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ESRF Newsletter

A brighter light for Europe

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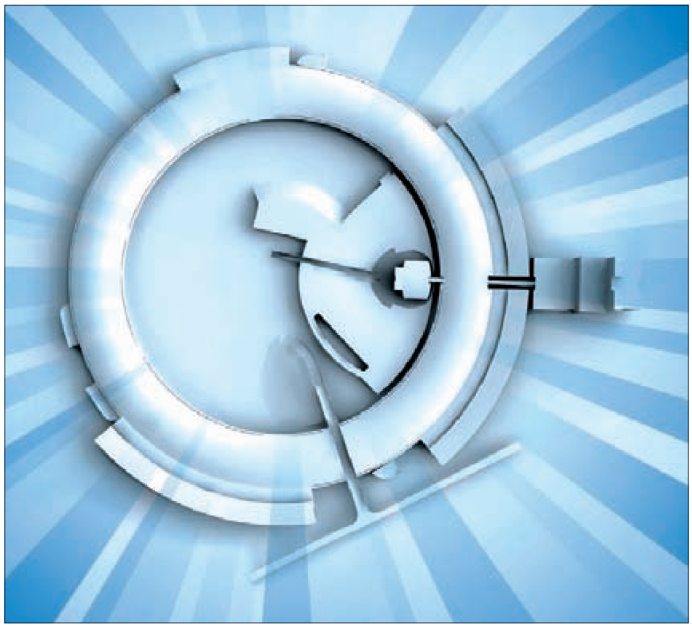


A brighter light for science. The ESRF prepares for its future.

Contents

The ESRF and Institute of Physics Publishing have formed a partnership to produce ESRF Newsletter. Institute of Physics Publishing produces ESRF Newsletter under contract. The ESRF provides editorial content and retains editorial control, while production, advertising sales, printing and distribution are handled by Institute of Physics Publishing. Institute of Physics Publishing is an experienced STM publisher and produces a portfolio of magazines, including Physics World and CERN Courier.

Editorial

W G Stirling, director general of ESRF

THE UPGRADE ADVENTURE IS ABOUT TO BEGIN...

Chantal Argoud

Participants at the User Information and Discussion Meeting on the upgrade.

The next few months will be a period of crucial importance for the ESRF as Council and the national delegations discuss and decide on the proposed Upgrade Programme, which is described in detail in this issue. I consider this ambitious programme of development and renewal to be essential, not only for our laboratory — one of the most effective and productive of the large European research infrastructures — but also for the future health of European science. The new research tools to be developed as part of the upgrade (nanobeams, nanopositioning, extreme sample environments, new imaging techniques, advanced detectors, cutting-edge computing, etc) will allow scientists from across the world to tackle the pressing problems of future decades, such as health and the environment, energy and transport, and new materials and processes. Without the boost to be provided by the increased investment over the period 2008—2017, there is a very real risk that the ESRF would gradually lose its leading position in world science.

The Upgrade Programme is the concrete realisation of the Long-Term Strategy, which has been worked out over the last four years in discussion and debate with the ESRF's scientific users and the Science Advisory Committee (SAC). As we consider the major projects affecting the X-ray source, the beamlines, the buildings and all support services, it is instructive to consider the manner in which the previous long-term plan (of 1998—2007) was carried out.

By any measure, the ESRF has been successful in achieving the objectives that were set by Council back in 1996. With the guidance of Council, the Administrative and Finance Committee (AFC) and the SAC, almost all of the important objectives were surpassed, as described in a report to the AFC meeting of October 2006. I am confident that this excellent performance will be repeated during the next decade, when the Upgrade Programme will become a reality.

Purple is the colour

The Purple Book — a worthy successor to the famous Red Book of 1987 — was the centrepiece of the debates during the User Information and Discussion Meeting on the ESRF Upgrade Programme of 24 October. This document, which is the result of many months of effort by colleagues from the ESRF and across Europe, describes the scientific case for the upgrade and the associated technical challenges and solutions.

