would be split between two different sites. A long-pulse source, initially 1 MW but upgradable to 5 MW and perhaps higher, would be built on a green-field site, while ISIS would be lifted-up to a 1MW short-pulse source. Such a positive scenario would maintain the network of quality neutron sources in Europe but, inevitably, some of the smaller reactor sources will eventually close.

The scenario in 2015

A decade from now, the SNS will have attained its design intensity and will be fully instrumented and supporting a user community of perhaps 2000 researchers, mainly of North American origin. European use will be either via particular CRG-like instruments (for example, neutron spin echo, p B.30) or by personal collaborations, and will not be significantly high. Its scientific output will have reached that of the ILL today, but by then ILL's scientific output will have risen by 50 per cent. ILL and SNS will be setting the standard.

A certain number of small reactors will have closed down, but FRM-II will have a flourishing scientific programme. A question mark must rest on whether LLB will still be operating in 2015 because of recent funding uncertainties, although technically this is not a limit.

The situation at ISIS will remain healthy. The second target station will have demonstrated beyond any lingering doubt the capacity of pulsed sources to generate cold neutrons. Most probably ISIS will have begun to implement the 1 MW short-pulse option for the ESS but it will not deliver neutrons until later in the decade. The SNS will, if its operations in the decade from 2005 to 2015 are successful, be building a cold neutron, second target station ready for operation in 2020.

The European Spallation Source project(s) will be well into the construction phase(s) by 2015. Most probably it will have been decided to build a 1 MW short-pulsed source at ISIS and a 1 to 5 MW-long-pulse source on a green field at one of the current site contenders. First neutrons would be expected for 2018 and full specification operation will follow only 5 years later, at the earliest. At that point, the OECD recommendation for a new high intensity neutron source in each of the major regions of the world will have been achieved.

The ILL should then have fully implemented the upgrade programme covered in this document and will have operated for 40 years. Its scientific output will have increased and its user programme will have diversified. Any decision about its future operability will depend greatly upon the situation with the European Spallation Source. It will be appropriate between 2015 and 2020, to consider the options for the ILL's future, but not before. Whether ILL continues to operate for a sixth decade will depend critically on whether its scientific output remains high, its quality first-class, its user community vibrant and innovative, and it is still cost-effective and environmentally acceptable. If the opportunities outlined in this document are seized upon and implemented, continued operation of the ILL will be difficult to argue against.

The key reactor

The production of our neutron beams is founded on a high power-density nuclear reactor – a technology that supplies much of Europe's electrical power, but nevertheless has negative associations in the public's mind


Looking down into the ILL reactor

Refit Programme – safety and risk assurance

The ILL's nuclear inventory – a single-element core containing 9 kilograms of fuel – is less than 1 per cent of that of a power reactor. Nevertheless, safety is a vitally important issue for us, and we recognise that the public both needs and deserves to be reassured that the ILL's reactor will be managed safely in the extremely improbable event of a serious accident, a large-scale earthquake, or even a terrorist attack.

Following the regular 10-yearly safety review of the ILL's reactor – the so-called *Groupe Permanent* – which took place in May 2002, we have engaged in a wide-ranging set of reinforcement and renewal activities over the whole of our nuclear installations. This programme of work – the Refit Programme – has been agreed to and closely monitored by the nuclear-safety authorities in France. It ensures that the ILL's installations meet the most stringent standards required to contain the consequences of our design accident in the event of a possible earthquake.

In addition, the Refit Programme enables us to minimise operational breakdowns, be they conventional or nuclear. The Seismic Refit Programme, which will cost approximately 30 M€ including staff, has been ongoing since mid-2002 and will be completed in 2007.

It has included the following tasks:

- Reinforcement of the building housing the reactor – a sealed double shell of concrete and steel sandwiching a pressurised annular space, together with the strengthening of adjacent buildings, constructed to a standard that would withstand an earthquake of magnitude never historically experienced in Grenoble or the surrounding geological plates;
- Establishment of operational and command-control systems that would ensure that all emergency-shutdown protocols and essential equipment would operate unperturbed in the case of such an earthquake, a severe malfunction or an extensive fire;
- Assurance that the supply and storage of our fuel element, from its point of manufacture, to its use to generate neutrons in the reactor core, and on to its delivery for reprocessing, is securely managed;
- The total revision of all emergency response protocols, together with an emphasis on staff

components

training and awareness through regular crisis scenario exercises;

- The vacuum vessels for the guides have been replaced following a total renewal of the damaged front ends of the 11 major guides and the implementation of strengthened diaphragms as the guides cross the double reactor-shell.

This process is managed by the Refit Management Committee and advised by an external Expert Advisory Committee. Frequent formal and informal meetings with safety authorities ensure the validity and integrity of our plans.

Further upgrades to neutron delivery and infrastructure

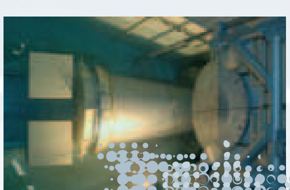
The ILL's reactor is extremely reliable – on average there have been fewer than two unexpected interruptions to the delivery of neutron beams per year over the past decade. The reactor itself was designed to be replaced as individual modules, according to life-time indicators of all major components. The vessel itself was totally renewed in 1995, and the beam-tubes and moderators undergo a regular process of exchange.

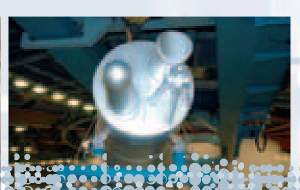
However, to ensure that the facility is always operational under optimal conditions and remains reliable in the long term, it is proposed within this *Perspectives and Opportunities* document that each and every key reactor component, and the beam-delivery systems, will be upgraded continuously rather than reacting to the findings of a 10-yearly review. Our aim is to deliver about 9000 instrument-days a year for science, by operating four cycles of 56 days at 58-MW power each year. In order to underpin this operational goal, specific tasks have been set within the proposed Key Reactor Components Programme.

- An upgraded fuel element will be developed which will lengthen the reactor cycle to 56 days at full power, thereby delivering 224 days of operation per year from 2008 onwards; cost-savings and operational convenience will result from this mode of operation.
- The purification of the ILL's heavy water is carried out in a purpose-built detritiation facility. The chemical processing plant of this facility has been upgraded but the integrity of its buildings against the consequences of an earthquake – which could include a hydrogen fire – needs to be totally re-examined and further secured.
- The two cold sources will be renovated, and the ultra-cold neutron source will be redesigned and relocated to generate neutron densities a factor of 50 higher than at present. A third cold-source will be installed.
- Many of the neutron guides are reaching the end of their operational life. Neutron guides were an initiative that put the ILL in a class apart from other neutron sources. A modest renewal programme was started in the early years of the Millennium Programme but this must be continued urgently since signs of damage and intensity losses are becoming increasingly evident.
- One hundred kilometres of original cabling – the coating of which is becoming porous and which carry essential control signals for the reactor – will be renewed or, where possible, replaced with wireless technology.
- A total evaluation of the reliability of structural instrument components will be carried out, particularly where the integrity of the beam tubes is threatened in the event of an earthquake.
- A full quantitative evaluation of mechanisms for the eventual decommissioning of the reactor and associated installations at the end of its operational life.

In addition, refurbishing the working environment is essential to maintain staff and user productivity and the precision of the instruments. Air-conditioning will be incorporated as new buildings are constructed and renovations carried out. Old buildings will be solar-protected where climate control is not cost-effective. Increased standards of cleanliness, improved and secured access to the instrument halls and other parts of the site, as well as enhanced safety procedures, will make everyday life at ILL more productive and secure.

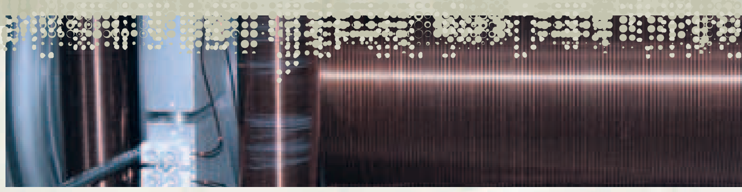
The Key Reactor Components Programme would start in 2007 and would require a capital investment of 39 M€.





The Millennium Programme – past present and future...

The Millennium Programme – begun in 2000 and still ongoing – was conceived as a continuous programme to foster a sustainable strategy for upgrading the ILL's instrument suite and its neutron infrastructure. Its aim was to incorporate the latest technical advances so that new ideas and techniques in neutron science could be capitalised upon, and the power and reliability of the neutron source could be fully exploited to produce the highest-quality science.



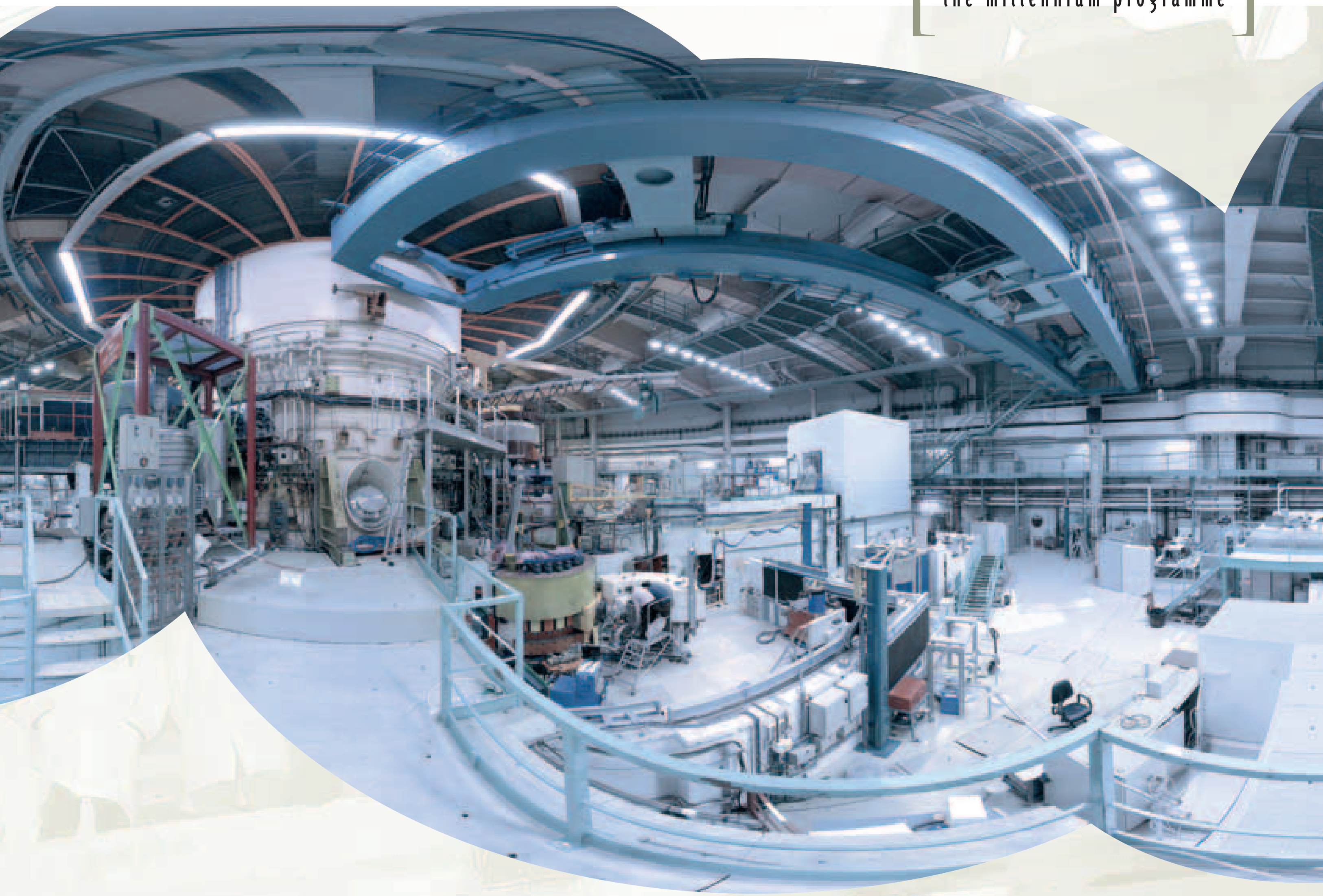
A foundation for science

The ILL's Millennium Programme was launched in January 2000. It was guided by a Roadmap published in April 2001 which framed the necessary developments for the decade 2000 to 2010 required to maintain the ILL in its leading position in neutron science. The overall investment foreseen at the time was 88M€. The rate of investment and development has been slower than required, with approximately 30M€ having been devoted to this goal in the past 6 years.

Following its launch, the Millennium Programme's first task was to complete the five instrument upgrades still underway from the mid-1990s. A cross-Divisional project management structure was put in place – the Millennium Programme Management Committee – to manage the work. This was a novel concept for the ILL.

These upgrades have been completed and are now delivering high-quality science:

- The Liquids and Amorphous Diffractometer **D4** with its extended microstrip detector is now five times more intense and 10 times more stable than its predecessor, and is able to address the most sensitive scientific problems in liquid or glassy structures.
- The performance of the Low Momentum Transfer Spectrometer **D16**, a unique instrument, was significantly enhanced with a focusing monochromator and a 2D microstrip detector for the study of biological membranes or intercalated materials.
- The Vertical Surface Reflectometer **D17**, is the first such purpose-built instrument within the ILL's suite, and was designed to be very intense, and as flexible as possible in terms of resolution and modes of operation.
- The primary spectrometer of the cold neutron instrument **IN5**, a real flagship which has set the standards for other instruments worldwide, was totally renewed, providing gains of between 10 and 15 depending upon the energy of the incident neutrons.
- The triple-axis spectrometer **IN8** has been totally rebuilt, in partnership with CSIC Madrid, and incorporates a high-brightness virtual source and a novel triple-faced, large area focusing monochromator.



In parallel with these projects, a new 1600-element microstrip detector was installed on the powder diffractometer **D20**, together with a focusing monochromator, and the **IN4** thermal time-of-flight spectrometer was fully rebuilt as a collaborative project with INFM Italy.

Instrument advances

In order to deliver these instruments, additional impetus was given to underpinning advances in neutron-instrument components. This has always been one of the ILL's strengths. These areas include:

- Cost-effective high-resolution and high-count-rate area detectors;
- Focusing monochromators with tailored crystalline properties for higher luminosity;
- Advanced technologies for producing and manipulating polarised neutrons;
- State-of-the-art sample-environment facilities enabling new areas of science to be embraced;
- A totally new concept for instrument-control and experiment-management.

These reinforcements to our technical development activities are paying dividends in the current phases of the Millennium Programme and provide a foundation to build even more powerful instruments. However, they need to be clustered together for greater effectiveness. This is the aim of the Advanced Neutron Technologies Centre (p A.36) mentioned in this *Perspectives and Opportunities* document. The externally visible part of the Millennium Programme has been, and remains, the rebuilding of the whole instrument suite to the highest standards, with the incorporation of the technological advances alluded to above.

Completed upgrades

The Millennium Programme was launched with the start of five upgrade projects, all of which are now completed:

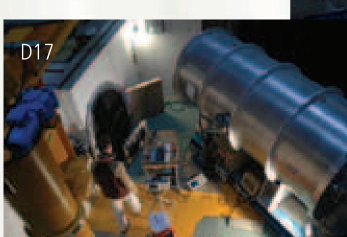
- **VIVALDI**, developed in partnership with the EMBL, is a compact diffractometer which uses an image-plate detector for single-crystal structural studies using thermal neutrons, building upon the experience gained with its cold neutron, sister instrument LADI. VIVALDI is particularly powerful for the rapid mapping of diffraction space where phase transitions in magnetic materials can be monitored.

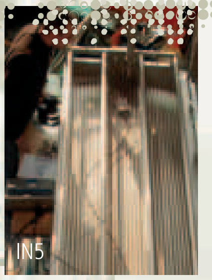
- The strain-mapping of engineering components has come of age with the construction of **SALSA**, with its unusual hexapod sample table, built in collaboration with Manchester University.
- Data-rate limitation have been totally eliminated for the **D22** small-angle scattering instrument by the development of a 2D array of position-sensitive detectors. The maximum data flow has been increased by a factor of 40.
- The hot-source single crystal diffractometer **D3** has been totally rebuilt, employing neutron techniques developed in-house, notably the CRYOPAD neutron spin controller (p B.30) and polarised helium-3 spin filters (p B.28). Very complex magnetic structures can be precisely and unambiguously determined.
- The classic three-axis spectrometer **IN20**, which uses polarised neutrons, has been reconstructed from the beam-tube to the detector, again using the virtual-source technique and a 2D focusing Heusler monochromator, also built in-house. An order of magnitude gain in intensity has been achieved accompanied by a 50 per cent wider energy scan.

Further instruments were added one by one after discussion and prioritisation at the Instrument Sub-Committee, the Scientific Council and subsequent agreement by the Steering Committee:

- A total rebuild of the **D7** spectrometer for polarisation analysis has been achieved, turning a demonstration technique into a powerful user instrument and opening up new scientific applications. The extensive and impressive array of polarising supermirrors (p B.28) has been the key to improving the count-rate by a factor of 35.
- Building on the D22 technology, the high-resolution powder diffractometer **D2b** has been furnished with a 2D detector and 128 Soller collimators, significantly improving both signal and background. A new monochromator will complete this instrument, which is well-suited for kinetic studies of chemical reactions.
- The **Lohengrin** mass spectrometer, which uses fission foils to generate exotic short-lived nuclei, has been upgraded to allow coincidence gamma-spectroscopy at the stopping point of the instrument. This has transformed the utility of this machine, allowing precise information to be captured about the characteristics of unstable nuclei which participate in the nucleosynthetic pathways that lead to the creation of the heavy elements in the Universe.
- The fibre and single-crystal diffractometer **D19** measures in the spatial range applicable to


IN8


D17



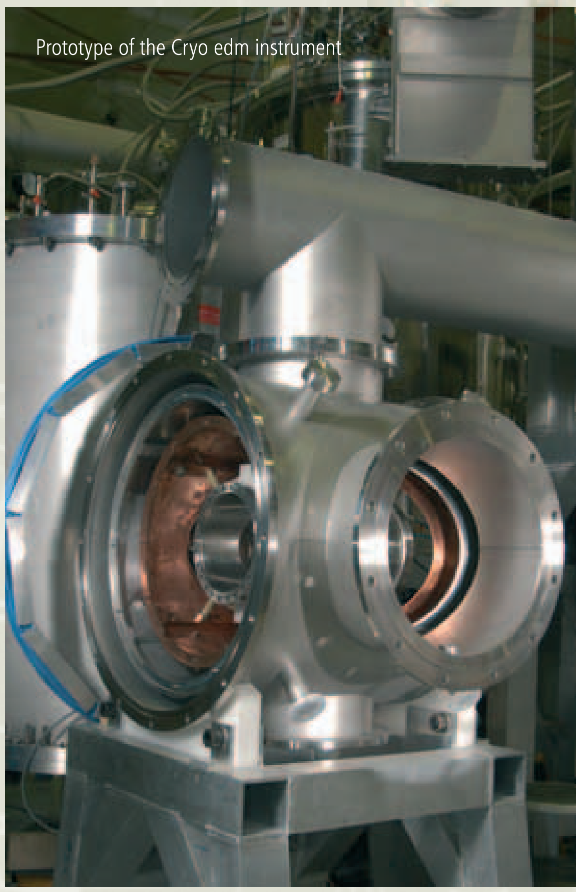
complex chemical structures and bio-fibres such as cellulose and DNA. The development and installation of a very large solid-angle, 2D area detector and an upgraded monochromator, in collaboration with the University of Durham, have made the instrument 20 times more powerful.

- Multi-analyser systems for three-axis spectrometers have never reached full maturity. However, the integration of a 31-element, so-called flat-cone geometry analyser onto **IN20** has created the ability to measure excitations in a 3D volume with unprecedented speed using small samples. This technique is applicable to all of the ILL's three-axis machines.
- Following the development of backscattering methods at the neutron facilities in Munich and Jülich, the ILL installed the first user-instrument IN10 with resolutions below 1 microelectronvolt. Twenty years of scientific dominance resulted in the field of neutron spectroscopy. The ILL's lead has now gone, and a totally renewed **IN16** spectrometer is being designed and built using a high-efficiency phase-space transformer to be located on a high-intensity cold beam.
- The **IN5** multi-chopper, cold neutron spectrometer has been unsurpassed for many years for studying low-energy dynamics. However, this position was being eroded by developments elsewhere. In the first phase of the Millennium Programme, the primary spectrometer was rebuilt, resulting in gains of 10 to 15 depending on the incident neutron energy. The **secondary spectrometer** is being replaced and will incorporate a very high solid-angle 2D position-sensitive detector comprising banks of 3-metre-long, helium-3 multi-tube detectors developed in-house in a 4-metre flight-path evacuated vessel. Further gains of a factor six will result.
- The ILL was relatively slow in embracing reflectometry. A vertical surface instrument D17, the most intense such machine in existence, is to be joined by **FIGARO**, a horizontal surface instrument of unprecedented intensity, allowing the study of liquid surfaces and interfaces.
- The incident beam of the **D11** small-angle scattering camera, a flagship instrument, was rebuilt in the first years of the Millennium Programme. The detector tank, more than 20 years old, is now being rebuilt in order to profit from advances made with the detector for the D22 instrument.
- The through-beam of Lohengrin nuclear physics instrument is the most intense neutron beam in existence. This beam has been opened up to create a **Radiography/Tomography** facility (p B.31) of particular interest to technologists (fuel cells), geologists (planetary interiors), archaeologists (ancient artifacts) and engineering companies (combustion processes in car engines).