Management is currently engaged in a series of detailed discussions with the national partners of the ESRF, with a particular emphasis on the profile of the increased funding, some €210 m over 10 years. At the last Council meeting, in June 2006, all delegations expressed their positive opinion of the concepts developed fully in the Purple Book, so I am optimistic that Council will sign up to the Upgrade Programme, and to the corresponding increased funding, at its spring 2008 meeting. After several years of intense reflection and effort, the ESRF is about to embark on an exciting and fascinating adventure, opening up new areas of science and pushing back the frontiers of knowledge.

Feature news

EUROPE'S LEADING LIGHT PLANS A BRIGHT FUTURE

The halls are buzzing with talk of a mysterious Purple Book at the ESRF. Containing detailed proposals for an Upgrade Programme, it has aroused curiosity and created anticipation among scientists, engineers, technicians and administrative staff alike, who are all commited to investing in the ESRF's future over the next decade.

2007	2008	2009	2010	2011	2012
Report on Upgrade Programme presented to Council	SPRING Upgrade Programme given go-ahead? AUTUMN Decision on architects for experimental hall extensions and funding decided	First technical design report on new beamlines completed	Limited shutdowns for experimental hall extension construction	Extensions of hall complete and ready to use	Start of construction of new long beamlines

The ESRF's future mapped out. The timeline of the Upgrade Programme for the next five years involves some ambitious plans.

The ESRF has always been at the forefront of science. Just two years after the start of user operations in 1994, scientists discovered the causes of "fast sound" in water. This was followed in 1997 by a major breakthrough in analysing the structure of the blue tongue virus, a serious disease that affects domestic cattle. Science and technology have come a long way since then, and, with the appearance of more third-generation synchrotron sources and new scientific and technical challenges, the ESRF is planning a major upgrade to ensure that it stays in its leading position for scientific and technological research in the future.

Although the synchrotron and its experimental stations have been continuously improved since their construction, the comprehensive Upgrade Programme will deliver greater improvements than "local" upgrades on individual beamlines.

Future plans include extended beamlines, an enhanced accelerator and source complex, and the creation of new scientific infrastructure. New instrumentation is also needed for optics, sample environment and positioning, detectors, data retrieval, storage and analysis. This will be complemented by the extension of the experimental hall, new ancillary infrastructure, and scientific partnerships with academia and industry.

Plans were initiated by the directors three years ago. After consulting the governing bodies, the science advisory committee, scientists and users, a group was set up to coordinate the upgrade for presentation to Council.

This resulted in the Purple Book, completed in September 2007, which outlines the upgrade from the scientific and technical projects envisaged, and the investments needed, to the new buildings and infrastructure. This will be presented to Council, which will take a preliminary position on the upgrade later this year, with a final decision expected early in 2008.

Better beamlines and more space

Primarily, the programme will consist of a newly refurbished and upgraded beamline portfolio, with improved performance and routine nanofocus capabilities. The extension of one-third of the experimental hall, housing much longer (120 m) beamlines, will enable nanometre X-ray beams and large-scale experimental configurations, and will offer more space for laboratories and offices.

The beamlines, the heart of the experiments, will increase in capacity and efficiency as a result of the upgrade. "Clusters" of scientifically linked beamlines will enable an integrated workflow across stations. There will be a specific effort to speed up the data-collection times for particular experiments from weeks to days, as well as a plan to introduce automated alignment and data collection on all beamlines, where possible.

At the same time, the accelerator and source will be enhanced, resulting in increased brightness, stability, reliability and operation flexibility. The upgrade includes new topping-up and fill patterns, increasing the ring current to 300 mA (with a future possibility of 500 mA), and new machine lattices with longer straight sections and more flexible undulator combinations. Longer straights and wider-angle canting will increase the potential for further beamlines in the future.

The accelerator and source works will be matched by developing new synchrotron radiation instrumentation, especially novel optics and vastly improved detectors. Further computing infrastructure will be added, focusing specifically on enhancing data analysis and scientific software. There are also plans to take advantage of modern technologies, such as the Grid, to increase storage capacity and improve offline analysis tools.

Making new science real

The upgraded facility will be beneficial to users and future scientific research. With improved infrastructure there will be more science-driven partnerships, with an increased participation from academia, research laboratories and industry. In total, there will be €210 m of new funding over the next decade.

The upgrade will also enable the ESRF to pursue new directions in science, particularly those which complement existing fields. For example, extending the current experimental hall can be seen as the most effective way of making nanometre-sized beam spots available on a large number of experimental stations. This will have many future benefits for biological science, research into semiconductors, and very-high-resolution imaging, among other fields.

The upgrade has put the ESRF on the 2006 Roadmap for the European Strategy Forum for Research Infrastructures (ESFRI). This identifies it as a unique, large-scale infrastructure, critical to the EU, and excelling in research and education, which has led to up to €5 m worth of funding. The programme will not only benefit the ESRF and its users, but its strong collaborative factor with other light sources, academic institutes and industrial partners will mean that new science and its related technical developments will be promoted even further. Specifically, it will enable the ESRF to recreate the success of the last decade, looking ahead to the future as the leading European light source.

ANYA POPE

WHY THE PURPLE BOOK IS PURPLE

Over the years, the ESRF has seen a range of reports produced in a whole spectrum of colours, including green, blue, yellow and, of course, the Bible of the ESRF, the Red Book. So why purple? Historically, the colour purple has always been associated with power and royalty, and it was an extremely sought-after colour due to the difficulty in producing it. Before synthetic methods were discovered, it was made from the mucus of the hypobranchial gland of various species of marine mollusc. It took some 12 000 shellfish to extract 1.5 g of the pure dye. It was therefore considered extremely precious, highly revered and valued more than gold.

STRONGER MAGNETIC FIELDS

Also on the horizon are plans to provide users with increased magnetic fields. At the moment there is a technological limit of 20 T for superconducting magnets, but many experiments require stronger fields. These can be produced by resistive coils with either a constant or a pulsed field. A constant field requires a huge installation but enables a much wider range of experimentation, whereas a pulsed field has a relatively small infrastructure but creates more difficult, or even impossible, experimental constraints. As it is the most expensive part of the upgrade, there is a strong possibility of sharing the development and construction within a consortium of expert institutes and with the ILL, to serve as a joint X-ray and neutron facility.

THE BIG CHALLENGE: REACHING THE NANOSCALE

One of the most important aims of the Upgrade Programme, science at the nanoscale starts to be a reality at the ESRF, where three pilot projects' beamlines use nanofocused beams. Over the next decade, these will become standard on the beamlines. Materials, surface science, biology and medicine are all areas set to benefit.

In medical research, investigation into systems to deliver drugs in the body is under way. These contain multifunction nanomaterials with unique physical and chemical properties. The assets that make them so attractive can also have toxic effects on cells and tissues, so there is still much research to be done before they can be used in humans, but they have the potential to have an outstanding impact on our health.

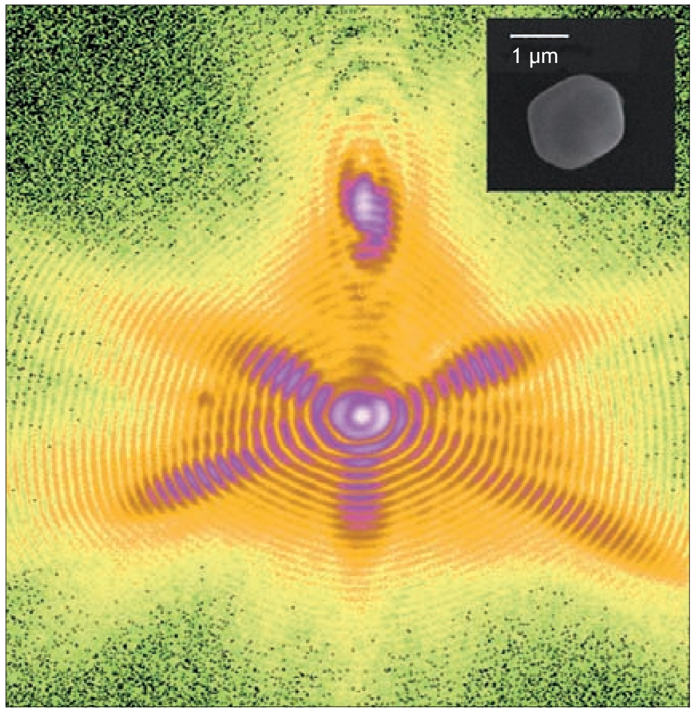
This is just one example of why a key line of research enabled by the Upgrade Programme is at the nanoscale. In the case of nanomaterials for drug systems, for example, X-ray nanotomography coupled with elemental and speciation nanoanalysis techniques will tackle the interaction of nanomaterials with cells. In other fields, such as microelectronics or superconductors, research in the nanoworld is equally beneficial.