Neutron infrastructure

Also included in the first years of the Millennium Programme were neutron infrastructure developments. Most notably these encompassed the first installation of radiation-resistant zircalloy beam-tubes, total renovation of the ILL's antiquated vacuum-pump park, a programmed (and necessarily ongoing) renewal of the ILL's neutron guides,

Dismantling IN5 as part of the Millennium Programme


Prototype of the Cryo edm instrument

modernised sample-environment equipment such as the 15-tesla cryomagnet, and a state-of-the-art instrument-control system **NOMAD**.

Managed within the Millennium Programme were the deuteration laboratory (**D-lab**) for biological samples now incorporated into the Partnership for Structural Biology (**PSB**) and the Facility for Materials Engineering **FaME**, both of which attracted grant funding and collaboration from outside the ILL.

Continuation of the Programme

The 2-year project definition and consultation period for the continuation of the Millennium Programme, which began in Cadarache in June 2004, now has crystallised into a consistent programme of upgrades. Less compromise on beam intensities, both thermal and cold, is aimed for, with the closure of certain instruments.

Within this *Perspectives and Opportunities* document, we set out the possible implementation over a 10-year period of these plans.

The current set of projects in the Millennium Programme (**M_0**) as detailed above would be terminated in **2008**, if no others were added. Overlapping with M_0, and forming a continuous process, a **Millennium-1** (**M_1**) programme has been defined, beginning in 2007 and lasting until 2011. M_1 contains instruments that have been debated and endorsed by the Scientific Council. It is envisaged that this programme will be based upon groups of geographically linked tasks, rather than as individual projects as was the case for M_0. Certain projects within M_0 will be carried forward into the management structure of M_1.

In **2012**, the **Millennium-2** (**M_2**) programme will be launched, centred on a third cold source and a high magnetic field laboratory. Naturally the instrument scenario and the costs in these later proposals are more schematic than for M_1, allowing decisions to be taken for the content of M_2 as the M_1 programme evolves.

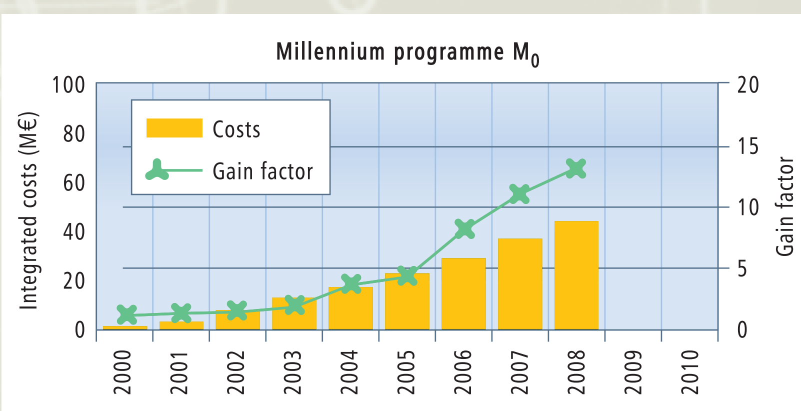
Millennium Programme M_1

Three types of projects are identified.

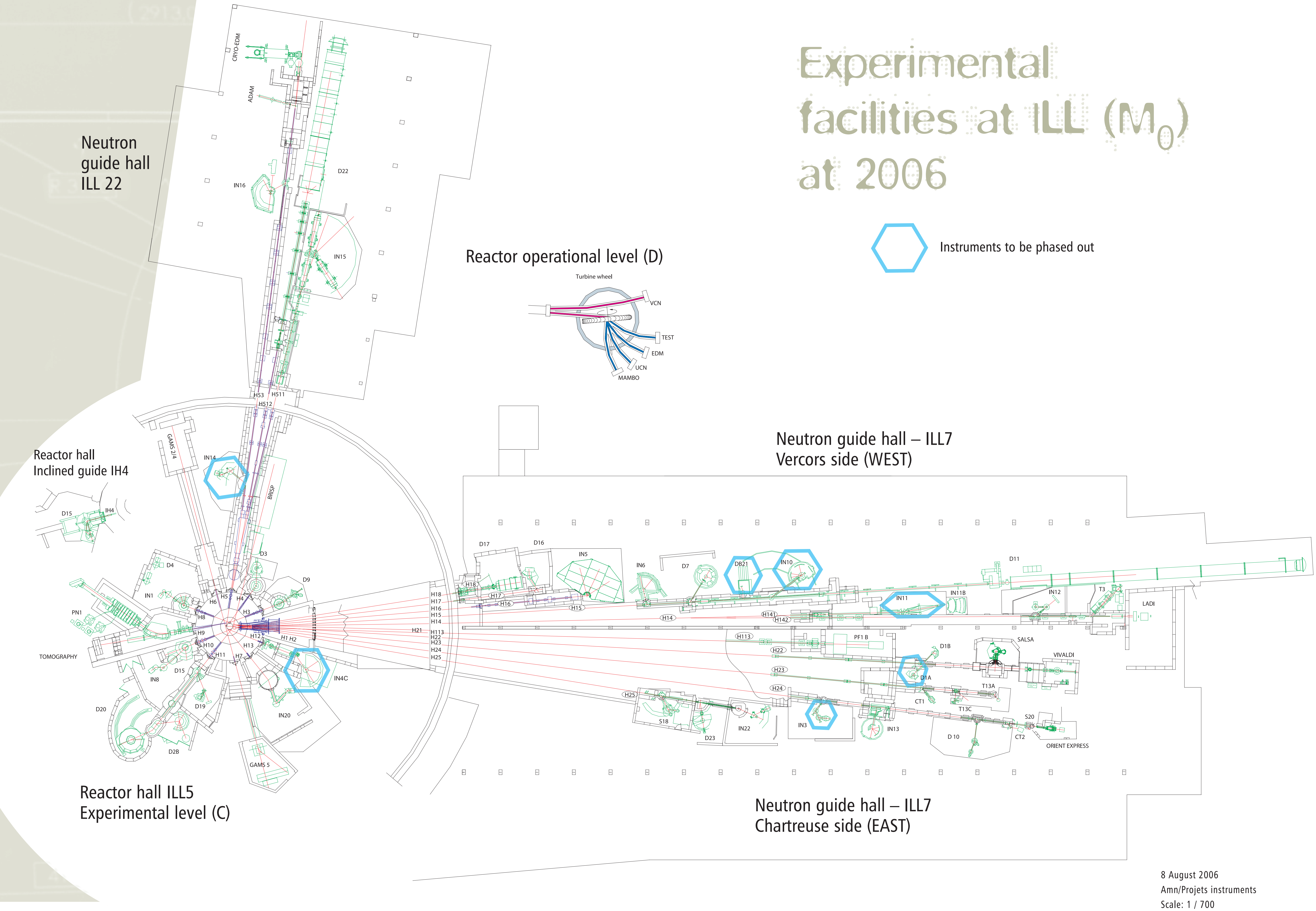
(a) Projects carried in from the M_0 Programme. These include **FIGARO**, **IN16** and **LADI-III** as described above.

(b) Projects which have been accepted by the Scientific Council and the Steering Committee but which have not yet started:

- The new detector and tank for the **D11** small-angle scattering instrument (see above).
- The **DRACULA** high-intensity, medium-resolution powder diffractometer, ideal for time-resolved experiments.
- The **WASP** wide-angle spin-echo spectrometer, which will provide data rates up to 50 times that currently available. **IN11** would be shut down.
- The **PASTIS** polarisation-analysis spectrometer, which will open up new scientific opportunities with neutrons in the area of dynamics. **IN4** would be shut down.
- **D33** would be a third small-angle scattering instrument to cope with the increasing demand for such instruments – but equally well to separate magnetic-field experiments (on **D33**) away from instruments that are sensitive to magnetic fields, such as the spin-echo spectrometers (p B.30).
- The **Cryo-edm**, a high-density superfluid-helium apparatus for ultra-cold neutrons, promises to deliver the first determination of a quantitative value for the electric dipole moment of the neutron. This is a CRG instrument (p.xx).
- Building upon the remarkable results achieved in quantising ultra-cold neutrons in the Earth's gravitational field, a significantly more sensitive



Experimental facilities at ILL (M_0) at 2006



instrument **GRANIT** is proposed, which will allow transitions between the different quantum levels in neutrons to be provoked by gravitational, electrical or magnetic perturbations. Certain transitions can be identified as the signature of graviton interactions (p.xx).

All these projects imply new beam positions or refurbished neutron guides, often with complex project interconnections. In order to deliver uncompromised neutron intensities for the instruments proposed in M_1, three new thermal guides will be installed in the H12 beam tube where IN4 is currently sited. The two new instruments DRACULA and PASTIS will be located on the outer pair of guides and the M_0 instrument VIVALDI will occupy the central guide, benefiting from a direct view of the thermal moderator with a gain in intensity of a factor of three.

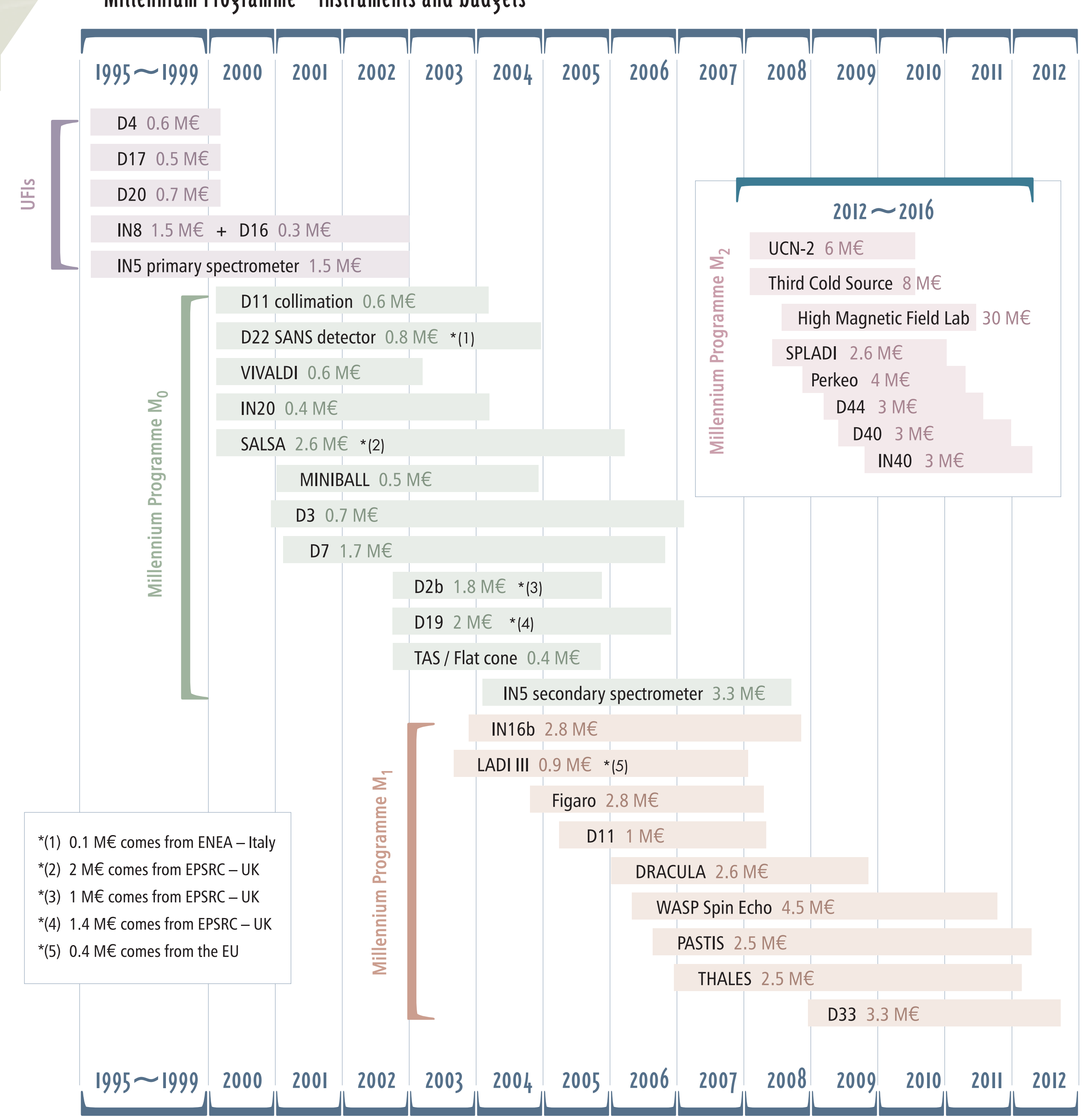
Millennium Programme M_2

The second 5-year phase of the proposed instrument development programme would last from 2012 to 2016. M_2 is focused on three significant initiatives, a third cold neutron source, a high density ultra-cold neutron source, and a high-magnetic field laboratory FORTE, the latter jointly with the ESRF.

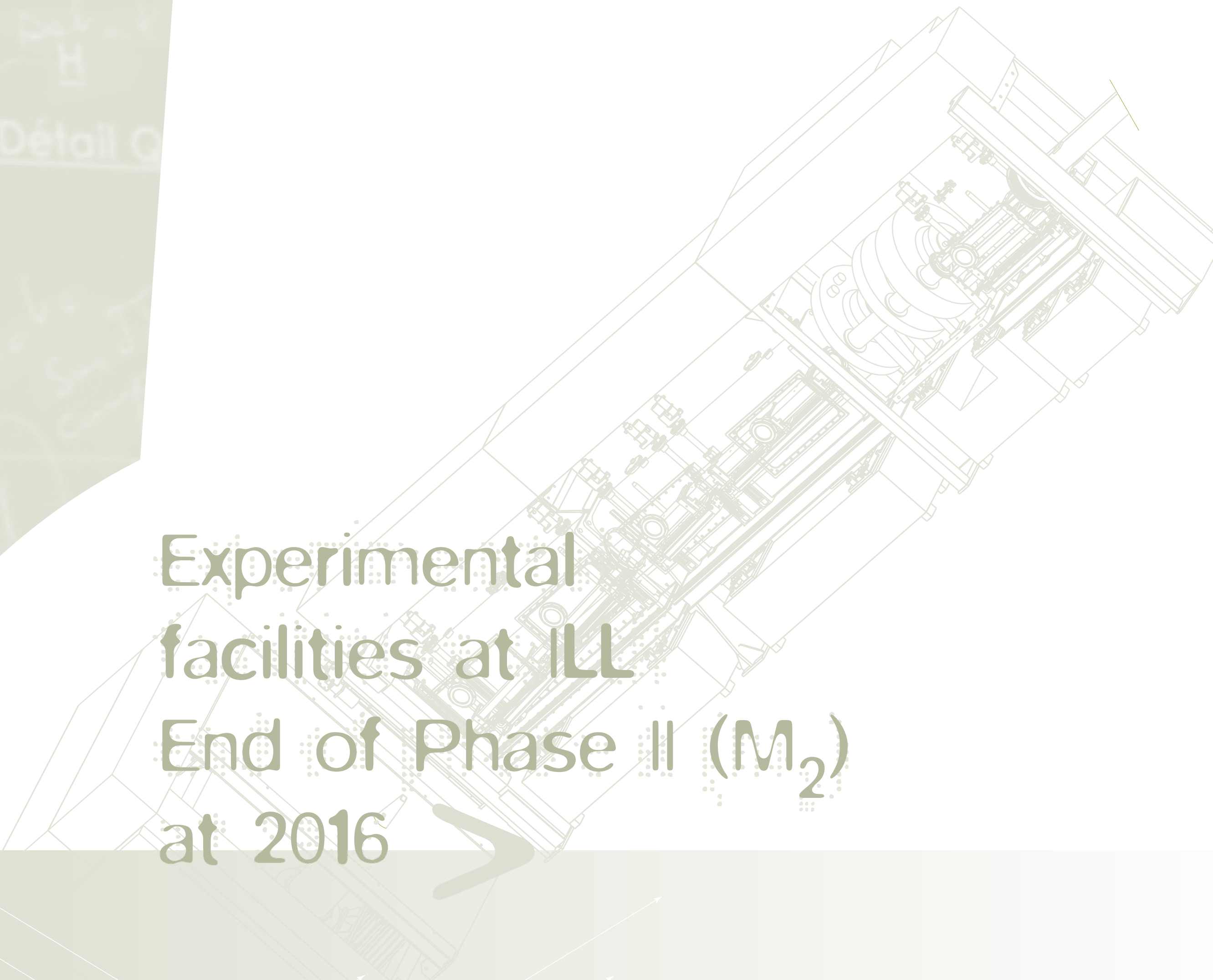
The third cold source will be a horizontal

PASTIS

Millennium Programme – instruments and budgets



Experimental facilities at ILL End of Phase II (M_2) at 2016



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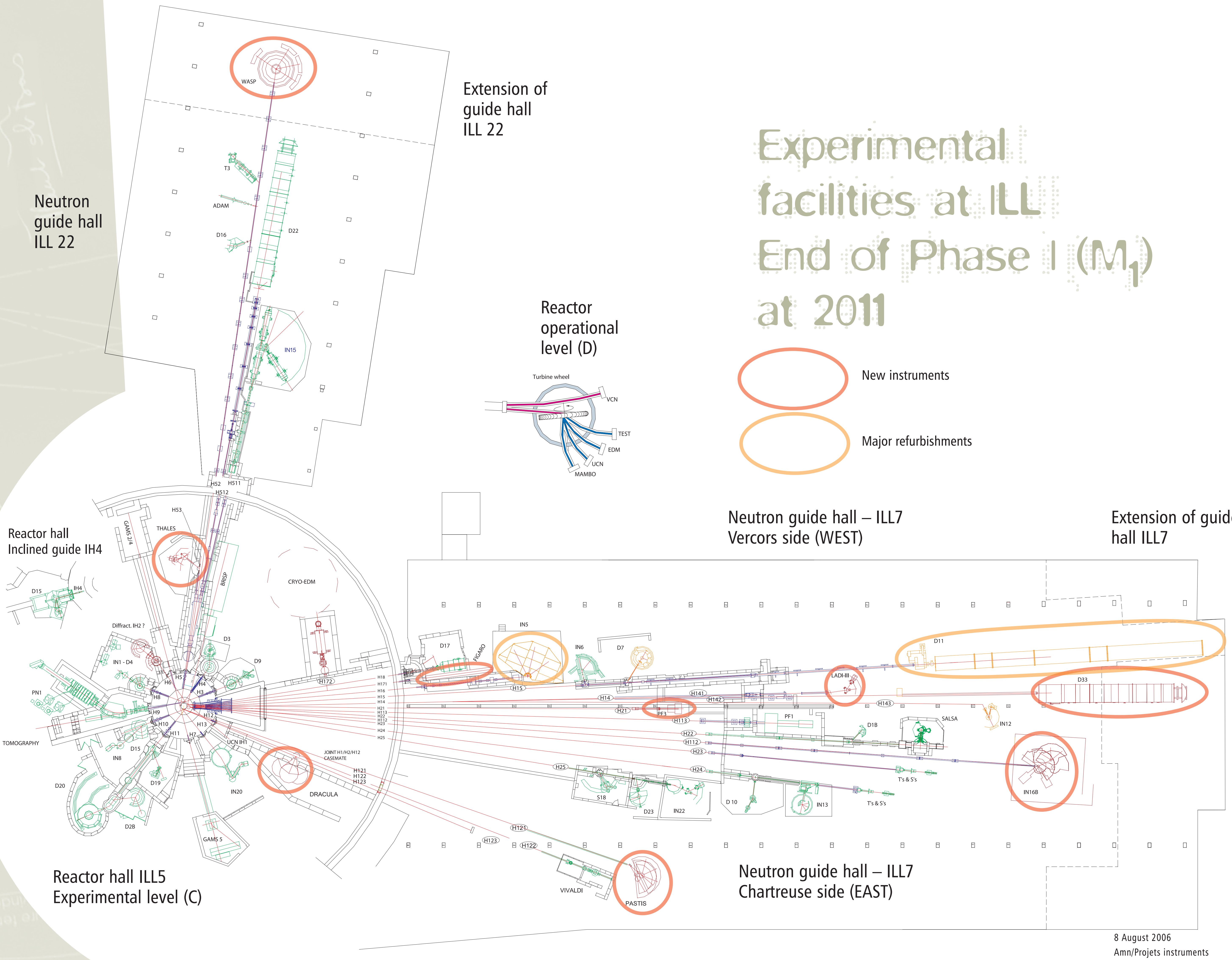
Experimental facilities at ILL End of Phase I (M_1) at 2011

New instruments

Major refurbishments

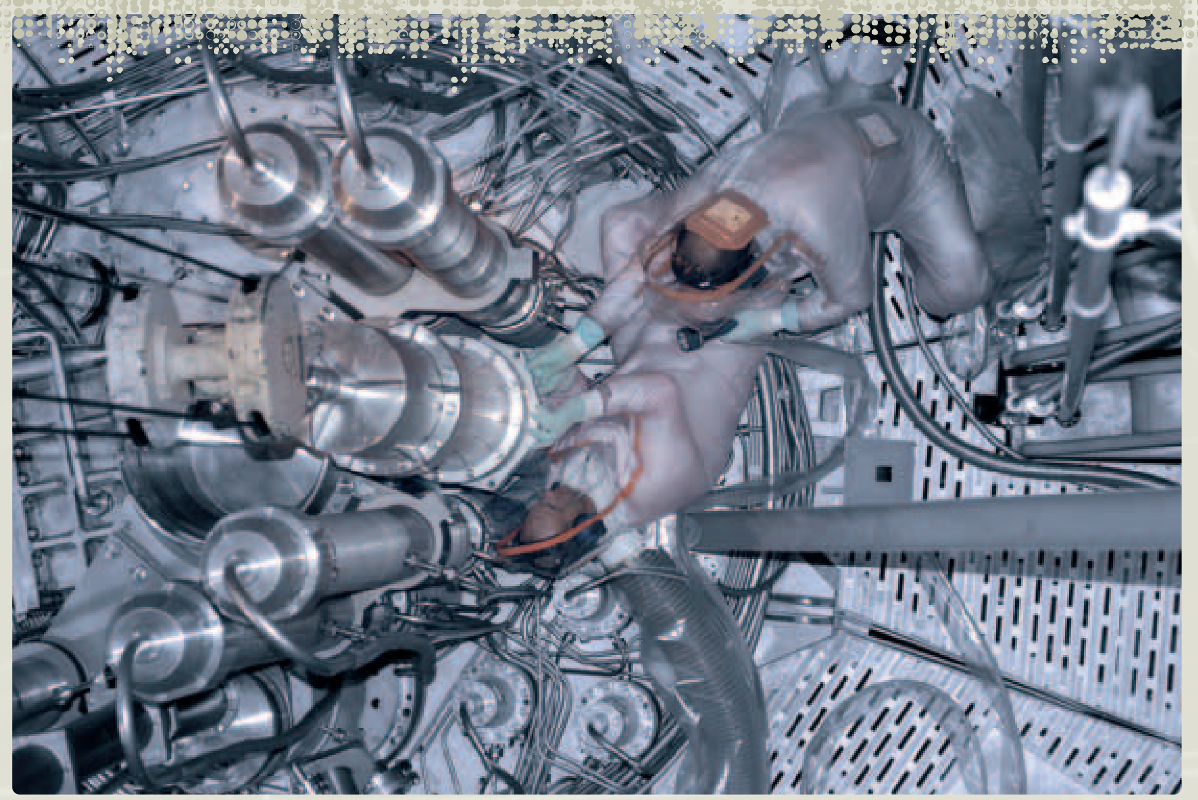


8 August 2006
Amn/Projets instruments
Scale: 1 / 700


cold source HCS-II, similar in concept to that located in beam-tube H5. HCS-II will transform the five existing thermal guides (H21 to H25) into cold or cold-thermal guides. A gradual change of the spectrum from thermal to cold across the guide-bunch will be possible, allowing the current CRG instruments to continue operating in optimum conditions but opening up more intense cold neutron positions. HCS-II will already have been designed and constructed within M_1 phase. Two possibilities for a high density ultra-cold neutron source are under consideration: its incorporation into HCS-II, or as a stand-alone source within the IH1 inclined cold beam.

The reference suite of instruments to be constructed in M_2 is as follows:

- A high-resolution time-of-flight diffractometer for thermal/cold neutrons built around a cylindrical **FORTE** magnet on H24. The flexibility of resolution and frame length of such an instrument makes it complementary to pulsed-source instruments.
- A two-axis/three-axis spectrometer built around a split-coil magnet at the end position of H23 viewing a fairly cold spectrum.
- A fourth small-angle scattering instrument **D44** would co-locate with a second cylindrical magnet and be dedicated to the highest magnetic field studies.
- A specialised LADI-type instrument **SPLADI**, which would allow nuclear polarisation of protons in biological samples. This would reduce the incoherent background and increase the coherent signal, opening up studies with neutrons to samples that are an order of magnitude smaller. Re-siting is planned for the strain imager SALSA on the new thermal guide-bunch, built in phase M_1, resulting in a factor of three gain in intensity.
- Further instrument positions become available as a result of these developments but remain uncommitted at the moment to allow future ideas to be capitalised upon.



Refitting the reactor

Experimental facilities at ILL End of Phase I (M_1) at 2011

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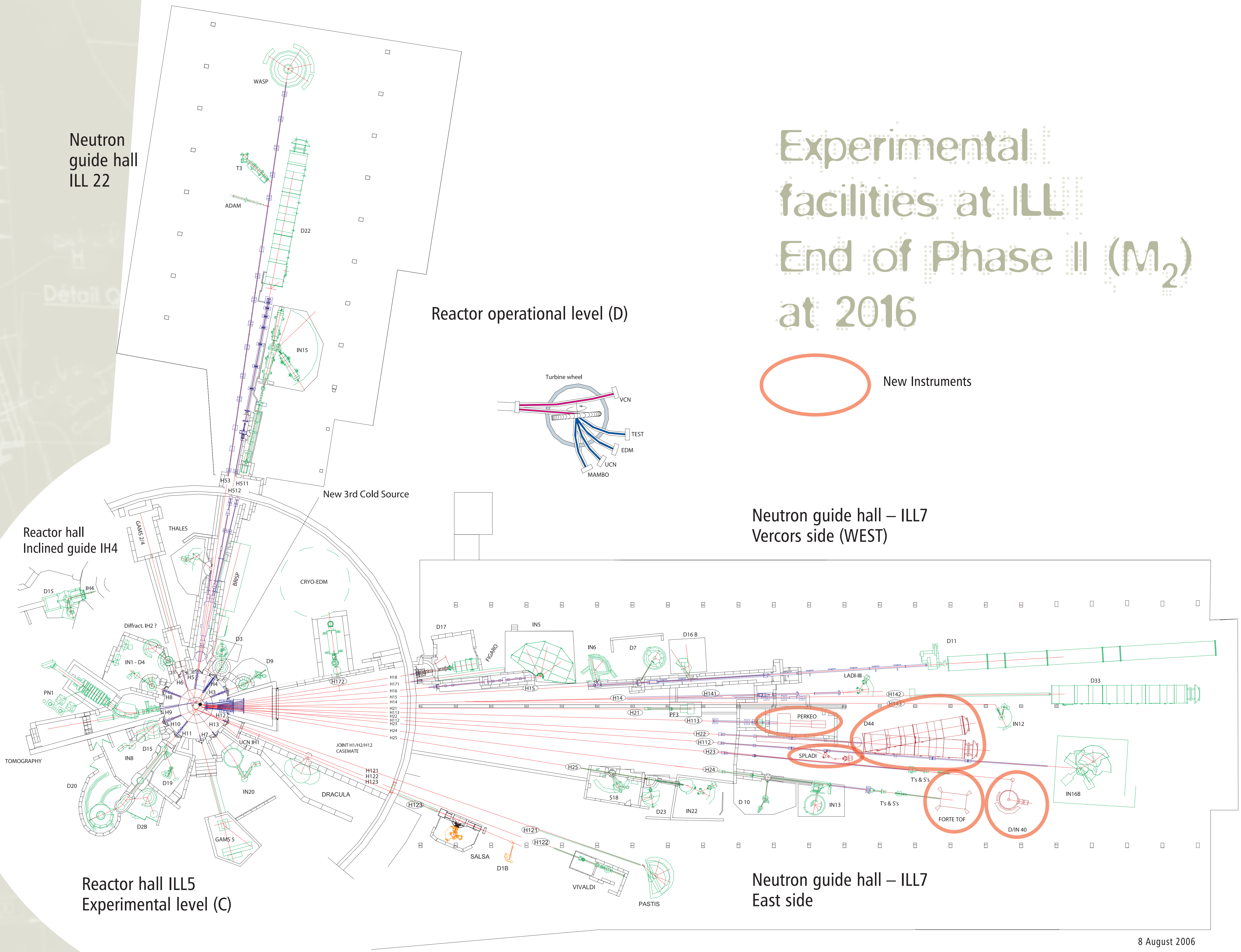
Experimental facilities at ILL End of Phase II (M_2) at 2016

New Instruments



8 August 2006
Amn/Projets instruments
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Formal opening of the PSB's Carl-Ivar Brändén Building

Partnerships for Science and Technology – making neutron techniques more user-friendly

The ILL is actively responding to the rapidly expanding range of scientific challenges amenable to neutron scattering in a number of ways

While neutrons are proving to be a powerful tool in new, emerging research fields such as engineering, planetary sciences and biology, the vast majority of scientists involved in these disciplines are still not familiar with neutron-scattering techniques. The ILL is therefore setting up training and support facilities for researchers in specific areas such as soft matter, materials science and biology so that new users can take advantage of the many possibilities neutrons have to offer and current users can gain more from their hard-won beam-time. New support laboratories have already been set up, such as the Partnership for Structural Biology (PSB), which includes the dedicated deuteration laboratory for

Experimental facilities at ILL (M_0) at 2006

TURN PAGE >>>

The newly opened Carl-Ivar Brändén Building

biological samples (D-Lab), and the Facility for Materials and Engineering (FaME), each developed as part of the Millennium Programme (p A.24).

Worldwide, we now witness the implementation of such 'interface laboratories'- stepping stones provided for specific groups of users clustered around new neutron and synchrotron sources to create a user-oriented access port. The ILL was at the forefront of proposing such developments under the 'more than simply neutrons' banner but now risks being left behind. In collaboration with the ESRF, we are therefore planning further interface laboratories as outlined below.

Partnership for Structural Biology – a first step

The Partnership for Structural Biology (PSB) was the first of these interface laboratories to be built. It contains the ILL/EMBL deuteration laboratory, as well as protein expression and crystallisation platforms for the ESRF, the EMBL and the neighbouring Institut de Biologie Structurale (IBS) – where state-of-the art NMR facilities are available. The IBS has joined together with the Institut de Virologie Moléculaire Structurale of Grenoble's Université Joseph Fourier so that a shared, purpose-built centre could be created on our joint site – the newly opened Carl-Ivar Brändén Building. This is now operational and proving very beneficial in attracting new high-quality proposals in bioscience to the ILL.

Partnership for Soft Condensed Matter – next step

A Partnership for Soft Condensed Matter (PSCM) is now proposed, building upon the success of the PSB. It will similarly allow our users to characterise samples just ahead of their neutron experiments, and to facilitate the performance of complementary measurements *in situ*, as well as drawing in modelling resources and advanced data analysis. In particular, a dedicated isotope-labelling facility would be created. The Partnership will also build on the ILL's expertise in rheology and in developing complex sample environments for carrying out advanced surface-science experiments. The complementary scientific expertise of the ILL and the ESRF will offer a synergy to users of both neutrons and synchrotron X-ray beams in a way not fully exploited at the moment. A working group of the Scientific Council has concluded that the PSCM will greatly enhance the throughput, quality, and scope of science in soft condensed matter performed on the ILL's instruments.

Partnership for Materials Science and Engineering

This Partnership, a laboratory for characterising and preparing samples with transient structures such as gas hydrates and similar unstable multi-component materials, would incorporate the FaME facility. The PMSE will, for example, enable materials that absorb or react with gases (such as hydrogen-storage materials, clathrates, zeolites and catalysts) to be prepared close to the instruments, immediately characterised using traditional laboratory techniques and measured using our neutron instruments. The use of beam-time will be optimised by preparing materials under extreme conditions of temperature and pressure prior to their transfer to the ILL's beams. Geophysicists have suggested an interesting initiative whereby they would use a combination of neutron tomography and traditional falling-sphere viscosity methods to study and model the viscous melts of planetary cores. Such experiments require massive equipment permanently located at the ILL.

Partnership for High Magnetic Fields

The fourth such interface laboratory would be dedicated to generating high magnetic fields up to 40 tesla so that complex magnetic phenomena can be observed using either neutrons or X-rays. Such facilities are expensive in terms of power requirements, and the location of the Partnership for High Magnetic Fields, equidistant from the beamlines of the ESRF and the ILL, makes economic as well as scientific sense. In the same way as cryostats became ubiquitous in the 1980s, so very high magnetic fields will be ever more in demand and expected at large-scale facilities. In Phase 2 of the ILL's *Perspectives and Opportunities* plan (2012 to 2016), three dedicated high-magnetic-field neutron instruments would be fed by this laboratory. It is even possible that an intense, finely focused neutron beam from the ILL should simultaneously illuminate a sample also being studied by synchrotron radiation from the ESRF – an idea clearly requiring further elaboration.

The Advanced Neutron Technologies building ANTs – A Partnership in Knowledge Transfer

The Advanced Neutron Technologies building (ANTs) would group together all the ILL's technological activities for neutron instrumentation.

ANTs would act as a nucleus for the development of neutron components, creating a network of human and technical resources from the different neutron laboratories in Europe. The building would be devoted to the development and refinement of monochromators, polarisers, supermirrors, sample environment equipment and detectors. This would enable all European neutron laboratories to share and benefit from new technologies.

[COMPONENTS OF ANTs]

Contained within the ANTs building would be:

1 **The Neutron Optics Laboratory**

Purpose-built components such as doubly-focusing arrays of single-crystal monochromators – polarising as well as non-polarising – are of exquisite complexity and deliver high performance. The ILL has the capacity to grow, characterise and orient the components for these devices, which are not available commercially. Further developments are planned: elements made of graphite intercalated with alkali metals, or assemblies of crystals cooled to low temperatures. The hard X-ray facility – an ILL initiative – would be an integrated part of this laboratory. Supermirror development (p B.28) would also be relocated in ANTs. Radiation-hard neutron guides are essential both for reactors and in particular for high-power spallation sources with their high neutron energy source spectrum.

At the ILL, three methods of polarising and analysing the spin of a neutron beam are being pursued: monochromators of single crystals of complex alloys such as Heuslers; supermirrors where magnetic layers are interspersed between non-magnetic layers; and polarised helium-3.

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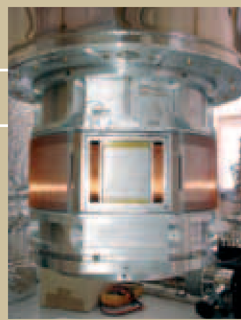


2 The Advanced Sample Environment Laboratory

Variable-temperature cryostats operating continuously from about 1K to room temperature were developed at the ILL, as were dilution refrigerators which can readily access temperatures as low as 15 mK. These cryostats employ cryogenic liquids – nitrogen and helium – and require skilled personnel to operate them. The ILL has embarked upon a programme to develop 'dry' cryostats using compressors and Joule-Thompson coolers, thus saving on expensive rare gases and optimising the use of skilled manpower.

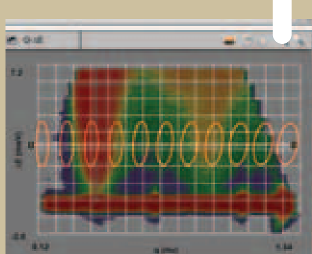
Furnaces, pressure cells and high magnetic field equipment would similarly be located in ANTs. One growth area, which is enhancing scientific impact of our beams, is the incorporation of specialised user-owned equipment for particular experiments, ranging from catalytic gas-loading cells under precisely controlled conditions to liquid-drop levitation devices for the study of supercooling. This adds a new dimension to the science programme at the ILL.

The combined expertise of the Neutron Optics Laboratory and the Advanced Sample Environment Laboratory are brought together in the development of CRYOPAD (p B.30) in which the magnetic properties of materials can be studied with unprecedented sensitivity, uncontaminated by the effects of the Earth's magnetic field. CRYOPAD, which is the culmination of scientific insight and technical brilliance, is the ultimate device for the manipulation of the neutron's spin. This principle has recently been extended to inelastic neutron scattering by the production of an elegant insert for the PASTIS time-of-flight instrument proposed in this *Perspectives and Opportunities* document.

3 Neutron Detector Laboratory

The final physical component of any instrument is the detector. Thereafter electronics, informatics and the human brain take over. Only a limited range of neutron detectors are available commercially. However, the challenge for many scientific studies is to collect as many as possible of the neutrons that interact with a sample. This has led to significant programmes to develop high-efficiency, low-cost and finely pixellated detectors. Such developments have already been implemented in the ILL's first wave of Millennium Programme instruments but there is still considerable potential for further advances. Multiwire detectors, image-plate detectors, microstrip detectors and multi-tube detectors are currently being worked upon and could be utilised on all neutron sources in Europe and beyond. Commercialising the manufacture of such detectors is one goal of ANTS.

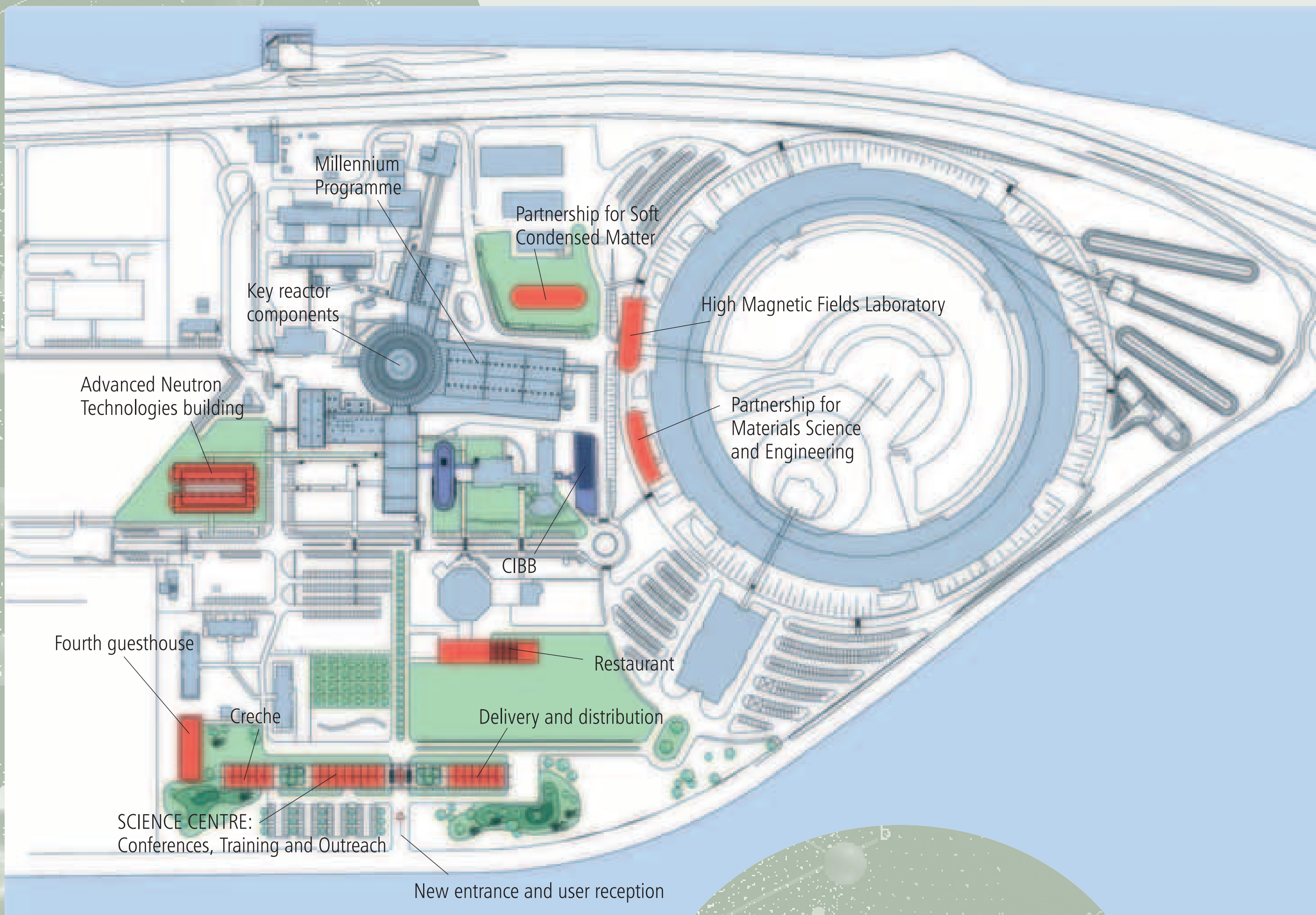
4 The Neutron Instrumentation Service



With instrument-upgrade programmes forming an integral part of the ILL's activity, a serious lack is the absence of an instrument-assembly area. Equally, the absence of clean-room facilities for detector development does not square with ILL's high-technology ambitions. An international laboratory like the ILL should go beyond *bricolage* – that very apt French word – in this area.

A new generation of instruments requires a new generation of instrument control. NOMAD fulfills these needs but a global monitoring system is also proposed within the *Perspectives and Opportunities* document. Remote monitoring, centrally, of sample-environment equipment on all instruments and equipment on stand-by will be implemented, as will beam-line status, guide-vacuum levels, and even alignment, chopper speeds and phases, using a wireless network.

The consequences would be that small manufacturing companies would cluster around ANTS, stimulating effective knowledge-transfer to industry and securing supplies of key components to the ILL's instruments and those from partner laboratories. The ILL's engineers could then concentrate upon development rather than production in a single common location where expertise from different technologies can cross-fertilise and nurture further advances.



The site plan

Occupying the same site as the ESRF and the EMBL outstation brings advantages in terms of potential for shared infrastructure and visibility. Up to now, these advantages have not been fully realised.

With the elaboration of this *Perspectives and Opportunities* document, and the definition in parallel of a 10-year strategic plan for the ESRF, we have together embarked on developing a concept of a scientific campus for the benefit of European science. Such campus ideas are being pursued elsewhere in Europe centred on national facilities. At the same time, Grenoble finds itself in a development phase in which the city and the region emphasises its identity with high-technology enterprises. The proposed site-infrastructure plan will provide greater visibility for the European laboratories and will provide Grenoble and the surrounding regions with a centre of excellence of which they can be proud.

A new site entrance is planned on the main Avenue des Martyrs arterial road. The site entrance would incorporate a visitor reception for the two radiation sources and would include a goods-delivery platform, thereby obviating the need for loaded vans and lorries to enter into the site where they could pose a security problem. A further added value would be the creation of a distribution centre for incoming deliveries run jointly by the ESRF and the ILL.

The new site entrance gives us the opportunity to put in place on a modest scale what has been missing from our facilities – a public-appreciation-

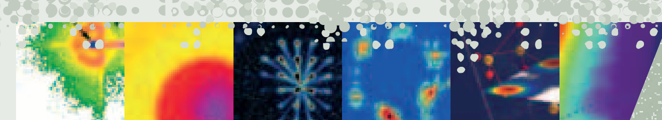
of-science area. Located on the edge of our campus, interested members of the public would have an opportunity to learn about neutron science and technology, and about the research carried out on the site.