Imaging techniques will offer new opportunities for nanoscience (e.g. combined diffraction, scattering and spectroscopy). The other technical advances that will make nanoscience real are nanofocus beamlines with hard X-ray nanoprobes and *in situ* experiments.

Long beamlines will be another trademark of the new ESRF. These will be 120—250 m long and will allow the source size (in both directions) to be exploited fully, while keeping the working distance large enough to accommodate innovative *in situ* experiments. New optics and detectors will have to be developed accordingly.

The nano star

When reading the Purple Book, you notice that an emerging technique, coherent diffraction imaging (CDI), which takes full advantage of modern synchrotron radiation sources, stands out in the different chapters. CDI, which is actively developed at other synchrotron sources, is a non-destructive 3D X-ray diffraction microscopic tool that can assess the shape, size, strain and composition of individual nanostructures, such as quantum dots in semiconductor materials, crystalline and non-crystalline materials, and disordered solids.



F Livet 2007 Diffraction with a coherent X-ray beam: dynamics and imaging *Acta Cryst.* **A63** 87–107 International Union of Crystallography.

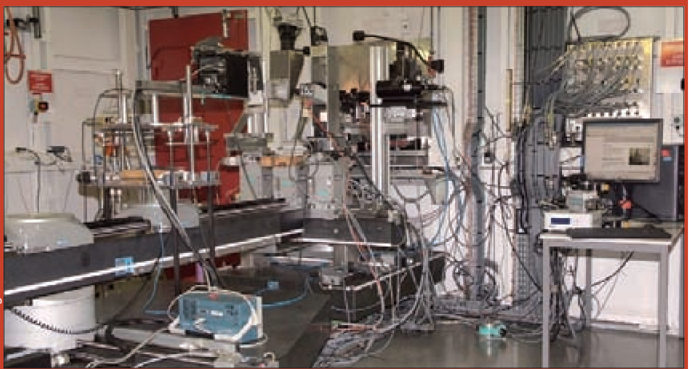
Coherent diffraction pattern. This was taken on ID01 from a 1 μm gold crystal measured close to the centre of a (111) Bragg peak. By rocking the sample through the peak and recording slices through the diffraction pattern, a 3D real space image of the crystal is obtained from algorithms and reconstruction.

It requires a highly coherent, bright and stable beam as well as theoretical developments to reach maturity. Therefore there is still some way to go, but preliminary experiments have already taken place on ID01 and ID10.

It is not only the development of CDI that depends on other factors for its success. In nanoscale research at the ESRF, the preparation of samples, detectors, optics and visualisation systems will all be integrated into a common, dynamic framework. The Upgrade Programme therefore includes the creation of a nanoscience platform to join efforts among different techniques and use the nanoprobe beamlines in the most effective way.

The platform will include the creation of a characterisation and preparation laboratory for the samples. Electron and light microscopes, and specific tools for sample slicing and cutting will be available.

LESSONS FROM THE THREE PILOTS


Chantal Argoud


Chantal Argoud


Chantal Argoud

The ESRF has had nanobeams since 2005. Three beamlines (ID11, ID13 and ID22) were used in pilot projects in nanodiffraction and scattering in high and low energy and nanoimaging. These will provide a strong technological background and expertise for new beamlines. A coordination group called the nanotechnology platform, which groups scientists and engineers, has been created. It explores all of the engineering issues that will have to be addressed carefully on the new nanobeamlines.