Integral to this new entrance would be a conference facility for up to 400 delegates which would allow us to run medium-sized international meetings and to host gatherings of our user community. The successful European training course for synchrotron radiation and neutrons, HERCULES (p B.20), would find a natural home within this conference centre particularly now that an additional element is the specialised training courses which have been funded by the EU through the HERCULES umbrella.

In order to cope with the increasing number of researchers gaining access to our facilities, a fourth guesthouse will be needed to provide cost-effective accommodation. Equally well, the current restaurant facilities on site are becoming inadequate, not only for the increased number of diners but also because the kitchen facilities fall below current standards when related to the number of meals served.

Related more to the technical scientific programmes of the Institutes, buildings for the proposed Partnership for Soft Condensed Matter, the Partnership for Materials Science and Engineering and the Partnership for High Magnetic Fields would be funded as part of the Site Infrastructure. The Advanced Neutron Technologies centre building is also included in this programme. The technical and scientific installations within these buildings would not be funded through local government sources.

After a series of meetings with various levels of local government, it has been proposed that the joint site plan be included in a submission to the French Contrat de Projets Etat-Région. The total estimated cost of this specific development is 30M€. It should be emphasised that this sum falls outside the costed programmes presented within this *Perspectives and Opportunities* document.



"Ah, but a man's reach should exceed his grasp.
Or what is heaven for ?"

Robert Browning
English poet, 1812-1889

HE INSTITUT LAUE LANGEVIN (ILL), IN SOUTH-EASTERN FRANCE, IS A WORLD-RENOWNED, INT
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UROPE AND THE REST OF THE WORLD COME TO USE THESE NEUTRON BEAMS TO CARRY OUT FRONT

A world centre for research

The Institut Laue Langevin (ILL), in south-eastern France, is a world-renowned, international research centre that makes use of neutrons – subatomic particles used to study the structure and behaviour of all kinds of materials in microscopic detail

A dedicated nuclear reactor generates intense beams of neutrons which are guided to a series of surrounding experimental areas equipped with a wide range of sophisticated instruments. Scientists from all over Europe and the rest of the world come to use these neutron beams to carry out frontier research in diverse fields – from designing engines, fuels, plastics and household products, to understanding biological processes at the cellular and molecular level, and to elucidating the underlying physics behind the latest electronic devices. Specially-tailored neutron beams are employed to probe the fundamental processes that help to explain how our Universe came into being, why it looks the way it does today and how it can sustain life.

Why we are special

The ILL hosts the world's most powerful neutron source. It is the only international laboratory exclusively dedicated to research with neutrons. The source is exceptionally reliable, the instruments are first-class, and there are excellent user-friendly support facilities to help researchers make the most of this indispensable scientific tool.

Since its foundation nearly four decades ago, the Laboratory has been an innovator in neutron science and technology, developing an ever-wider range of novel instruments and experimental techniques which have continually broadened the scope of scientific problems that can be tackled at the Institute or elsewhere using neutrons.

Our site partners

The ESRF

The ESRF is one of the three most powerful synchrotron radiation sources in the world and the best-instrumented. Funded by 18 countries, more than 5500 scientific users come to research a wide variety of materials ranging from biomolecules and nanomagnets to ancient Egyptian cosmetics and metallic foams.

The EMBL

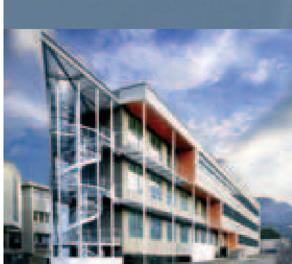
The EMBL outstation in Grenoble (the main site being in Heidelberg) is charged with:

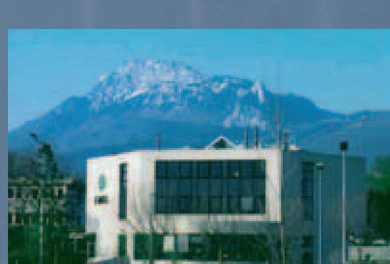
- carrying out fundamental research in the life sciences;
- providing a scientific bridge for biologists in Europe to gain access to the neutron and synchrotron instruments on site;
- constructing and developing novel instrumentation for the synchrotron and neutron sources relevant to the evolving field of biology.

Wherever possible, joint facilities are set up, managed and shared by the three organisations. The launch of a site development plan in 2006 in parallel to, but funded separately from this *Perspectives and Opportunities* plan comprises improvements to the user support facilities of each of the three Institutes, together with a common element, which is a totally modernised site infrastructure.

The Partnership for Structural Biology

The efforts of the ILL, the ESRF, the EMBL and the IBS (the Institute of Structural Biology, p A.35) are formally grouped together under the umbrella of the Partnership for Structural Biology (PSB). The PSB is located within the new Carl-Ivar Brändén building (CIBB) recently inaugurated on the site. The CIBB pools the expertise in biological sciences of the ILL, the ESRF, the EMBL, the IBS and the Institute of Structural Molecular Virology of Grenoble's University Joseph Fourier. The purpose of the PSB is to give users access to the neutron beams at the ILL, the synchrotron beams at the ESRF and the NMR facilities at the IBS in a more effective way by providing a critical mass of scientific and technical expertise and instrumentation. It is funded in part by a generous grant from the EU Framework Programme 6.





NEUTRONS FOR SCIENCE

ESRF

Max von Laue, Paul Langevin, Heinz Maier-Leibnitz, Louis Néel

Not surprisingly, the ILL's resident and visiting scientists are prodigious in producing research results of the highest quality which are published in the world's most respected journals. The output of high-impact scientific papers far exceeds that from any other neutron facility. Measurements made at the ILL have often underpinned Nobel Prize-winning work.

Our origins

The idea of developing a reactor designed as an intense source of neutrons for peaceful scientific purposes came from a highly respected German scientist, Heinz Maier-Leibnitz, who cherished this long-term vision. With the support of the eminent French Nobel Laureate Louis Néel, they persuaded France and Germany's leaders to agree to the setting-up of a joint facility in Grenoble. And so, in January 1967, the Institut Max von Laue-Paul Langevin was born as the world's first genuine service research laboratory, with resident expert teams, where scientists could come and measure with neutrons. This mode of research activity has since become the model of choice copied throughout the world. The first beams were produced in August 1971, and 2 years later, the UK joined as the third equal shareholding member of the Partnership.

Neutrons for Europe

Nine other countries have since become Scientific Partners: Austria, Belgium, the Czech Republic, Hungary, Italy, Russia, Spain, Sweden and Switzerland and more countries are likely to join soon. Each Scientific Partner contributes a fixed proportion of the ILL's annual budget.

Scientists from non-member nations are also able to use the Laboratory facilities, if their research

THE INSTITUT LAUE LANGEVIN (ILL), IN SOUTH-
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ONTIER RESEARCH IN DIVERSE FIEL

The ILL was created in 1967

proposal is of particularly high scientific merit, although their access is limited to 10 per cent of the overall experimental programme.

Increasingly, world-class research projects involve international collaborations linking several user institutions as well as ILL staff. Groups of users – Collaborative Research Groups (CRGs, p B.17) – may also come together to build and operate instruments at the ILL for a specific programme of research.

Research students and postdoctoral fellows from member nations are often sent to the ILL to carry out their doctoral and postgraduate research training, where they learn the techniques of neutron science and associated technologies. Indeed, the training of a scientifically and technically skilled workforce is one of our most valuable products. Most of our staff are bilingual and many are trilingual, and are therefore an ideal human resource for creating a knowledge-based European economy.

Today, 1100 researchers from 430 institutes in 32 countries annually carry out their experiments at the Institute, working hand in hand with ILL experts on about 700 experiments, making the most of the 40 or so instruments available. In 2005, 504 scientific papers were published. As instruments improve and experimental throughput becomes more rapid, and as the application of neutron techniques expands

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Some facts and figures

The ILL's name

The ILL was named after the German physicist Max von Laue, who was awarded the Nobel Prize in 1914 for demonstrating that crystals can diffract X-rays, and the French physicist Paul Langevin, a pioneer of the study of paramagnetism and fundamental diffusional processes, and an early proponent of nuclear power.

Membership

The three founder countries:

- France, via the Commissariat à l'Energie Atomique (CEA) and the Centre National de la Recherche Scientifique (CNRS)
- Germany, via the Forschungszentrum Jülich (FZJ)
- The United Kingdom, via the Council for the Central Laboratory of the Research Councils (CCLRC)

The Scientific Member partner countries:

- Austria, the Czech Republic and Hungary, via the Central European Neutron Initiative which comprises the Austrian Academy of Science, the Charles University of Prague and the Hungarian Academy of Science
- Italy, via the Consiglio Nazionale delle Ricerche
- Russia, via the Federal Agency for Atomic Energy, Rosatom
- Spain, via the Ministerio de Educación y Ciencia
- Switzerland via the Bundesamt für Bildung und Wissenschaft
- Sweden, via the Vetenskapsrådet – Swedish Research Council
- Belgium, via the Belgian Federal Research Ministry

Forschungszentrum Jülich in der Helmholtz-Gemeinschaft · cea · CNRS Centre National de la Recherche Scientifique · CCLRC into more and more scientific disciplines, the number of users will grow substantially over the coming decade, as will the scientific range of the user community. In the past 3 years, 2500 individual researchers have made measurements at the ILL.

A Force for European Science and Technology

Set against a stunning alpine backdrop, the ILL is sited in the cosmopolitan city of Grenoble – a high-technology hub renowned for its research centres, its electronics industry and its university. Indeed, it was this rich scientific environment that prompted the decision to set up the laboratory in 1967 on the City's Polygone Scientifique located between the Isère and Drac rivers. Ten years later, the ILL was joined by an outstation of the European Molecular Biology Laboratory (EMBL) to enable biologists to take full advantage of the facilities that the ILL could offer them. Then, in 1988, the world's brightest source of synchrotron light, the European Synchrotron Radiation Facility (ESRF), was built beside the two laboratories to create an internationally-recognised centre that could offer a unique combination of extremely intense neutron and X-ray beams. Today, the site attracts almost 10,000 scientific visitors every year and the ESRF is also preparing its own long term strategy, many elements being in conjunction with the ILL.

Because the ILL, the EMBL and the ESRF have succeeded in pooling scientific resources from many countries, both human and financial, their joint research activities are contributing towards the construction of a knowledge-based European economy as proposed in the Lisbon and Barcelona Accords. Indeed, these three laboratories have recently joined forces with the four other major European research laboratories – CERN (European Organisation for Nuclear Research), ESA (European Space Agency), ESO (European Southern Observatory) and JET (Joint European Torus) – to set up the EIROforum collaboration to share best practices (p A.11), to enhance the public appreciation of science and to help inform European decision-makers. Close links with the European Commission mean that the EIROforum laboratories are truly at the heart of the European Research Area and are a microcosm of it.

The expansion of the EU is being reflected in the enlargement of the ILL's own membership. Further European states including those in northern Europe (Norway, Finland, Denmark, the Netherlands) and in Eastern Europe (Slovakia, Slovenia, Poland and Romania) are currently engaged in negotiations. Ireland, Greece and Portugal are also in discussions as are other countries. Finally and most importantly, the ILL – as the premier neutron source in the world – can occupy that position only thanks to the network of national neutron facilities in Europe which underpins its neutron ethos, and generates and sustains the wide user community.

Why neutrons are useful

Neutrons, along with protons, make up the nuclei of atoms constituting everyday matter. They are electrically neutral, and atoms of a particular element can have different numbers of neutrons, which are called isotopes

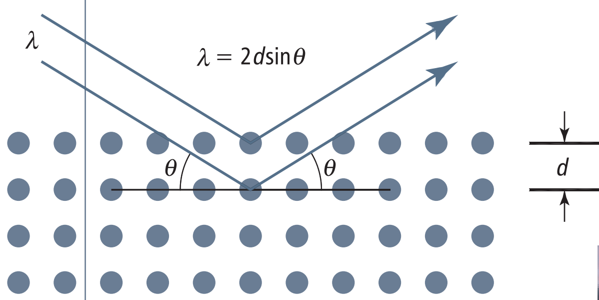
What's so special about neutrons?

• THEY ARE WAVE-LIKE

Being subatomic particles, neutrons obey the laws of quantum mechanics – the theory describing matter at the smallest scale. Quantum theory predicts that they behave like waves as well as particles. This means that, like X-rays, neutron waves can diffract elastically from atoms in a sample of a material. Because the neutron wavelength is similar to the distance between the atoms in condensed matter, the reflected neutron waves interfere with each other to give a diffraction pattern that contains detailed information about the positions of the atoms and the distances between them, and therefore leads to the microscopic three-dimensional structure of the material. A wide range of structures can be determined from neutron-scattering patterns – from simple crystalline materials to molecular, ionic or magnetic solids and biological membranes, as well as glasses, liquids and dense gases. As the distance between atoms increases, so the angle of neutron scattering decreases. Small-angle neutron scattering, or SANS, is an important technique for studying larger-scale structures extending to clusters of atoms relevant to nanotechnology and the chemical and biotechnology industries.

• THEY ARE NEUTRAL AND HAVE A MASS

Since neutrons are neutral particles which possess mass, they can penetrate deep into matter in a nondestructive way. They are largely unaffected by the charged electron cloud which makes up the bulk of an atom and it is the central, dense nucleus that they scatter off. The intensity of this scattering process depends on the type of nucleus, and so neutrons can distinguish between different elements



Neutron 'waves' are diffracted by consecutive layers of atoms in a crystal in a precise way that gives information about the crystal's structure

and their isotopes. Because isotopes of an element may have very different scattering strengths, substituting, say, hydrogen with its heavier isotope deuterium in a material provides an excellent way of 'highlighting' different structural components using a technique called contrast variation. This is particularly useful for complex materials such as biological samples or polymers, which contain a large proportion of hydrogen atoms.

As well as penetrating deep into materials and probing bulk properties, neutrons also reflect off surfaces and interfaces so that ultra-thin layers can be investigated such as metallic insulating films on window glass, lubricating layers on the surfaces of bearings, or biomolecular membranes.

• THEY ARE MAGNETIC

Neutrons have a spin and an associated magnetic moment, and so they are sensitive to the magnetic moments of atomic electrons, which also have spin. Neutrons are therefore a very powerful probe of the magnetic properties of materials. Furthermore, by aligning the spin of neutrons to create a polarised beam, detailed and otherwise unavailable information about structure and magnetic properties can be gleaned, such as the delicate interplay of magnetism and superconductivity in novel oxide compounds used in nano-switches.

• THEY ARE MODERATELY ENERGETIC

A cloud of neutrons behaves much like a gas, in dynamic equilibrium with its surroundings. The energy of the neutrons can be tuned to gather specific information. Neutrons can lose or gain energy when interacting with an atom that is moving or changing in some way (inelastic scattering). Measuring this energy exchange reveals how a material's structure fluctuates over very short times. Inelastic neutron scattering techniques are used to investigate fluid flow, how polymer chains meander, or to monitor subtle changes in electronic materials in magnetic fields.

The fundamental characteristics of neutrons themselves and how they assemble with protons into nuclei tell us how the forces of nature work. Very low energy neutrons, cold or even ultra-cold, are needed to study the properties of the neutron itself. Higher energy neutrons, thermal or hot, are used to explore nuclear structure by inducing nuclei to decay and to emit gamma-rays or fission fragments which are then studied. A knowledge of the properties of the exotic nuclei created in this way is key to understanding the evolution of the life-cycle of stars, of the Universe itself, and how the heavier elements (essential to the evolution of life) came into existence via the hugely destructive and yet ultimately creative nova and supernova explosions of stars.

Neutrons complement X-rays

The different information obtained from neutron and X-ray scattering is complementary, and using both techniques often provides more precise insights than the use of either technique alone. Increasingly, the strategic wisdom of having the ILL and the ESRF on the same site is paying scientific dividends, as researchers using one facility appreciate and exploit the potential of the other.

Intense beams of both neutrons and X-rays are used to study the structure and behaviour of matter. Experiments with the two types of radiation achieve results in a highly synergetic way because of their different qualities:

- Neutrons are subatomic particles whereas X-rays are high-energy electromagnetic radiation.
- Neutrons interact mainly with atomic nuclei, and so pinpoint the exact location of the centre of an atom. X-rays interact with the electron cloud around a nucleus and give the electronic shape of an atom or molecule.
- The intensity of X-ray scattering depends on the number of electrons in atoms. X-rays are particularly sensitive to heavy elements but are less good at seeing light elements, or in distinguishing between chemical elements with similar numbers

of electrons. Neutrons can distinguish between isotopes of the same element and are good at detecting light elements in the presence of other light elements.

- Neutrons, perhaps surprisingly, are more penetrating than X-rays, and so can be used to examine materials in pressure cells or chemical reaction vessels or probe deep inside welds in metals. Much brighter beams of X-rays can be generated so they can observe the detail in very small samples.
- Neutrons, again surprisingly, are a gentle probe and rarely damage samples. High-intensity X-ray beams can damage delicate biological samples and special care must be taken.
- Neutrons have a magnetic moment, and so can probe the underlying microscopic magnetic properties of materials. X-rays beams can also highlight these effects but require special equipment.
- Neutrons can probe the motions of atoms and molecules since their energies match those of atomic vibrations and molecular rotations, and the diffusion of molecules themselves. X-rays have much higher energy and do not lend themselves easily to the study of dynamics but very precise instruments are now able to detect such motions.
- Neutron-scattering data are easier to interpret and relate to theoretical models than are X-ray data.

How to make the most of neutrons

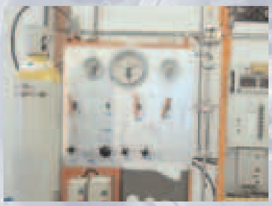
Neutrons can be released from a nucleus, either by breaking up the nuclei of an isotope such as uranium-235 (fission), as happens in the ILL's reactor, or by evaporating neutrons from nuclei with a high-energy particle beam (spallation), which is the method used by accelerator-driven neutron sources such as ISIS in the UK, the SNS in the US and J-PARC in Japan (p A.18).

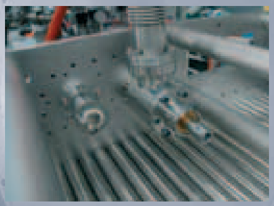
The ILL reactor is optimised to produce the brightest possible source of slow neutrons and has a single fuel-element core. The energy – and therefore the wavelength and equivalent temperature – of the neutrons can be moderated to produce beams of cold neutrons using liquid deuterium, or beams of hot neutrons using a heated graphite block. Extremely slow neutrons – ultra-cold neutrons, which are sensitive probes of the fundamental nature of matter – are generated by special moderating devices. ILL has pioneered ultra-cold neutron studies for 30 years.

The neutrons stream out of the reactor through a series of tubes which conduct beams of hot, cold or thermal (room temperature) neutrons to experimental areas. Each neutron beam is tailored for a particular experiment in terms of its wavelength and divergence. For magnetic experiments, the neutron beam may first be polarised using novel devices using supermirrors or polarised helium-3. In some experiments, the neutron beam is chopped into sharp pulses to measure the dynamics in samples using the time-of-flight method. Perhaps counter-intuitively, pulsed sources are not necessarily best for time-of-flight experiments. The flexibility of a continuous source to allow changes in frequency and pulse length, which translate into dynamic range and measuring precision, is invaluable.

Once the neutron beam impinges on the sample, the scattered intensity (and optionally the energy or polarisation) is measured at various scattering angles using banks of neutron detectors. In SANS, this angle is so small that the detector has to be placed a long way from the sample in order to measure the deflection of the beam accurately. Since neutrons are electrically neutral, detecting them after scattering from the sample relies on nuclear interactions in special helium-3 detectors. The neutron-absorbing gas in the detector produces charged particles which generate a tiny electrical impulse. Newly developed large-area, highly pixellated detectors (p B.29) allow researchers to observe many scattering angles with high precision simultaneously.

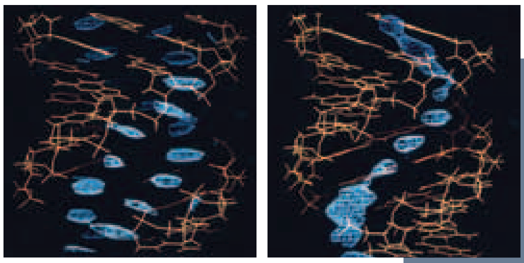
Over the past 30 years, the ILL has pioneered many of the novel techniques and instruments commonly used today. Neutron instrumentation, like telescopes, space probes and satellites, must be purpose-built and cannot be bought commercially. The Institute continually upgrades its own instruments and develops new ones for its flagship Millennium Programme (p A.24) currently underway to upgrade instruments and infrastructure, thereby producing excellent scientific dividends. The latest plans are contained in this *Perspectives and Opportunities* document.





Scientific applications of neutrons

Neutrons provide a powerful tool in investigating Nature at all levels, from testing theories about the evolution of the Universe to elucidating the complex processes of life. The ILL offers experimental facilities and expertise covering all these areas

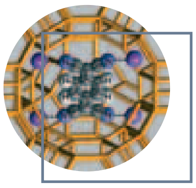


In the early days, neutrons were solely used to study the structure and dynamics of very simple materials using quite rudimentary instruments. With the invention of ingenious techniques and more precise instruments, experiments using neutrons can now explore an ever-increasingly broad range of scientific problems, the majority being at the very cutting-edge of basic knowledge and directly relevant to new 21st-century technologies. Industry frequently collaborates with university teams on research programmes using the ILL's instruments to shed light on technological problems.