To visualize and manipulate samples of nanometre size, researchers will use scanning probe microscopes (SPM). It is therefore the aim of the Upgrade Programme to integrate them into beamline instruments. ●

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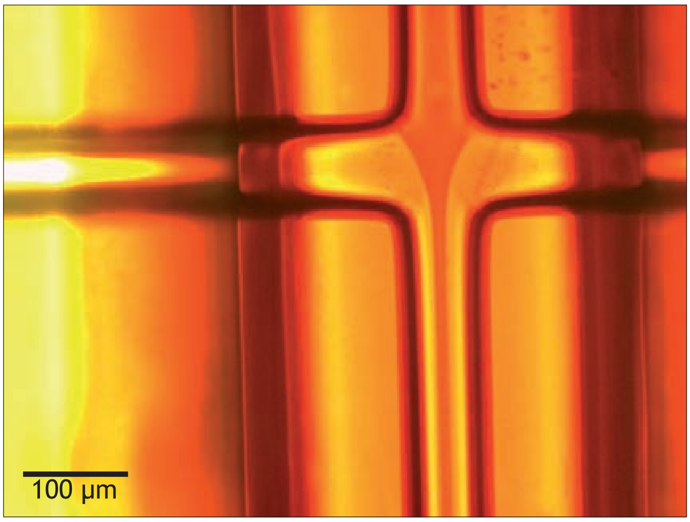
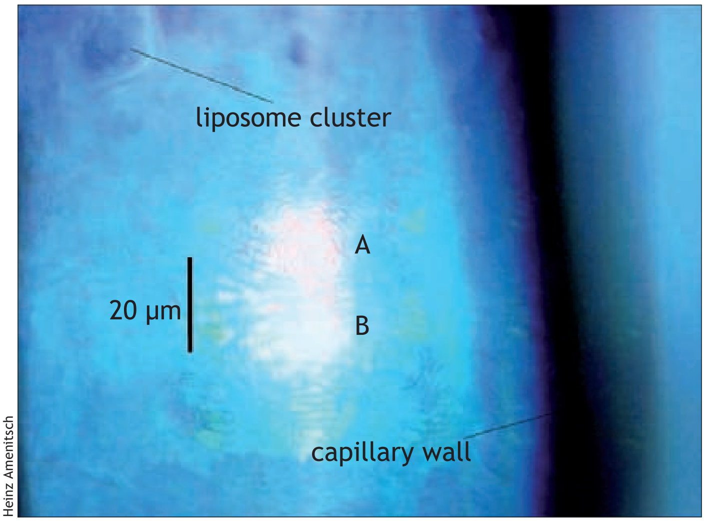
ESRF 'VILLAGE' WILL ENCOURAGE CLOSER WORKING

The goal of arranging the biology and soft-matter beamlines in a cluster at the ESRF will benefit both of the related user communities. The Upgrade Programme stresses the need for the closer location of the beamlines, and also for the development of new approaches to research into biological materials and soft-matter physics.



Anne Martel



Heinz Amenitsch

Handling fragile, tiny samples. Left: hydrodynamic focusing microfluidics cell. Right: liposome aggregates (A and B) trapped in a glass capillary by optical tweezers. These images show the type of development necessary in the sample environment, and the experimental apparatus and sample manipulation/support needed on the upgraded beamlines.

It won't have a town hall, nor will it have a village green, but this "village" will allow its inhabitants to work with each other for the prosperity of the community. The biology and soft-matter community is expected to be established in a very similar way to a real village. Instead of houses, a bunch of beamlines with complementary capabilities will be set up next to each other. This will allow more interactivity between scientists and an improved interface between soft condensed matter and biological sciences.

The idea arose out of a need for a multidisciplinary approach to the study of complex systems, such as those encountered in biology and soft matter. A beamline village would permit (e.g. in macromolecular crystallography) the screening of hundreds of samples followed by their transfer to the appropriate beamline.

Membrane proteins are a good example of this new research concept. These proteins perform crucial biological functions, including respiration, signal transduction and membrane transport, so they are important drug targets. To work, they often exploit metal ions, and these can also be used to reveal the proteins' 3D structure. To monitor the metal's environment, researchers need to use two complementary methods: X-ray diffraction and spectroscopy. In addition, the quality of the crystals of these proteins tends to be variable, so a large degree of automation will enable the screening of many samples.

The hierarchical nature of complex systems will be revealed in greater detail and precision as a result of the upgrade. The workings of these systems will be revealed not only by macromolecular crystallography but also by the deployment of the X-ray scattering techniques of modern X-ray imaging. The use of multidisciplinary approaches will benefit the village and will enable structures to be revealed and their function understood.

Exploring self-assembly

In soft condensed matter, the combination of different scattering techniques will offer a more complete picture of some research areas. In self-assembly materials like surfactants and biomaterials, scientists use small-angle X-ray scattering and ultra-small X-ray scattering, plus grazing incidence SAXS and diffraction, to elucidate the bulk microstructure and the interface properties, respectively. The equilibrium dynamics of the material are elucidated through X-ray photon correlation spectroscopy. All of these techniques explore the way in which soft condensed matter self-assembles to achieve a certain structure and function. Underpinning all of these techniques, the upgrade will offer further improvements in the form of fast detectors with single photon sensitivity, along with high spatial and time resolution.

Soft matter includes colloids, polymers, surfactants, foams and biological membranes. Some of this material needs careful manipulation owing to its size and nature, and the Upgrade Programme is taking this into account. Microfluidics technology will be implemented at the ESRF to study dynamics in fluids, such as protein folding and solid–liquid interfaces, as the action takes place. Optical traps in a microfluidic environment will also be developed to handle the tiny samples.

The fragility of the samples clashes with the idea of synchrotron radiation. X-ray exposure deteriorates samples. Although solutions like cryocooling have contained the problem, it's an issue that will be further studied in the Upgrade Programme. This problem proves more complicated in soft condensed matter because samples must be kept at a certain thermodynamic state in a confined experimental configuration.

Nanosamples will become ordinary in the next decade at the ESRF. This is why the upgrade will allow scientists to study nanosamples on nanosecond timescales with nanobeams. Reducing the beam size to the nanoscale will provide opportunities for studying the surface of objects such as single cells.

The village structure proposed for the biology and soft-matter beamlines represents only the starting point of future development in these fields. The upgrade stresses the interest in creating partnerships (which could be called "regions" in "geographical" definitions) that will let the villages evolve at a faster pace and with more means. For the skeptics, the proof is in the pudding: the Partnership for Structural Biology has proved a success after five years of existence. It brings together the expertise of three international institutes (ESRF, European Molecular Biology Laboratory, Institute Laue Langevin) and one national institute (Institut de Biologie Structurale) in the quest to solve biological structures. ●

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LOOKING CLOSER AT MATTER AND ITS CHEMISTRY

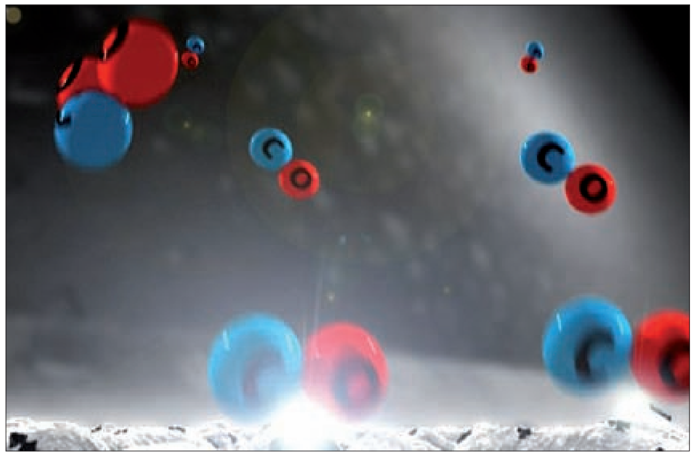
The detail of photosynthesis in plants, what Jupiter is made of at its crushing depths, how to create new high-performance materials for aerospace, and how to understand the formation and propagation of cracks in aeroplane wings. These are some of the issues that the Upgrade Programme hopes to be able to address.

The properties and performance of a material depend on its structure at the microscale (how the individual grains join together) and the nanoscale (how the atoms making up the grains are arranged and interact with each other). Studies at these different scales are one of the main interests of materials science, and this is the most straightforward way of studying matter. However, scientists at the ESRF also investigate how materials respond to different conditions, such as the effects of temperature, stress and strain, and on different timescales.

The upgrade will allow these experiments to be quicker and to study smaller parts of the sample, thanks to the development of high-energy nanofocused beams. It will also be possible to study novel synthetic compounds formed by self-assembly mechanisms by collecting data from delicate microcrystals. The focused beam, coupled with specific software, will allow scientists to collect information from the crystallites. For example, for studies of cracks in aeroengine turbine blades, new time-resolved tomography and diffraction on the upgraded high-energy beamline will provide relevant information for solidification modelling.