Chemistry and materials

Neutron diffraction is ideal for determining the structure of materials containing light atoms such as hydrogen, carbon, nitrogen and oxygen. We need to understand the structure of materials before we can understand their properties and how they react. The scattering process pinpoints the position of atomic nuclei so that the distances between them can be measured accurately, and thereby an accurate three-dimensional model of the atomic arrangement in the sample can be assembled. This is particularly useful for investigating minerals and geological samples containing light metals such as lithium, and for arrays of molecules held together with weak hydrogen bonds – a universal phenomenon in biomolecular materials and highly relevant to the burgeoning area of nanotechnology. The ILL also has a large inventory of special equipment to examine crystal structures under high pressures, high magnetic fields, low or high temperatures, as well as other complex environments.

AREAS OF APPLICATION
Catalysts for the chemical industry
Toxic waste treatment
Pharmaceuticals
Materials for batteries and sensors
Environmentally-friendly fuels
Reaction chemistry
Oil prospecting
Hydrogen-storage materials
Earth and planetary science



Engineering

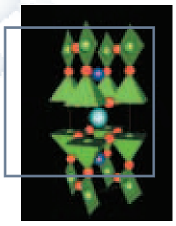
Because neutron diffraction determines interatomic distances, it can be used to monitor minute changes in these distances caused by the deforming of a material. Furthermore, since neutrons can penetrate deep into matter they can map stresses in bulky objects such as engine components. The ILL has a special strain-imaging programme dedicated to addressing engineering problems. The SALSA strain scanner and the FaME engineering support laboratory are the centrepieces of this strategy (p A.35). Monitoring the changes in the structure of a metal or an alloy over time provides information about their durability. These methods are also applied to archaeological artefacts, supplemented by new imaging (neutron radiography and tomography) techniques

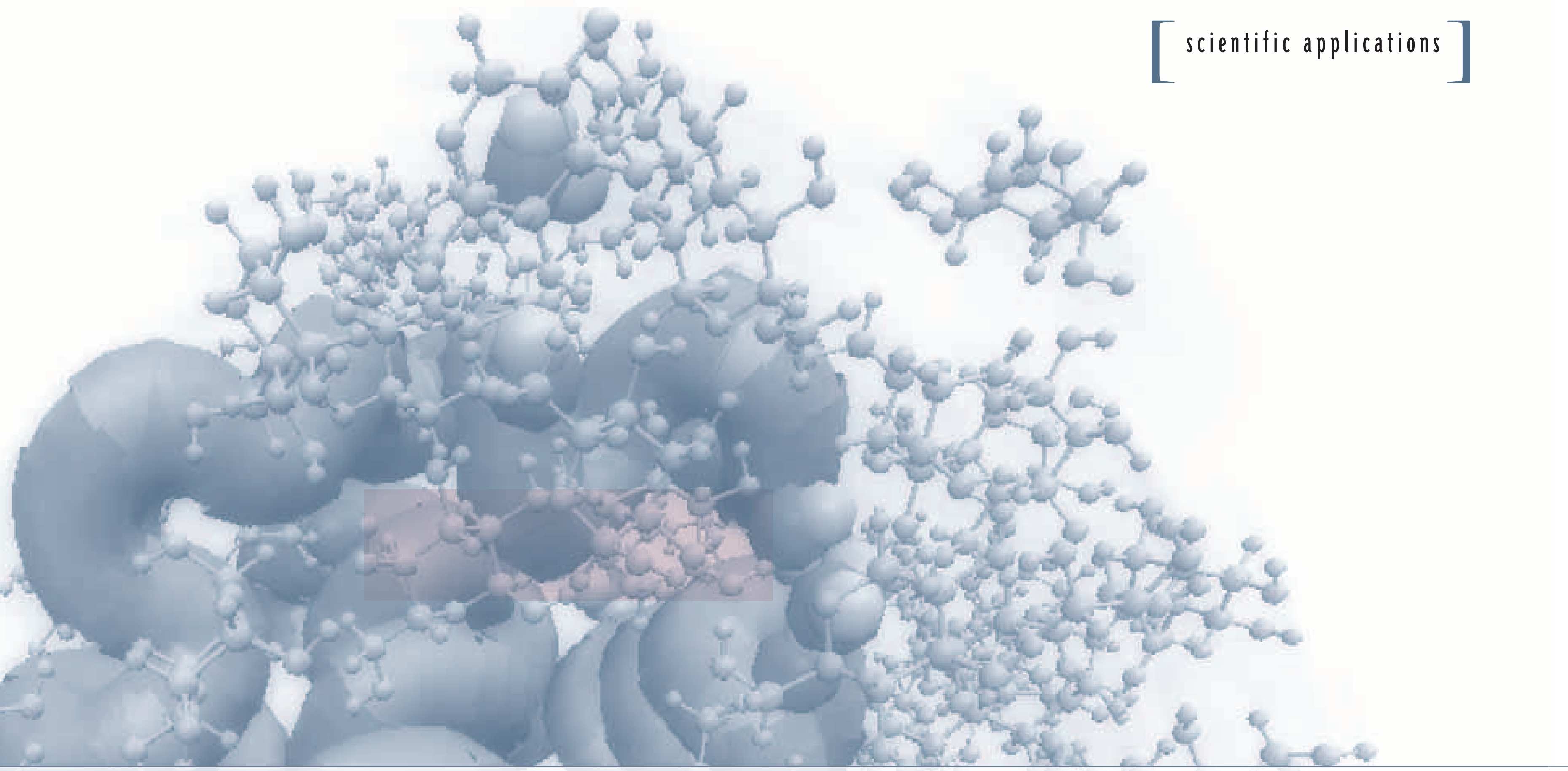
AREAS OF APPLICATION
Operation of engines and efficient combustion
Composite engineering materials
Welding and surface treatments
Fuel cells
Degradation of structural and constructional components
Sandstone, marbles and archaeological artifacts

Magnetism and electronics

Neutrons are one of the most sensitive probes of magnetism. Scattering due to interactions with the electrons responsible for magnetism in a sample is both direct and strong. The ILL has highly-refined instruments for studying materials with exotic magnetic properties. These not only disclose novel physical phenomena but also lay the foundations for new generations of electronic devices.

AREAS OF APPLICATION
Exotic magnetic behaviour
Field-sensitive switches
Molecular magnets
Nanoelectronics
High-temperature superconductors
Magnetic recording devices
Nanomechanical components
Magnetic thin films for novel electronics
Planetary magnetism

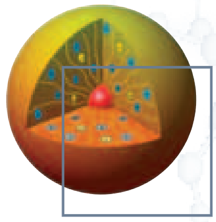




Liquids and soft matter

Small-angle neutron cameras can record scattering patterns on the intermolecular scale. This is useful for studying materials in which molecules are self-organised into complex assemblies – for example, food products (emulsions, foams and gels), lubricants (graphitic oils), personal-care products (soaps, sun screens and shampoos) and cosmetics. Because such materials contain high proportions of hydrogen atoms, particular components (often arranged as colloidal particles, layers and chains) can be highlighted by substituting the hydrogen atoms in them with deuterium. Deuterium scatters quite differently from hydrogen. The ILL's neutron source and instruments are extraordinarily stable, which allows high-precision studies of subtle structural disorder and aggregation in complex glasses and molecular liquids to be carried out.

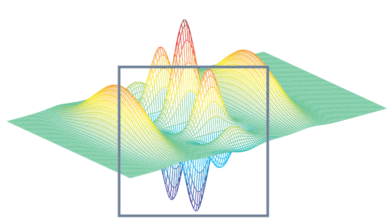
AREAS OF APPLICATION
Plastics – bottles and packaging
Domestic products – detergents and foods
Cosmetics
Multi-component lubricants
Pharmaceuticals – drug delivery
Engineering materials
Viscosity



Fundamental physics

Neutrons are subject to all four of the fundamental forces of Nature – electromagnetism, the weak and strong nuclear forces, and gravity. Researchers at the ILL carry out a range of subtle measurements using a variety of beams generated in the reactor – unstable neutron-rich nuclei, gamma-rays, cold and ultra-cold neutrons – to test theories about how these forces came into existence at the beginning of the Universe. Intense beams of slow neutrons from the reactor core are also used first to create and then to study the complex behaviour of short-lived nuclei beyond the very edge of stability. Of growing interest is the role of certain key short-lived nuclei in building up all the elements which are created in stars.

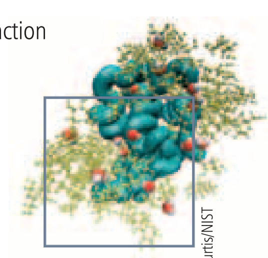
AREAS OF APPLICATION
The basis of quantum mechanics
Fundamentals of the gravitational force
Refining theories of particles and forces
Cosmological evolution
Stellar astrophysics
Medical imaging
Cancer therapy
Transmutation of nuclear waste



Biology

One of the most exciting and expanding areas of application of neutrons is in the life sciences. Mapping the human genome has unleashed vast programmes of work that promise to uncover how proteins and other large complex molecules control living processes, both normal and pathological. Neutrons offer an excellent probe of these structures in their natural aqueous environment. Advanced large-area detectors which view the sample from all angles can map the hydrogen atoms and visualise the weak hydrogen-bonding network that holds together the complex molecular assemblies found in cells. Neutrons also reflect off the molecular layers that make up cell membranes, giving information about their functioning. Insights have been obtained into molecular mechanisms which enable living creatures to adapt to extremes of temperatures and thus allow them to thrive in inhospitable environments.

AREAS OF APPLICATION
Enzymatic mechanisms at the molecular level
Cell membranes
Carbohydrates such as cellulose
Bone, teeth and muscle
Digestive processes
Drug delivery and action
Gene therapy



J.E. Curtis/NIST

PORTRAIT OF AN INTERNATIONAL

The ILL has excellent facilities for its users

The reactor and its beams

At the heart of the ILL is the 58.3 megawatt, single-element nuclear reactor, the core of which was rebuilt in the early 1990s. It is the most intense neutron source in the world for scientific research. Its safety record, reliability and availability are impeccable, and it is expected to continue to operate until 2024 at least. The reactor operates with a fuel inventory – supplied by one of our member states, Russia – that is less than 1per cent of that required by a nuclear power station.

The Institute is well-furnished with specialised moderators, close to the reactor core and at different temperatures, in order to provide intense beams of neutrons over a wide energy range, from hundreds of nanoelectronvolts to 1 electronvolt. Emerging from the reactor are 18 beam channels which deliver hot (high energy or fast), thermal (medium energy), cold (low energy or slow) and ultra-cold (very slow) neutrons. One specially dedicated beam channel feeds 12 neutron guides and another feeds four neutron guides. These 16 neutron guides conduct beams of neutrons to instruments in large experimental halls. This radical innovation in the 1970s became the hallmark of the ILL's advanced thinking on instrumentation, which continues today.

Beams of gamma-rays and unstable nuclei are also produced within the reactor by absorbing neutrons in a variety of targets. The various beams are conducted to surrounding experimental areas, which house about 40 instruments. These comprise high-precision devices that select and detect the beams once they have illuminated the many samples, simultaneously but independently being investigated by the different research teams present at the ILL at any one time.

While the ILL's neutron source has remained essentially unchanged during the lifetime of the Institute, our suite of instruments and their components have been continually developed and improved to increase their effectiveness (see Millennium Programme, p A.24).

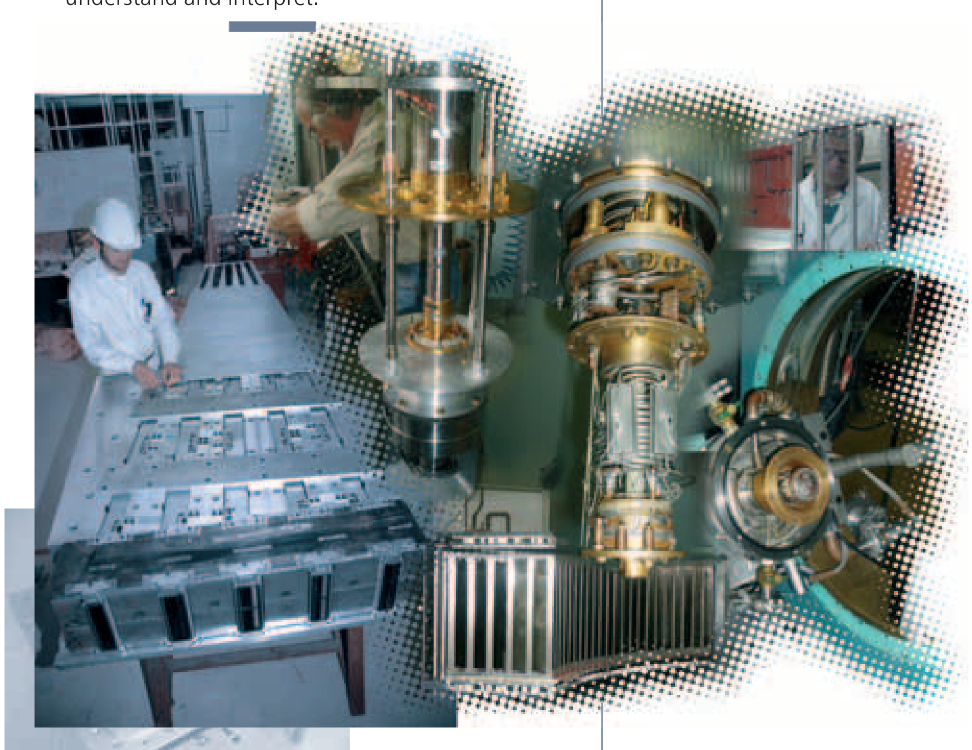
The different types of instruments

Reflectometers, diffractometers or spectrometers measure changes in the neutron direction, wavelength, energy, or spin as the neutron beam passes through and interacts with the samples

- Reflectometers are designed to investigate surfaces and interfaces by observing cold neutrons reflected at glancing angles.
- Diffractometers record the intensity of neutrons at different angles which have changed their direction, but not their energy, and provide structural information.
- Small-angle cameras are set a long distance away from the source and the sample so as to measure very small angles of scattering accurately, to provide structural details at the nanometre scale.
- Spectrometers, of which there are a number of varieties, observe the energy exchange between the neutron and the sample. Three-axis spectrometers select the incident neutron energy, scan the scattered neutron energy and study collective excitations in single crystals. Time-of-flight spectrometers measure the velocity of neutrons arriving at the detector in timed pulses and study molecular vibrations. Spin-echo spectrometers measure changes to the rate of rotation of the neutron's spin and study slow motions in polymers.
- Special instruments have also been constructed – gamma-ray interferometers, *exotic isotope spectrometers*, neutron bottles and gravitational traps – to investigate the properties of highly unstable nuclei, and to study low-energy nuclear and neutron physics.

Specialised instrument components

- Neutron guides transport the neutrons towards the samples to be studied, without loss in intensity;
- Collimators, filters, choppers and monochromators select the neutrons, according to direction and energy;
- Optical devices such as supermirrors are increasingly used to guide and focus neutron beams, while spin filters polarise the neutron spin;
- A variety of cryostats – both general-purpose and extremely specialised – maintain samples at near absolute zero temperatures;
- Pressure cells and furnaces allow researchers to access a wide range of temperatures and pressures;
- Superconducting cryomagnets are used to apply very high magnetic fields to samples;
- Detectors count the number of neutrons scattered by the sample. The ILL has many different detector types – gas and solid-state detectors, ranging from single-point detectors to large one and two-dimensional multi-detectors, the most advanced of which are developed and built in-house;
- Automated instrument-control and data-collection electronics manage the individual experiments according to the aims of the visiting research team;
- Sophisticated data-reduction and data-analysis suites transform the raw data into the physical quantities that the researcher can visualise, understand and interpret.



The ILL's Scientific Groups

ILL's instruments – like the reactor – operate for more than 200 days a year, currently delivering 6500 instrument days for science at a cost of about 12,000€ per instrument-day. They are operated by five groups of scientists and technicians.

The Diffraction Group operates 13 specialised diffractometers for examining all aspects of the structure of the various forms of materials – single crystals, powders, fibres, glasses, liquids and dense gases. The ILL is furnished with a rich array of high-quality instruments for structural studies.

The Three-Axis Group operates seven three-axis spectrometers, instruments in which the monochromator, sample and analyser can each be aligned independently. Inelastic scattering experiments on these instruments determine the dynamics of microscopic matter waves in arrays of atoms in single crystals and the analogous waves of magnetic spins in exotic materials.

The Time-of-Flight and High-Resolution Group operates three distinct kinds of instrument that measure the atomic, molecular and crystal motions of samples in powder, glass or liquid form:

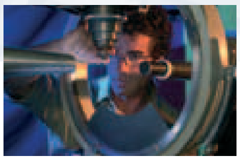
- time-of-flight spectrometers which analyse the changes of velocity of neutrons on interaction with the sample by measuring their time of arrival;
- backscattering spectrometers, a special version of the three-axis spectrometer with very high resolution, achieved by reflecting the scattered neutrons under normal incidence from perfect crystals;
- spin-echo spectrometers which measure small changes in neutron velocities very precisely by analysing how their spins precess – like the axis of a spinning top – before and after interacting with the sample.

The Large Scale Structures Group carries out experiments on the structure of matter (polymers, magnetic materials, thin films and biological materials) on scales up to micrometres. It operates two small-angle scattering instruments, three diffractometers and three reflectometers. The instruments in this group use cold neutrons exclusively, which have long wavelengths particularly appropriate for studying materials with structural order – one-dimensional, two-dimensional or three-dimensional – up to many hundred of nanometres, such as biomolecules, polymers and magnetic flux lines.

The Nuclear and Particle Physics Group operates four instruments, two being dedicated to nuclear physics and applied nuclear physics aspects, while the others cover mainly neutron physics aspects:

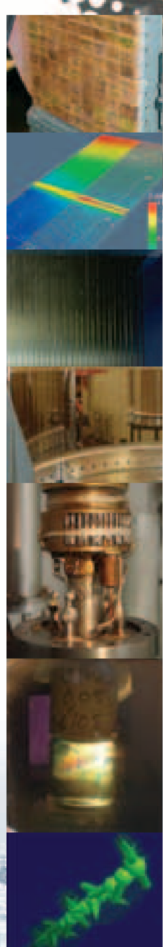
- The field of study of the mass separator spectrometer LOHENGRIN is gradually shifting from studies of fission to spectroscopy of very neutron-rich nuclei.
- The high-resolution gamma ray interferometer GAMS targets the application of gamma spectroscopy, benefiting from the highest possible energy resolution. Many studies carried out on this instrument have aimed to contribute to our understanding of the structure of nuclei. Others are devoted to the determination of standards and fundamental constants. Recently the precise equivalence of energy and mass ($E=mc^2$) was verified.
- A cold-neutron beam facility is installed at the end position of the H53 neutron guide and is used by the impressive prototype Cryo-edm set-up designed to attempt to measure the electric dipole moment of the neutron. PF1, which previously occupied this position, has now been relocated on the very intense ballistic guide H113 dedicated to studies of the parameters of neutron decay.
- The ultra-cold neutron facility PF2 was built by TU Munich in collaboration with the ILL. Experiments carried out recently on this facility concern a precise determination of the neutron lifetime and a lowered upper limit of the neutron electric dipole moment.

The Theory Group – working side by side with the ESRF theory group – studies the properties and behaviour of matter relevant to neutron research, enriches the value of the experimental environment and attracts many well-known scientists to our site.

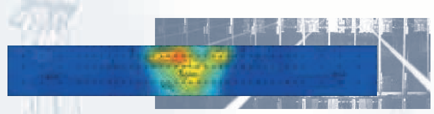


The ILL technical groups

Developing and building advanced neutron technologies, and providing support for users, is the goal of the ILL's technical services



The ILL recognises the importance of putting in place effective operational structures to make the most productive use of our instrumentation. The Institute also has a duty to the outside community to ensure the safety of the facility and to communicate how resources are deployed. Therefore, the range of services to support the users' goals is continuously being expanded:



The Sample Environment Service provides equipment for specific experiments requiring high or low temperatures, high pressures or high magnetic fields. Users' own special equipment, such as chemical-reaction vessels or liquid-drop levitation furnaces, are increasingly being incorporated into our instruments. We strongly encourage this.

The Neutron Detector Laboratory turns new detector concepts into operational detectors, particularly sophisticated two-dimensional position sensitive detectors. They also maintain and develop the vast suite of detectors on the public and CRG instruments.

The Neutron Optics Laboratory develops and manufactures advanced neutron optical components, supermirrors, focusing monochromator arrays and novel polarisers to increase the luminosity and power of ILL instruments.

The Chemistry Laboratories have a wide range of laboratory equipment and the necessary chemicals for sample preparation and analysis and have been set up especially for users to interface to the neutron instruments.

The Deuteration Laboratory – the ILL/EMBL deuteration platform within the Partnership for Structural Biology (p A.35) – allows researchers to synthesise their own deuterated bio-materials for neutron scattering experiments, exploring new synthetic technologies in collaboration with our specialist biotechnologists.

The Facility for Materials Engineering, FaME, is a purpose-built engineering science laboratory, in partnership with the ESRF and our user community, which enables metallurgists and engineers to rehearse and optimise their experiments, developing efficient alignment and measuring protocols in advance and providing a scientific environment for the growing engineering community.

The Computation Laboratory assists and advises ILL scientists and visitors with data analysis, and interfaces with the Instrument Control Service. Its work focuses increasingly on simulation methods, ranging from the simulation of samples to the simulation of instruments, and harnessing the power of grid computing (distributed computing networks) to optimise instrument design.

Both instruments and experiments can be simulated and the simulations can run in parallel with real experiments as an aid to an effective decision-making protocol during an experiment and in the subsequent interpretation of data. In the near future, 'virtual teams' of scientists off-site and on-site will work together.

Supporting our users

The ILL is dedicated to helping its visiting researchers to make the most of its facilities

We strive to provide a complete service to researchers using our suite of instruments. As experiment throughput increases, thanks to the ongoing Millennium Programme (p A.24), then so must the quality and effectiveness of this service. Responsiveness and flexibility are vitally important.