Benefiting techniques

It doesn't end with the study of matter in a passive state. The ESRF is renowned for *in situ* studies of chemical reactions, such as those in catalysis. The Upgrade Programme will focus on these by developing concerted techniques that probe the local structure (e.g. X-ray absorption spectroscopy; XAS). For solid-state processes, the improvements in the source and detectors will allow techniques such as powder diffraction to investigate materials better and faster while reactions take place, such as those occurring in a battery during the electrochemical cycle.



Catalysis in cars. A catalytic converter transforms the three main pollutants (NO, CO, unburned hydrocarbons), into benign ones (N_2, H_2O, CO_2). Here, CO is transformed into CO_2.

Catalysts can promote the viability of chemical reactions and are currently used in most industrial processes. Applications include dealing with the exhaust from car engines that use catalysts to transform toxic gases into harmless ones; zeolite catalysts used to refine crude oil to produce fuel; and the efficient processing of vegetable oils and fats via hydrogenation, which happens faster due to a catalytic process.

At the ESRF, scientists will be able to investigate further in this field by applying different spectroscopic techniques simultaneously. Two that the upgrade will make available to users are X-ray emission spectroscopy (XES) and resonant inelastic X-ray scattering. Reactions taking place on surfaces will also be exploited by studying single particles during the catalytic process, thanks to the new nanoscale X-ray beams.

In situ experiments are already used in research into car-exhaust catalysts, where the action in the mixture of gases expelled from an engine is reproduced in a specially designed cell, but this will be expanded to studies of other catalysts. Other reactions where the chemistry is induced by laser pulses, such as protein motion in a biological reaction, have already been monitored at the ESRF to a time resolution of 100 ps, but the upgrade is going further. Two dedicated pump-probe beamlines will be created – one for scattering and diffraction, the other for spectroscopy experiments. The upgrade developments (and the acquisition of new picosecond lasers and advanced 2D detectors) will permit the study of larger, more-complex proteins as a reaction takes place. The laser pulses used to excite the proteins will be stretched to 10 ps, which will mean that the entire protein will be excited (currently it is only 10–20%) and there will be less radiation damage.

In biological reactions, such as photosynthesis, metalloenzymes – complex proteins with a central metal – manage and catalyse the multistep reactions. Research at the ESRF has identified an important intermediate step in oxygen evolution using time-resolved spectroscopy. In the future, XAS and XES combined will be able to address structural changes, as well as electron transfer and spin dynamics in complexes.

Complex chemical processes are ubiquitous and of fundamental interest in planetary science. On Jupiter the temperature and pressure are so high that it is difficult for scientists to investigate the dynamic processes there. The development of high-pressure beamlines along with a large-volume multi-anvil press will offer the possibility of bigger samples, reaching higher temperatures and pressures, and controlling their gradients as well as their redox potentials. This will benefit research on planets (including Earth), the structure of which is still not completely known or understood.

The developments in high-pressure and high-temperature experiments will also have an impact on research into novel materials, such as very hard components. Advances in this direction have already taken place. ESRF users from the University of Bayreuth have created the densest and least compressible form of carbon (more so than diamond) currently known.

The research proposed in the Upgrade Programme in high-pressure, catalysis, structural chemistry and materials science, while varied, needs to be developed along similar lines. Upgrades in the source, optical components and detector developments are essential for the success of any new experiments.

Whether we can understand what is going on on Jupiter, every step of photosynthesis or where and why cracks appear, these represent only some of the mysteries to be solved. It is hoped that the Upgrade Programme will answer these questions and others. •