The **Scientific Coordination Office** provides the framework to help researchers to access our instruments. The ILL's **User Club** is a fully electronic communication portal to speed up the submission of proposals and give access to data, as well as dealing with more mundane matters such as researchers' transport and accommodation needs. Individual researchers have immediate access to their own database through this User Club which includes, thanks to the implementation of the new NOMAD instrument control environment, instant recall of an instrument's set-up parameters from the users' previous experiments.

User feedback is an important element in improving our facilities and our services to users. A number of different methods are used:

- detailed operational statistics are gathered each cycle from the individual instruments where reasons for downtime are recorded and discussed at regular meetings of the appropriate Chefs de Service.
- An electronic feedback form is available for users to complain, comment or even praise the facilities and support for users.
- Each cycle, a user forum is organised in which those users on-site at that time are invited to a meeting to hear about latest developments at the Institute and to feedback any difficulties they may have experienced in their current or previous experiments.
- Very occasionally big meetings of our user community are arranged but such interactions normally take place through the meeting of the national neutron communities run in the different partner countries at which we are always present.

Europe has a community of about 5000 scientific users of neutrons, and the demand for ILL beam-time is high and rising. It is consistently twice that available, even as capacity is increased. Visiting researchers and ILL staff tend the instruments around the clock so as to make the most efficient use of equipment and beam-time. Out of hours support for technical assistance ensures that any inevitable breakdowns do not jeopardise the success of experiments. The reactor control room is manned 24 hours a day, 365 days a year, and safety services such as radiological protection are continuously present.

A typical team of users consists of between two and five collaborating scientists, who often come from two or three different institutes or countries. About 80 per cent of all experiments at the ILL involve a multinational collaboration.

The ILL's network of instrument scientists and technicians, and local scientific contacts, ensures that expert advice is available at all stages – from conception and definition of the experiment, in preparing the submission of the proposal, during the experiment itself, and afterwards with the analysis and interpretation of data, up to publication and communication of the results. ILL scientists are normally co-authors of the resulting scientific papers. They are internationally renowned in their own right, and receive recognition through national and international science awards, as well as regularly being invited to speak at seminars and conferences.

Advisory bodies and peer review

Like all large international facilities, the ILL has a management structure responsible to the member states

The Director, supported by the Management Board composed of the Science Director, the Projects Director and the Heads of the Reactor and Administration, is responsible for all aspects of the functioning of the Institute. The overall policy, strategy and budget is set by the Steering Committee which – with input from the ILL's Directors – is advised by its Subcommittee on Administrative Questions and the Audit Commission.

The ILL's Scientific Council meets twice a year to advise on the scientific priorities of the Institute, and to select from the many hundreds of research proposals from prospective users. These are peer reviewed by the ILL's eight subject colleges. Accepted proposals are carried out in the following 6 months.

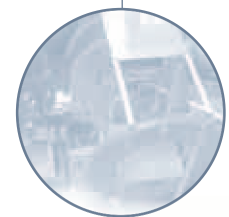
The Instrument Subcommittee advises on the feasibility of new instruments and prioritises such projects, advising both the Scientific Council and the ILL Directors.

A particularly visible aspect of the ILL's scientific life are the specialist seminars given by highly renowned scientists. More than 150 such seminars are given each year. A similar number are given at the ESRF and perhaps 50 at the EMBL. In addition, the Colleges organise workshops, each attended by around 100 researchers from around the world. About eight such workshops and conferences are held at the ILL each year, many in collaboration with our neighbouring institutes.

Such a rich scientific environment is particularly valuable for broadening the horizons of the 100 or so doctoral students permanently located on site. These students are jointly supervised by senior scientists at the ILL, the EMBL and the ESRF whilst being registered at universities in our Partner Countries.

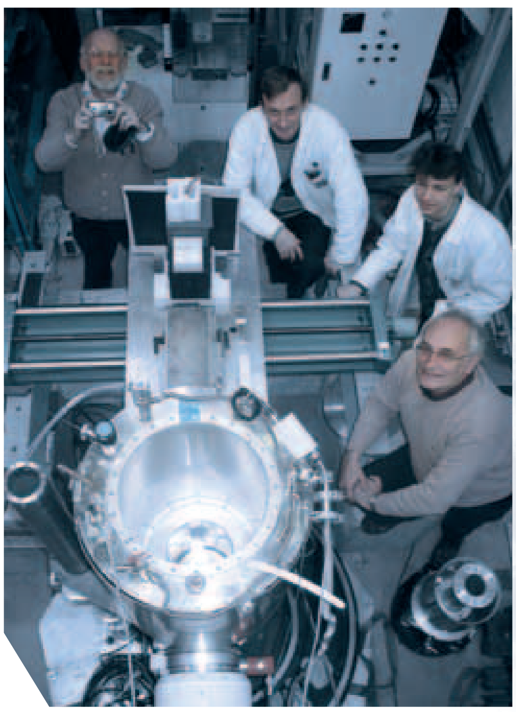
The ILL's scientific life is organised into 10 colleges:

College 1	Applied physics, instrumentation and techniques
College 2	Theory
College 3	Nuclear and particle physics
College 4	Magnetic excitations
College 5A	Crystallography
College 5B	Magnetic structures
College 6	Structure and dynamics of liquids and glasses
College 7	Spectroscopy in solid state physics and chemistry
College 8	Structure and dynamics of biological systems
College 9	Structure and dynamics of soft condensed matter



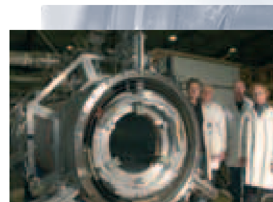
Collaborating Research Groups

A particularly successful form of long-term international scientific collaboration is the Collaborative Research Group (CRG)



CRGs are composed of scientists from one or two research disciplines, often multinational, who pursue a common research programme centred upon a private instrument. CRGs build and manage private instruments on ILL beamlines to carry out their own research programmes, and have exclusive access to these instruments for at least half the time. These CRGs add breadth to the ILL's suite of instruments, enhancing the appeal of the whole instrument suite to new research topics, and are especially potent in the training of new researchers and neutron instrumentalists. CRGs are required to be cost-neutral to the ILL although the neutron beams are provided free of charge.

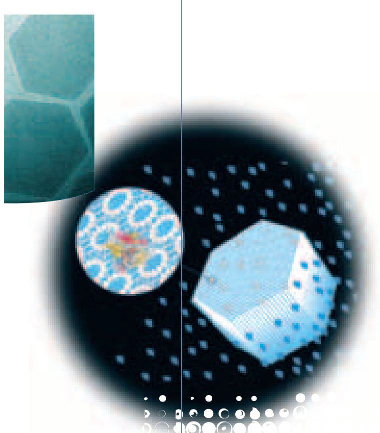
There are currently 10 CRGs and we have the capacity to increase this number to 15 by the year 2012, fuelled by the increased number of Scientific Partners.

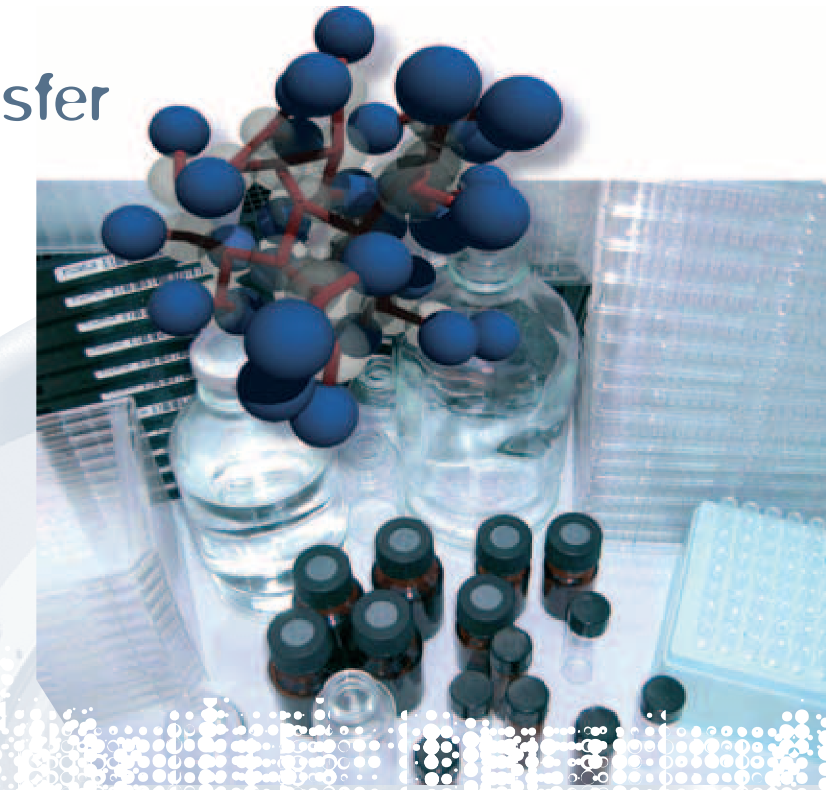


The ILL's Collaborating Research Group instruments

Instrument name	Instrument type	Partners
ADAM	Reflectometer	University of Bochum
BRISP	Brillouin spectrometer	Universities of Florence and Perugia / University of Marburg
D1B	Powder diffractometer	CNRS Grenoble / CSIC Madrid
D15	Four-circle diffractometer	CEA Grenoble / CSIC Madrid
D23	Two-axis diffractometer	CEA Grenoble / FZ Jülich
IN12	Three-axis spectrometer	FZ Jülich / CEA Grenoble
IN13	Backscattering spectrometer	UJF Grenoble / CNRS / LLB Saclay / University of Parma
IN22	Three-axis spectrometer	CEA Grenoble / FZ Jülich
S18	Neutron interferometer	Atominstitut, Vienna
Cryo-edm	Neutron edm	University of Sussex / Rutherford Appleton Laboratory

Industry, knowledge transfer and intellectual property





About one-quarter of experiments carried out at the ILL have direct relevance to industry

Work on catalysts, pharmaceuticals and polymers is a common theme but more specific work concerns, for example, studies of the delivery of antibiotics, the permeability of packaging materials or the integrity of exotic welds. Most industrial collaborations are pursued indirectly via contracts placed with university groups for specific research programmes rather than through direct participation.

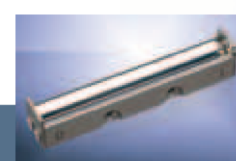
European companies also take advantage of the ILL's facilities via direct academic collaborations. For example, the Swedish company **Camurus**, based in Lund, develops a wide range of drug-delivery systems based on lipid liquid crystals (similar to soap molecules). These form nano-structured particles that can encapsulate drug molecules such as anticancer drugs, painkillers or anaesthetics. Camurus has been working with a research group at Oxford carrying out neutron reflectivity experiments at the ILL to look at the fundamental properties of these nanoparticles. The aim is to understand their molecular properties and structure, and how they interact with biological interfaces such as cell and artery surfaces, the mucous lining of the mouth and the gastrointestinal system.

Industry's use of our beams for research studies is but one means of interaction. Just as important is the spin-out of technology to small companies such as **XENOCS** (supermirrors, p B.28), **INEL** (detectors), or **AS Scientific** (cryostats). Another important aspect is that engineering firms benefit from the high technical standards demanded in the supply of components to us, often manufactured from unusual materials and to high precision. A survey carried out by CERN, one of our EIROforum partners (p A.11), revealed that such development contracts enable

industrial companies to increase their business by more than three times, as a result of expertise gained in contracts with the European laboratories.

Another commercial spin-off is that work at the Institute generates many jobs in the surrounding community. A study by the ESRF found that for every post within the laboratory, 2.2 times as many posts in local industry and services were created. This means that the 1250 employees on the ILL, EMBL, ESRF site amplify up to almost 4000 full-time jobs that are dependent on our continued existence.

The protection of the ILL's intellectual property has long been neglected and in today's climate we need a more professional approach. Through our EIROforum links, we are exploring how to benefit from the experience and expertise of EMBLEM – the EMBL's enterprise management arm and CERN.

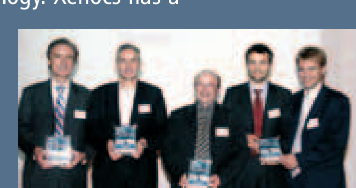


XENOCS

The ILL leads the world in developing neutron optics, and is capitalising on that knowledge which had been built up over three decades. A spin-out company, XENOCS, set-up in 2000 by two ILL scientists makes and markets a variety of optical components for industry and research-based organisations.

Peter Høghøj, the Managing Director of XENOCS, did his PhD at the ESRF working on X-ray optics. He then moved to the Optics Group at the ILL in 1994. Guiding and focusing neutrons as well as high-energy electromagnetic radiation, X-rays and gamma-rays, requires similar technology – that of precisely-formed multi-layered surfaces. "Using sputtering methods, we reached a level of perfection that started to excite interest outside the Institute from other laboratories and from industry," says Dr Høghøj, "so we decided to set up a commercial enterprise." With the ILL's blessing, and with guidance from the French Atomic Energy Commission (CEA), the researchers teamed up with people from the Grenoble Business School to propose a business plan. After winning seedcorn money from a French government innovation competition, and with local government support, the embryonic team signed a technology-transfer agreement with the ILL, and XENOCS was born.

The company is based in Sassenage, a suburb of Grenoble close to ILL, and now employs 32 people. It produces complete optical components for X-ray equipment used in analysis and metrology. Xenocs has a prestigious contract with the European Space Agency to develop reflective coatings for mirrors to be used in the next generation of high-energy X-ray telescopes. "In terms of algorithms used, the method for making the coatings is very similar to that employed for neutron optics. There is a direct link between the neutron mirrors first developed at the ILL in the 1970s and this frontier work," says Dr Høghøj.



The XENOCS team win the OSEO Anvar Prize for innovation

Training

Training at ILL has at least three interlinked elements:

- New neutron users have little knowledge or experience of the experimental techniques involved in neutron scattering, unlike for synchrotron radiation where laboratory X-ray sources abound in university research centres. The ILL runs training courses for students and provides exploratory beam-time to newcomers. The ILL's scientists help to organise and teach on the HERCULES course (see below) and at summer schools in our member countries. In carrying out experiments, users are exposed to the state-of-the-art technologies.

- The ILL has an international PhD student programme and is planning to coordinate the training of the 100 or so doctoral students on the joint site, particularly in ancillary technologies such as cryogenics and soft skills such as project management and the writing of good grant applications. The ILL is considering implementing the European Charter for Researchers along with our EIROForum partners. An EU-supported Erasmus MSc in Materials Science with the Universities of Rennes, Turin and Munich is another initiative currently under consideration. The ILL plans to set up a 2-year Postdoctoral Fellowship Programme for up to 10 young researchers to pursue new ideas in developing and using instruments.

- Our staff are encouraged to realise their full potential. Training is an important ingredient in our future success, and is now regarded as a life-long activity. The ILL, within its Staff Plan, is exploring the best way to achieve this. Honorary appointments for senior ILL scientists with collaborating universities is one option being looked at to validate and motivate our best researchers as well as disseminating knowledge about neutron techniques.

Leading on from these aspects is the support that the ILL can provide for a knowledge-based economy in Europe by nurturing the next generation of skilled personnel.

HERCULES courses

Students and young researchers who are unfamiliar with the intricacies of neutron scattering need to learn about using neutron methods. Together with the ESRF, the EMBL and Grenoble's University Joseph Fourier, the ILL runs the HERCULES (Higher European Research Course for Users of Large Experimental Systems) international programme which offers basic theoretical and experimental training. The annual 5-week course for 80 international students, includes lectures, practical sessions and tutorials. HERCULES is funded by the EU and French Government agencies. At the moment, the course consists of two sessions: one on physics and chemistry and one on life-science applications. Both courses cover technical aspects of neutron and synchrotron radiation instrumentation. Shorter courses on nanotechnology and biotechnology are new initiatives started in 2006.

EUTRON TECHNOLOGIES AND PRO USERS, IS THE GOAL OF THE ILL'S TEC
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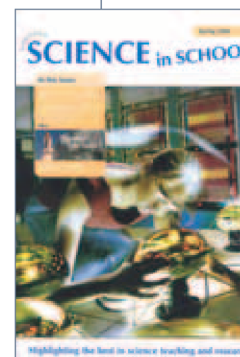
Public awareness and education



Most people know little about neutrons – what they are and what they can do. It is important, therefore, that the public, which ultimately funds the facility, as well as the funders of the research carried out, should be aware of the value of neutrons in advancing scientific knowledge. With this in mind, the ILL publishes a series of popular booklets of themed scientific highlights.

It is extremely important for us to have good relations with the local community and local government, and we plan to open parts of the site to informal public access, in particular schools.

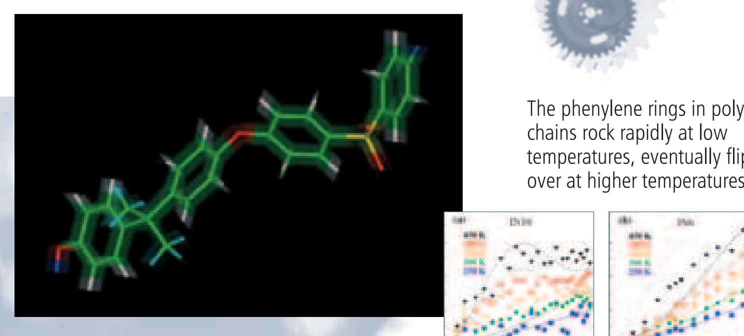
The ILL participates fully in the annual 'Science Week' public awareness event in Grenoble, and in the '100 scientists for 100 schools' programme. Around 50 tours comprising 2000 visitors are conducted around our facilities each year. These are composed mainly of final-year school students and undergraduates who come from far-flung parts of Europe. Our radiation-protection staff regularly explain to an interested public the reality and the risks of radioactivity in an attempt to demystify this natural process.

Through EIROforum (p A.11), the ILL is also participating in European school science education. EIROforum has won significant grants from the EU for the European Science Teachers Initiative (ESTI) to run the successful European education event *Science on Stage*, and to launch a new European education journal, *Science in Schools*. The next *Science on Stage* festival in spring 2007 is to be organised jointly by the ILL and the ESRF, and will take place on our joint site. We expect to welcome 400 science teachers and students from more than 30 countries, raising awareness of our facilities and of the excellent location of Grenoble and the infrastructure of the Rhône-Alpes Region.

The ILL participates in the *Science on Stage* festival

Scientific successes

Many important insights could not have been achieved without the use of neutrons. A few examples out of many hundreds of recent scientific breakthroughs at the ILL are described below

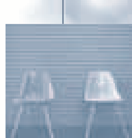


The phenylene rings in polysulfone chains rock rapidly at low temperatures, eventually flipping over at higher temperatures

Rock 'n' roll plastics

Constructional thermoplastics such as polycarbonate or polysulfone are both extremely strong and resilient. This is because they possess stiff, strongly bonded phenylene rings spaced along the polymer chains. They can, nevertheless, rotate about the polymer axis, absorbing energy when stress is applied and permitting the chains to slide smoothly against each other so as to impart some flexibility to the plastic.

Silvia Arrese-Igor and **Juan Colmenero** of the University of the Basque Country in San Sebastian, Spain, have been studying these so-called secondary relaxations in polysulfone using inelastic neutron scattering. The polysulfone backbone was deuterated so that only scattering from hydrogen atoms in the phenylene rings was visible. The motion of the rings was then followed over a wide range of temperatures from 2 to 450 K, just below the point at which the plastic softens. They found that at low temperatures the rings simply oscillate around the chain axis. As the temperature is increased, the oscillations get faster until, above 200 K, the rings have sufficient energy to flip right over like a pancake. These experiments not only address fundamental questions about the origin of secondary relaxations in polymers but also provide valuable information for designing new plastics with tailor-made mechanical properties.

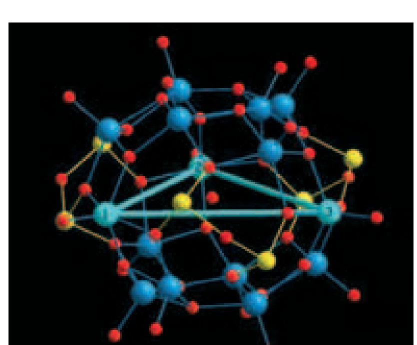


An unusual molecular magnet

Molecules containing a cluster of magnetic metal atoms are fascinating because of the surprising ways in which their constituent spins can interact. One example is a heavily hydrated complex consisting of 15 vanadium atoms, each with a spin of one-half. The vanadium atoms are arranged as two opposing hexagons with a triangle sandwiched between them. The spins on the hexagons form strongly coupled non-magnetic pairs, which also interact weakly with individual vanadiums in the central triangle, so that these atoms are also weakly coupled with each other. At very low temperatures (around 2 K) the system is effectively magnetic, made up of three indirectly interacting spins. At least two of these spins are always forced to be parallel, while they would all prefer to be antiparallel. This means that there are two possible lowest quantum energy levels for the molecule, depending on which spins are up or down. An eventual goal of this work is to discover a molecular material which is ferromagnetic at room temperature.

Grégory Chaboussant and **Hans Güdel** at the University of Bern in Switzerland have investigated the energies of the two ground states using high-resolution inelastic neutron scattering. With the sample cooled to around 50 mK, the experiment was carried out with magnetic fields going up to 1 tesla. The results revealed five distinct inelastic transitions, which can be explained by three sets of unequal couplings between the central triangle of antiparallel spins. There is a tiny but significant energy gap between the two lowest states, most likely induced by the distortion of the vanadium triangle as a result of one water molecule sitting inside the cluster and disordered water molecules sitting in the crystal lattice. The data also suggest that the ground states are 'entangled' – a property of quantum systems in which states are intrinsically linked. Entangled states are of great current interest in the burgeoning field of quantum computing as a future way of encoding and processing large amounts of data.

In 2005, together with Albert Furrer, Hans Güdel was awarded the Walter Hälg Prize of the European Neutron Scattering Association (ENSA).

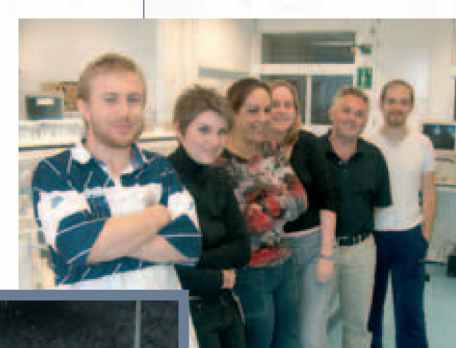


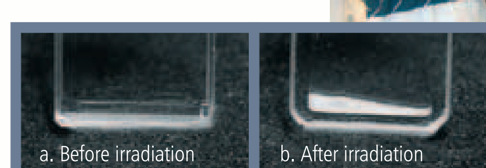
Molecular structure of the vanadium cluster showing the triangle of vanadium ions

Photo-sensitive emulsions

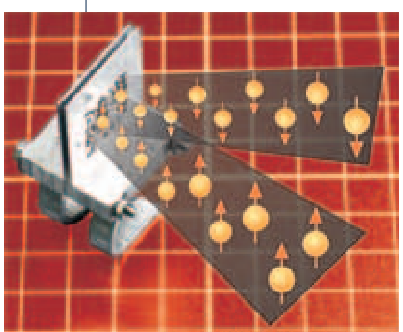
One of the most significant uses of neutrons today is in studying soft materials having a complex structure at the nano-level, such as detergents, or surfactants. These chemicals adsorb at the interfaces between liquids that are normally immiscible, such as oil and water, and create a colloidal suspension of tiny droplets of one liquid in the other (an emulsion). Synthetic surfactants are crucial ingredients of all domestic or industrial cleaning products but can also be used to deliver drugs or even genes into cells. Knowing their structure and controlling their behaviour is therefore of key importance.

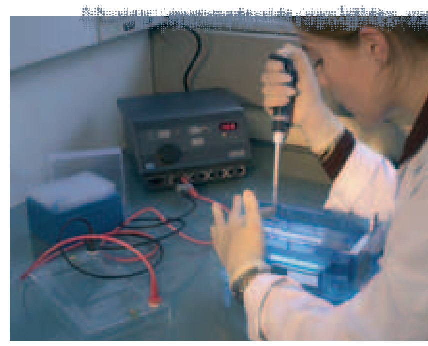
Julian Eastoe of Bristol University in the UK has been exploring novel surfactant systems that are affected by ultraviolet light. A light-sensitive emulsion is a candidate delivery system for active chemicals in a variety of applications. He prepared micro-emulsions of nano-sized droplets of water in oil using a mixture of a surfactant that is broken up by light and one that is inert. Changes in droplet structure on UV irradiation could then be followed using small-angle neutron scattering (SANS), which is the classic technique for observing phenomena at this scale. By substituting some of the hydrogen in the water or in the oil with its isotope deuterium, the SANS experiments were able to pick out and measure different components of the nanodroplets.

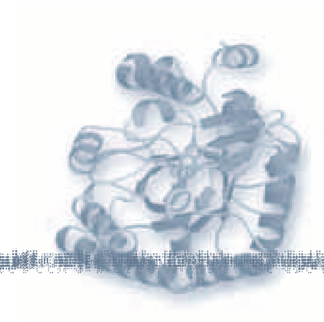




Julian Eastoe's team irradiate a microemulsion with UV light: initially it is transparent but becomes milky as the nanometre-sized droplets grow in scale





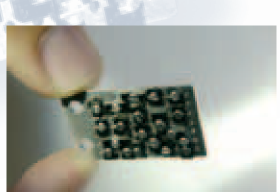


Deuteration is used to highlight components in the structure of proteins and other bio-materials

Inside superconductors

The so-called cuprate superconductors, some of which conduct electricity without resistance even above liquid-nitrogen temperatures, continue to fascinate and mystify scientists. Cuprates consist of weakly-interacting copper-oxide (CuO_2) layers, with electrical, optical and magnetic properties in the plane of the layers that are fundamentally different from those in the perpendicular direction. This complex behaviour presents a major challenge to explaining the mechanism behind their superconductivity. One controversial idea is that the charge carriers responsible travel along one-dimensional (1-D) stripes in the copper-oxygen layers.

Inelastic neutron scattering is the only technique that can directly reveal the stripes by tracking the 1-D dynamics of the carriers' tiny magnetic moments. This requires sample crystals carefully prepared by a method called de-twinning to ensure that all stripes – if they exist – run in the same direction. Recently, **Vladimir Hinkov** and **Bernhard Keimer** of the Max-Planck-Institute (MPI) for Solid State Research in Stuttgart, Germany, succeeded in preparing 180 tiny, de-twinned crystals and then aligning them to form a large composite sample that would give a signal strong enough to measure. Using the thermal triple-axis spectrometer IN8 at the ILL – the best of its kind in the world – they ruled out static stripes. However, the experiment showed that the electronic structure of the copper-oxide layers is actually unstable. A possible explanation for this behaviour is the existence of dynamic stripes with a fluctuating orientation in two dimensions.

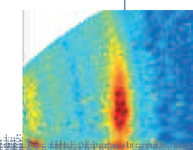


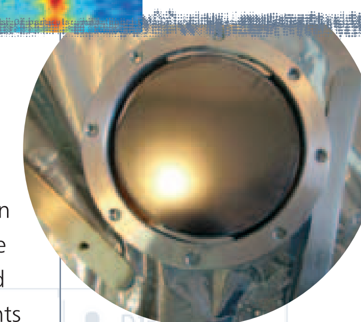
The aligned de-twinned crystals

Analysing the structure of proteins

The complex three-dimensional structures of proteins and other large biological molecules have traditionally been solved using X-ray crystallography. However, X-rays do not scatter off hydrogen atoms effectively and cannot easily pinpoint them within the molecule. Knowing the position of the hydrogen atoms is extremely important in understanding the detailed conformation of proteins – particularly in their natural aqueous environment where water molecules may mediate weak hydrogen bonding within the protein structure. Neutrons, however, scatter strongly off hydrogen atoms and provide the ideal tool for analysing protein behaviour. The scattering is enhanced if hydrogen atoms are replaced by deuterium.

Recently, the ILL has set up a dedicated laboratory for deuterating biological samples – the D-Lab which is now incorporated in the Partnership for Structural Biology (p A.35). Special techniques have been developed to produce deuterated proteins and other bio-materials. Bacteria, genetically engineered to express the required protein, are fed with heavy water (D_2O) and deuterated nutrients. Such a process, properly elaborated, produces the fully deuterated material. Some complex proteins may consist of two or three subunits. In these cases, the deuterated and undeuterated forms can be prepared, then taken apart and reassembled so that only selected subunits are deuterated; their scattering patterns are then highlighted. Recently, **Marie-Thérèse Dauvergne** and **Alberto Podjarny** of the University of Strasbourg in France have analysed a number of important protein structures including aldose reductase, an enzyme implicated in diabetes, and have identified a key structural element previously unseen which may give insights into the biological activity of this enzyme.

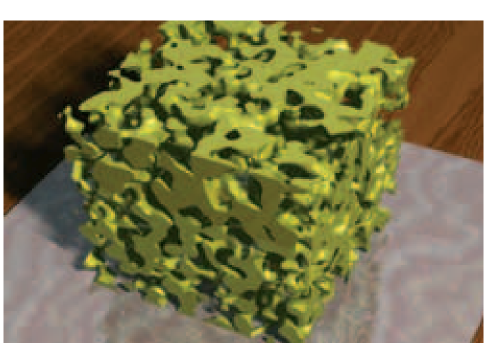




Magnetic emulsions

Because neutrons have a magnetic moment, they are excellent probes of magnetism. **Bob Cywinski** of the University of Leeds in the UK has observed some very unusual magnetic behaviour using magnetic small-angle scattering. The yttrium-manganese alloy, YMn_2 is not magnetic at high temperatures but becomes magnetic when cooled. The crystal structure also expands, and can be made to accommodate some iron. However, this material appears to lose its magnetism altogether, despite the fact that iron is, of course, the archetypal ferromagnet (the iron atoms in the pure metal have ordered parallel magnetic moments).

As more iron is added to the alloy, signs of disordered magnetic behaviour appear, and eventually, at high concentrations, the iron dominates and the material does become ferromagnetic. Professor Cywinski considers that the iron-containing material is never really nonmagnetic but contains antiparallel magnetic moments – antiferromagnetism – which fluctuate so rapidly that they appear to have no magnetic order. The alloy can be regarded as a kind of magnetic emulsion in which islands of ferromagnetic iron are surrounded by an antiferromagnetic phase, rather like droplets of oil in water. The magnetic scattering data reveals that the emulsion possesses a rarely seen, highly convoluted structure.

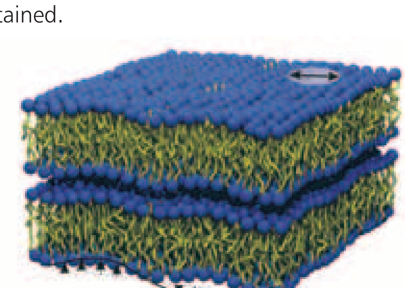


Simulation of a magnetic emulsion

Moving membranes

Another important set of biological systems that can be studied with neutrons are cell membranes. These consist of arrays of phospholipid chains sandwiched in bilayers so that hydrophilic phosphate components face outwards and the oily lipid chains form the sandwich filling. These layers are far from static, and understanding both their structure and dynamics is vital in elucidating many biological processes as well as for developing methods of delivering drugs and genes into cells. Of particular importance is the interaction between the phospholipids and the water molecules immediately surrounding them.

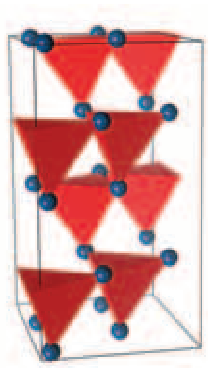
Using a high-resolution neutron scattering technique, two German scientists at the ILL, **Maikel Rheinstädter** and **Thilo Seydel**, probed very slow motions occurring over a few nanoseconds in a model lipid bilayer system. To obtain a strong signal, the sample consisted of a stack of several thousand highly aligned lipid bilayers. The researchers measured the weak inelastic signals over temperatures ranging from 100 to 315 K. These measurements showed that the lipid chains were immobile up to a temperature of 294 K when they became significantly more fluid, undergoing collective motions across the layers on length-scales of about a nanometre. The scattering data also revealed another transition at about 271 K which the researchers attribute to the melting of the water between the stacked phospholipids. The behaviour of this layer is probably modified by being hydrogen-bonded to the phospholipids, so that it melts at a slightly lower temperature than bulk ice. This is the first time that such detailed information about membrane dynamics and the surrounding water has been obtained.



A lipid bilayer in motion

Order out of chaos

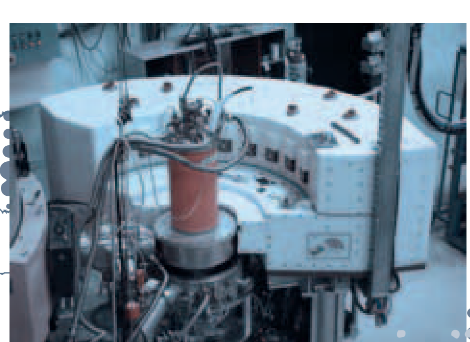
Much of the research with neutrons involves understanding the structural properties of matter at the most basic level. Armed with this information, scientists can then go on to develop new materials and technologies. **Phil Salmon** of the University of Bath in the UK has been studying compounds which do not organise themselves into an ordered crystal structure when molten and cooled down quickly; instead they become glasses in which the atoms appear to be randomly arranged at large interatomic spacings. Industrialists are interested in glasses because they contain open networks that can host or entrap various atoms. They are prime candidates to be used to store nuclear waste safely.

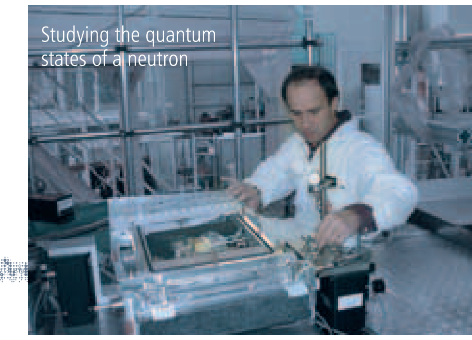


The zinc dichloride structure

Dr Salmon looked at two glassy networks with extreme types of bonding – germanium diselenide in which bonding electrons are shared between the atoms (covalent bonding), and zinc dichloride in which the bonding electrons are transferred from the zinc to the chlorine atoms (ionic bonding). At first sight it might appear difficult to study the structure of these materials using neutron diffraction because the sharp peaks normally associated with a crystal structure would not be present. However, by employing isotopic substitution to provide contrast, it is possible to glean very precise information about the distances between pairs of similar atoms and pairs of dissimilar atoms, for example, between the zinc-zinc, chlorine-chlorine and zinc-chlorine pairs.

The D4 instrument, upgraded in the Millennium Programme, and viewing the new intense hot neutron source at the ILL, enabled Dr Salmon to disentangle the complex scattering patterns measured on very small samples thanks to the stability of the ILL's neutron source and the instrument's innovative microstrip detector developed in-house. He could discern the proximity of one atom to its surrounding atoms out to its 30th nearest neighbours, and found that, in fact, the materials were less randomly arranged than expected. There is some structural order even at these long length scales. The results offer an insight into why some liquids form glasses when they cool down and some do not, and could lead to new technologically useful glassy materials.





Studying the quantum states of a neutron

The quantum neutron

As well as providing a tool to probe complex materials, experiments on the neutron itself offer a powerful and intriguing way to study matter at the most fundamental level. Recently, **Valery Nesvizhevsky** and colleagues designed a remarkable experiment to observe the quantum states of a neutron in a gravitational field. We know that microscopic particles like neutrons possess distinct quantum energy states manifested when subjected to fundamental forces such as an electric or magnetic field, or the strong nuclear force. Gravity, however, is extremely weak compared to other fundamental forces, and any quantum effects due to gravity have, up to now, been too small to see on Earth.

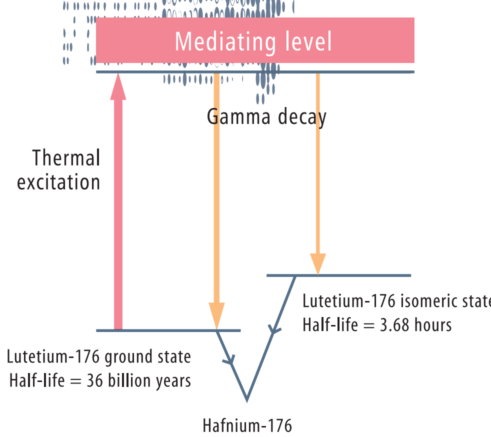
For the first time, Dr Nezviszevsky has shown that the trajectories of very low energy, ultra-cold neutrons, when gently balanced on a mirror and allowed to segregate under gravity, are composed of discrete quantised layers. His team is now planning a series of experiments using more precise equipment to investigate gravity further through the medium of extremely slow neutrons. These measurements will test current ideas about the gravitational force, possibly leading towards a unified description of all the forces.

Using mirrors to trap the neutrons, the collaborators will measure accurately the population of neutrons in different quantum states. They will then perturb the system, either by causing the mirrors to vibrate, or by applying an electric or a magnetic field, or by introducing an oscillating gravitational field from a rotating heavy mass. At certain well-defined frequencies, neutrons will be transferred from a lower to a higher quantum state or vice versa, as revealed by the change in population of the different levels. If an electric field, for example, induces a change, then this will be a measure of the neutral neutrons's internal electric charge – as predicted by certain unified theories. Causing transitions of the neutrons from one level to another with a gravitational field could infer the existence of the associated quantum particle, the graviton, predicted to have a spin of 2. This would reveal for the first time gravity's true quantum nature, and would represent a major breakthrough in our understanding of the Universe.

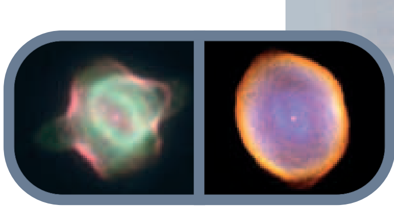
Not a cosmic clock but a stellar thermometer

The neutron is a component of the nuclei of all elements apart from hydrogen, and the ILL's neutron source is used to study various kinds of unusual exotic nuclei. An area of growing interest is investigating how nuclei were first built up in stars. For example, the nuclei of one group of heavy elements are created only in stars known as red giants. Laboratory measurements show that one of these isotopes, lutetium-176 has a very long half-life of 36 billion years. Its decay to hafnium-176, could therefore, in principle, be used as a clock to determine the age of other elements in red giants. As with the familiar carbon-dating process, the idea is to determine the concentration originally created in a red giant and then compare it with how much remains today.

However, studies at the ILL by **Franz Käppeler** and **Hans Börner** have revealed a problem. As well as decaying via a process channelled through the long half-life, the lutetium isotope can also decay by another route which is dependent on temperature and takes only a few hours. As it gets hotter, on a stellar scale, the lifetime of lutetium appears to get shorter. Using high-resolution gamma spectroscopy, the researchers were able to study these two processes. They found that up to 150 million degrees the half-life of lutetium-176 remained at its room temperature value, but at the temperatures found in red giants its half-life drops to about a year. So while lutetium-176 is not in fact useful as a cosmic clock as supposed, it could act as a thermometer for measuring the temperatures inside red giants – which is postulated to be between 200 and 300 million degrees.

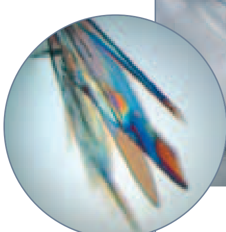


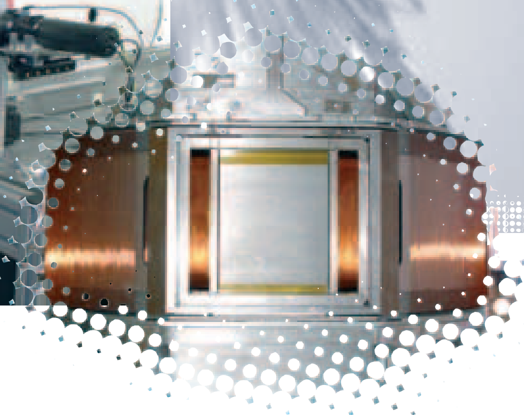
The competing decay processes for lutetium-176



Technical innovations

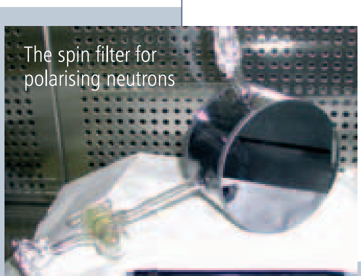
The ILL has a continuous programme of instrument development to make the most of its powerful neutron source





A cool polariser

One of the most successful concept developed at the ILL in recent years has been the helium-3 spin filter which polarises the spins of neutrons extremely efficiently. Polarised neutrons are required for several kinds of experiment, particularly those investigating magnetism and the fundamental properties of the neutron itself (subtle measurements of the neutron's spin properties are a test of theories about the fundamental forces). The filter works on the principle that helium-3 absorbs only neutrons with spins antiparallel to its nuclear spin. The spins of the helium-3 nuclei are first polarised with an infrared laser beam, so that only neutrons with spins in the same direction can pass through. The spin filter cells are small and portable and can be used on various instruments; they can also polarise neutron beams with a wide range of wavelengths. The technology is now being applied at other neutron facilities around the world including the UK neutron facility ISIS, and the FRM-II reactor in Munich.



The spin filter for polarising neutrons

Super supermirrors

Neutron beams can be guided and concentrated by special reflecting devices known as supermirrors. These consist of silicon or float-glass substrates coated with a series of very thin layers of material with contrasting powers of reflection such as nickel and titanium. Each additional layer increases the reflecting power. Recently, precise computer control of the process for depositing the layers has led to improved mirrors with a larger number of ever thinner layers. The latest nickel-titanium mirrors now have thousands of layers, giving four times the acceptance angle of pure nickel – the original mirror material used. Polarising supermirrors are also made by the same technique with iron-silicon multi-layers. These exciting developments are leading to better focusing devices resulting in instruments with high luminosity. Most notably, this has been applied to the D7 polarisation analysis spectrometer within the ILL's Millennium Programme (p A.24). The instrument is already producing spectacular results.

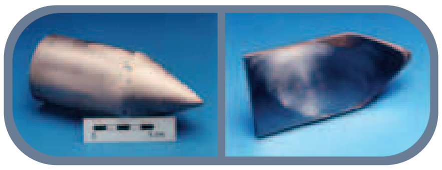
A supermirror


The VIVALDI instrument

A monochromator array


Large monochromators

Monochromators – single-crystals of metals or insulators – are essential devices that select the wavelength of neutrons required to illuminate the sample. Modern monochromators consist of many elements arranged on a doubly curved surface with variable geometry to focus the beam on the sample. The ILL has a dedicated team of scientists and engineers that produce these beautiful devices – growing the original crystal ingots, cutting, polishing and annealing them so that they have the precise properties required for a specific instrument. Properly designed, they can enhance the effective power of the source by 10 to 20 times, or even more. Monochromator arrays fabricated from crystals of so-called Heusler alloys not only focus neutrons but also polarise them as well. The team is now working on cooled monochromators to enhance further the quality of the signal.


Crystals made from Heusler alloys

Large area detectors

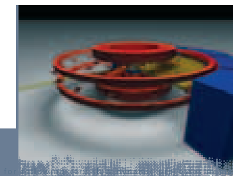
An important advance that has allowed neutron diffraction to be extended to large biological structures is the development of large area, finely pixellated detectors. These collect the scattered neutrons at all angles simultaneously, instead of via the usual method of rotating the sample stepwise and detecting them at a number of specific angles. The ILL's current LADI instrument has a cylindrical wrap-around detector which is based on a phosphor detector that builds up a latent image similar to that on a photographic film. The newer, large-area detector instrument, VIVALDI, based on the same technology but using thermal neutrons, is being used for rapidly scanning new materials, as they undergo structural phase transitions in real time, and for revealing structural information previously unobserved.

Much effort has been devoted to developing new types of detectors that are hybrid devices similar to those used in high-energy physics – microstrip and gas detectors combined. Such detectors are now operational on the D19 instrument, for example, to carry out diffraction studies of biological and industrial fibres, such as DNA, cellulose and synthetic polymers used in anti-terrorist protective clothing.


The D19 detector

Specialised neutron techniques

With novel instrumentation come new kinds of experiments that extend the range of scientific problems that neutrons can tackle.



The proposed WASP spectrometer

Contrast enhancing and matching

ILL Deuteration Laboratory

This technique, which makes neutron diffraction unique in the information it can provide, exploits the differing scattering powers of hydrogen and its isotope deuterium. As explained on page B.23, substituting hydrogen with deuterium in selected molecular components of a system highlights those parts. If dissolved in water, then a proportion of the water can also be replaced with deuterated water so that its scattering properties match those of various components in the system rendering them 'invisible'. A component with different scattering properties then stands out. Contrast matching is a key method in structural biology studies and is the reason for building a special deuteration laboratory.

An even more powerful means of contrast matching comes from aligning the spins of all the hydrogen nuclei in a sample, thereby greatly amplifying and clarifying the data. The ILL is exploring how to do it, since it would have significant applications in protein crystallography.

Neutron spherical polarimetry

Some materials have extremely complex magnetic structures in which the magnetic moments of the constituent atoms may be aligned in various directions; they can also involve subtle interactions between nuclear and electronic magnetic moments. To obtain a complete picture of such systems requires not only good beams of polarised neutrons but also a stable environment in which the spins of the scattered neutrons can be measured in all directions – spherical neutron polarimetry. The ILL has, over the years, perfected a method for analysing magnetic scattering in a zero-field environment using a device called Cryopad. It can supply polarised neutrons in any chosen orientation and then measure changes in orientation of the outgoing neutrons. Cryopad consists of a cryostat containing a cylinder which is shielded from extraneous magnetic fields by superconducting coils. Inside is a series of electric coils that can be rotated and used to orient the polarised neutron beam.

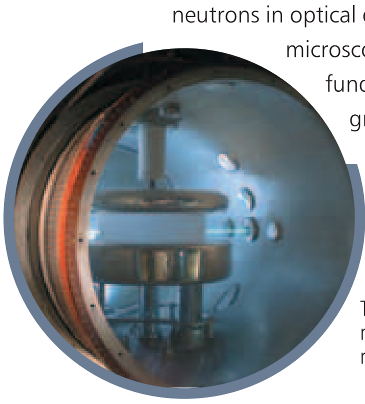
Cryopad

Neutron spin-echo

A remarkable technique called neutron spin-echo, pioneered at the ILL by Feri Mezei and John Hayter, offers a highly sensitive method for following very slow dynamic processes in materials. The neutron beam is first polarised and then passed through a magnetic field. This causes the neutron spins to precess like spinning tops. The number of precessions depends on the time each neutron takes to traverse the field, which in turn depends on its energy. After being scattered by the sample, the neutrons pass through a second identical magnetic field, which winds the spins back through exactly the same number of precessions over the same period of time so that the spins achieve their original orientations thereby creating a strong echo. If, however, some of the neutrons have lost or gained minute amounts of energy by interacting with molecular constituents of the sample, they will not all end up with the same spin polarisation that they started with. This deficiency then provides a clever method of measuring the tiny energy changes associated with slow movements such as that of a polymer chain wriggling through the tangled mass of other polymer chains or of biological cells and membranes responding to a change of pH (acidity/alkalinity) of the mother liquor. The proposed WASP spectrometer will make this method even more sensitive and maintain the ILL's 20-year lead in the field.

Experiments with ultra-cold neutrons

The ILL produces the coldest neutrons in the world. A vertical beam of ultra-cold neutrons is first extracted from the surface of the liquid deuterium cold source, and is then cooled even further by passing them through a neutron turbine. This consists of a wheel nearly 2 metres across with 690 cylindrical blades along its outer edge. The moving blades reflect the neutrons while receding from them, so slowing them down in the same way that a tennis-player executes a drop volley. Ultra cold neutrons are totally reflected from the surface of most materials, which offers the possibility of storing them as a gas in so-called neutron bottles. The gas can then be used to study several fundamental characteristics of the neutron itself such as its decay parameters or its electric dipole moment. Accurate measures of both properties are crucial to theories of fundamental particles and forces. Another option is to employ the trapped neutrons in optical devices such as a neutron microscope, or to search for the fundamental origins of the gravitational force.



The experiment to measure the neutron electric dipole moment requires ultra-cold neutrons

Seeing with neutron eyes

Just as X-rays can be used to see inside objects, so can neutrons since they penetrate matter even better than X-rays do. The varying levels of attenuation caused by internal structures in an object produce the image. However, because neutrons interact with various light elements which are not greatly affected by X-rays, neutron radiography can reveal structures otherwise invisible. Three-dimensional images can also be compiled by taking neutron snapshots in slices across an object and then combining the 2-D images. In this way it is possible to create detailed images of fuel passing through an engine and the consequent combustion process, the internal structure of archaeological artifacts such as axes, spoons or buried pots, or the delicate structures inside biological plants and the manner in which they take up water and transpire. The ILL has a new high-intensity experimental station for neutron radiography and tomography. One remarkable image taken recently reveals fossilised leaves from a monkey puzzle tree inside a rock found in Antarctica and estimated to be 50 million years old.

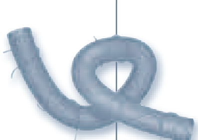
Fossilised leaves as seen by neutron tomography

Being an ILL scientist takes you...

Benefiting from the experience offered by working at the ILL, many of the ILL's instrument scientists have gone on to achieve academic success elsewhere

Dame Julia Higgins is one of the UK's most eminent scientists. As well being Professor of Polymer Science at Imperial College London, she is currently Chairman of the Engineering and Physical Sciences Research Council (the Government body that funds a major proportion of academic research in the UK) and Vice President and Foreign Secretary of The Royal Society. She is also active in promoting opportunities for women in science.

Dame Julia was one of the group of researchers who pioneered neutron techniques in the early 1970s. Following postgraduate work at the University of Oxford using neutrons to probe the motions of molecules trapped in an organic cage, she then went on to apply neutron scattering to polymers while at Manchester University. "We were among the first chemists to do neutron scattering," she says. After being introduced to the then-new technique of small-angle neutron scattering, SANS (p B.5), at CEA Saclay in Gif-sur-Yvette, France, Dame Julia was recruited by the ILL which was just starting up. "It was fantastic," she recalls. "I was one of the first to use the new D11 instrument, which has been for many years the most powerful SANS instrument in the world. The backscattering IN10 instrument also came on line which allowed me to look at the motion of polymers." Eventually, Dame Julia moved to Imperial College where she continued her polymer studies, exploiting the powerful neutron spin-echo technique developed at the ILL (p B.30) to look at the slow, reptilian motions of polymer chains. Despite a busy schedule helping to manage UK science, Dame Julia still collaborates with European teams on experiments at the ILL. In 2006, she was awarded the Holweck Prize by the SFP (Société Française de Physique), a prize that illustrates the fruitful relationship between French and British scientists.



The Royal Society

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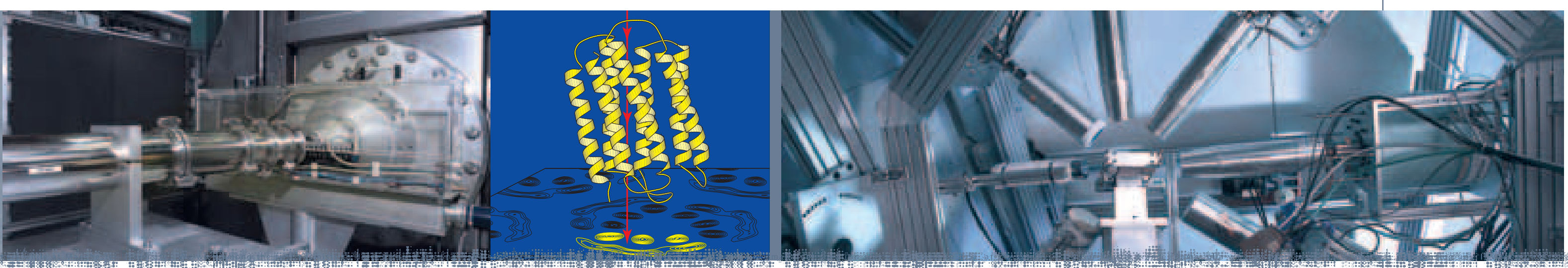


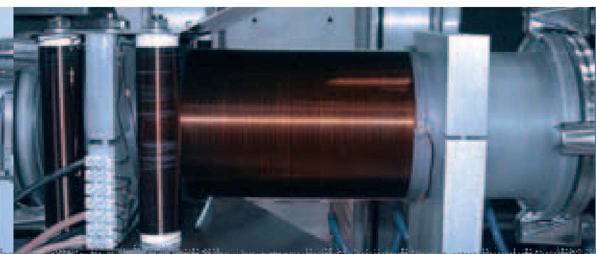
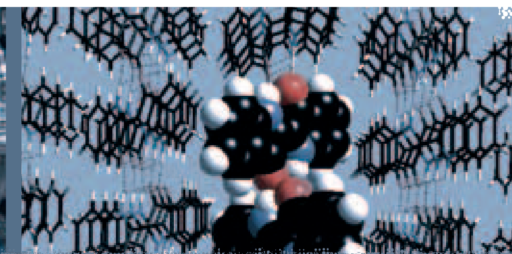
Like many molecular biologists, **Professor Eva Pebay-Peyroula** started out as a physicist, and it was working at the ILL that pushed her scientific interests towards the life sciences. She is now Director of the neighbouring Institute for Structural Biology (IBS) and is involved in the Partnership for Structural Biology (p A.35). After a PhD and post-doctoral fellowship in molecular physics at Grenoble's University Joseph Fourier, Professor Pebay-Peyroula took up a position at the ILL looking after the D16 diffractometer which she used to study cell membranes. "I wanted to stay in Grenoble because I was already settled there with a young family. Neutron techniques were new to me, as was biology, but I soon became very interested in the lipids and proteins making up membranes. Because I was new to the field, I was not afraid of tackling problems that were known to be difficult," she says.

Professor Pebay-Peyroula later worked on the DB21 instrument used for low-resolution crystallography on membrane proteins, and she has remained in this field after moving to the IBS. She also teaches at the University: "I try to explain to students that to understand this new biology requires a knowledge of physics," she points outs. A fascinating topic which she has studied is the membrane protein, rhodopsin, which certain bacteria utilise to transform light into chemical energy, by pumping protons across a cell membrane.

Professor Pebay-Peyroula's work in this burgeoning field has recently been recognised through her election to the prestigious French Academy of Sciences. In 2006, she was awarded the silver medal of the French CNRS (Centre National de la Recherche Scientifique) as a recognition of the scope of her research in terms of quality and originality, both at the national and international levels.

Professor Jochen Schneider joined the ILL before it had even been fully set up as a neutron laboratory. He is now one of the world's foremost experts in producing high-energy synchrotron radiation for research purposes. Starting as a PhD student in 1968 at the University of Hamburg, his job was to investigate the crystals to be used as monochromators (p B.29) for the neutron beams. "We had to learn how to identify good crystals. I had to set up a gamma-ray spectrometer to study diffraction in imperfect crystals, which was a hot topic at the time," he says. Following a postdoctoral fellowship at the ILL studying electronic structure in solids, Professor Schneider then moved to the Hahn Meitner-Institut in Berlin in 1976, still working with colleagues who wanted to perfect neutron monochromators but pursuing his own basic research with gamma-rays on the same samples as used for neutron scattering.

Professor Schneider has worked with gamma-rays and hard X-rays ever since: "All my scientific life I've been in love with very hard X-rays. I continued this love at the DESY Laboratory in Hamburg, setting up beamlines and instrumentation for high energy synchrotron radiation experiments at the storage ring there." He became Head of the Hamburg Synchrotron Radiation Laboratory HASYLAB and continued to work on complex electronic materials until becoming Director of Research in charge of photon sciences at DESY in January 2000. Although tempted by offers to head-up the neighbouring ESRF in Grenoble, and the Advanced Light Source in the US, Professor Schneider has taken on a new challenge to build Europe's most powerful X-ray free electron laser facility which will open up new frontiers in structural research.

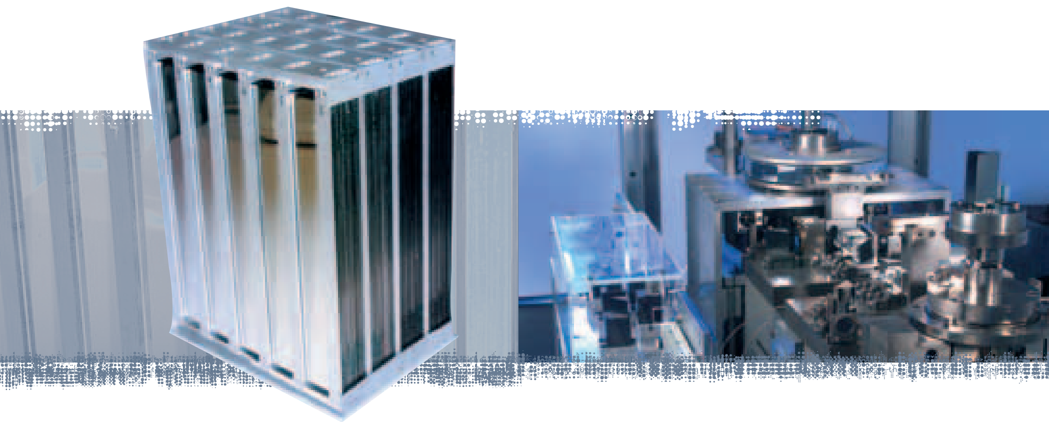
Accelrys

ILL doctoral students

Students working at the ILL obtain a range of skills that equip them for the job market in academia, industry and elsewhere. They learn to work in international teams covering all the sciences. They become familiar with a wide range of instrumentation and techniques. They hone their analytical and computing skills, as well as furthering their knowledge of cutting-edge areas of research in fields that are often of technological significance.

Dr Andrew Wills is currently a Royal Society Fellow at University College London, where he works in the borderlands between physics and chemistry, studying magnetism. He was recently awarded the 2004 Willis Prize by the UK Institute of Physics and the 2004 PANalytical prize of the British Crystallography Association. Dr Wills began working in this field during his PhD in the 1990s at the University of Edinburgh, after which he worked at McMaster University in Canada and the CEA-Grenoble. In 2001 he joined the ILL as a scientist co-responsible for the D3 instrument. Dr Wills says: "My time at the ILL has been quite definitive in terms of the science I do now – it allowed me to pull together the different aspects of magnetism that interest me." Dr Wills also works on developing polarised neutron scattering as a tool for chemistry, and supervises his own PhD student at the ILL.

Dr Marcus Neumann now carries out specialised molecular modelling for pharmaceutical companies. He did a joint PhD at the ILL and Grenoble's University Joseph Fourier, working on the structure and dynamics of organic molecules. This work gave him the freedom to develop his computer skills, which, combined with fluent languages, led to his first job with Molecular Simulations, now called Accelrys, in Cambridge. There, he worked in the marketing department, providing expertise in tools to solve and predict the crystal structure of drugs – a vital aspect of their commercial production. After 3 years, Dr Neumann decided to set up his own company in Paris, called Avant Garde Materials Simulation, and he has since hired two more people from the ILL. Dr Neumann says that working at the ILL gave him the chance to give talks at international conferences: "It also helped to develop my presentation skills which was a definite plus in my first job."



Dr Charlotte Anderson works at the European Patent Office in Munich. She found that her time at the ILL gave her the opportunity to perfect her language skills also while working on state-of-the-art technology. After a physics degree at the University of Liverpool, she did part of her PhD at the Institute studying superfluid excitations in liquid-helium-4. Dr Anderson then spent a further year in the neutron optics department before moving to Garching to work on the reflectivity of multilayers. While an undergraduate, she had taken a year out to study German in Aachen and an advertisement for a job at the Patent Office which required fluent English, German and French had caught her eye. "That was one of the reasons I decided to do my PhD at the ILL," she says. "I was fluent in German and could work on my French." Working there also gave her a broader view of the scientific activities across the disciplines than would have been obtained within a specialised university research group. Dr Anderson now examines patents concerned with telecommunications, with the aim of protecting the intellectual property rights of, among others, university research groups

Dr Timo Hauschild has been based at the German Federal Office for Information Security (BSI) in Bonn for 4 years, where he works on standards for internet security. "We make recommendations to public organisations and businesses such as banks on how to use the Internet safely," he says. Dr Hauschild studied physics in Hamburg and did a combined PhD at the Rossendorf Research Centre in Dresden and the ILL. There he worked with the GAMS spectrometer measuring energy parameters of solids needed for molecular dynamics studies. The work involved observing nuclear trajectories within single crystals. This was done by measuring the Doppler-shifted emission of secondary photons when the moving nuclei decayed after neutron capture. He also simulated the predicted spectra using computational techniques. This interdisciplinary work gave him the problem-solving experience he needed to work on global IT security issues, says Dr Hauschild, and indeed a large proportion of people working at the BSI are physicists or mathematicians.

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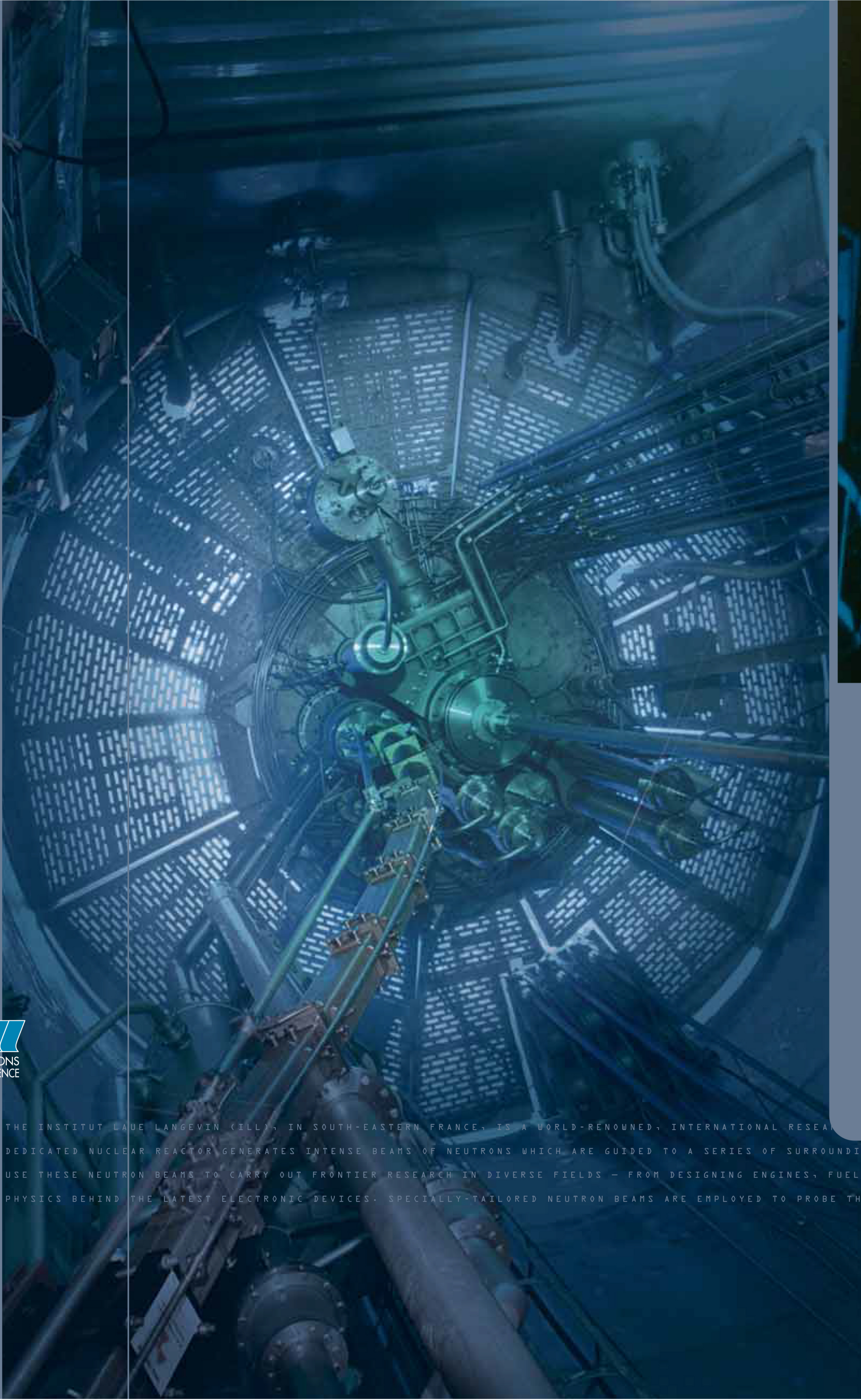

NEUTRONS FOR SCIENCE

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