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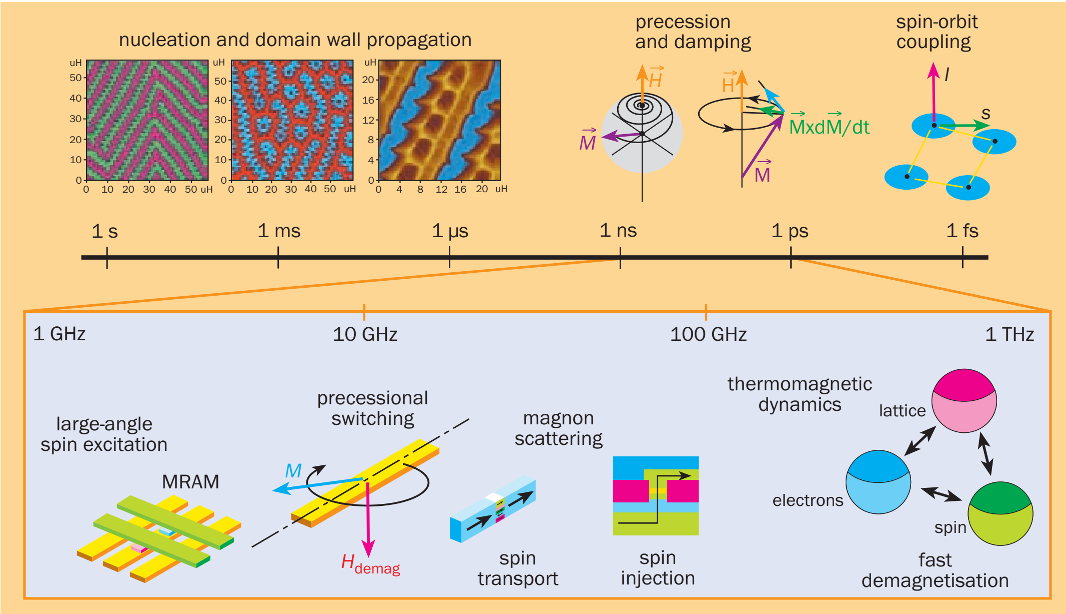


Adapted from A G Temiryazev *et al*. *Journal of Magnetism and Magnetic Materials* 258–259 Surface domains in inhomogeneous yttrium iron garnet films. © 2003 with permission from Elsevier.

Better access to improved techniques. The major processes involved in the dynamics of magnetisation, are shown on a timescale that goes down to femtoseconds. The Upgrade Programme will make access to these regimes possible by the development of new time-resolved and frequency domain X-ray spectroscopy techniques, together with new detector systems.

SMALLER, FASTER, STRONGER...AND ALL DUE TO THE UPGRADE

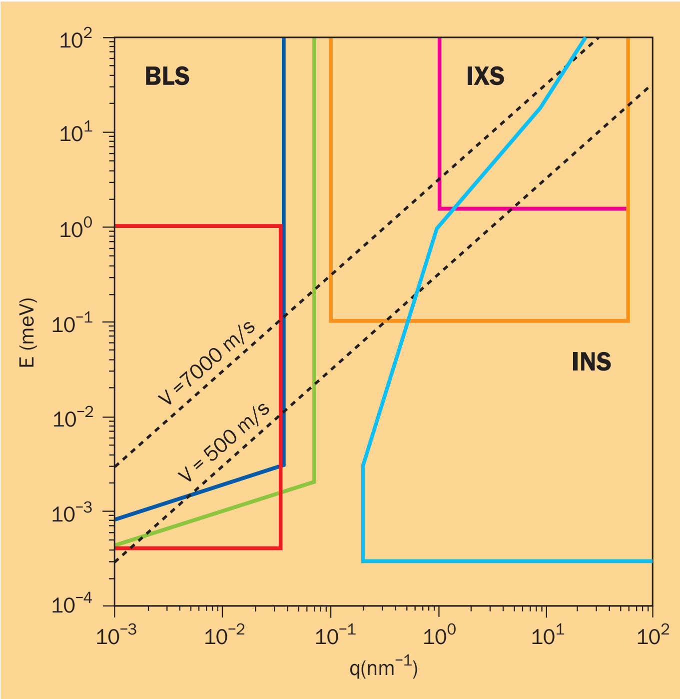
The ESRF Upgrade Programme will, among other things, make possible a more comprehensive study of magnetism and the dynamic properties of materials.

Compare technology today with that of 20 years ago, and there's a dramatic improvement in device performance, coupled with progressively smaller sizes. Take, for example, a 40 GB iPod. It can store 10 000 songs, whereas the first computer with a hard disk, in 1956, could store just one. This progress is a result of better knowledge of the electronic, dynamic and magnetic properties of materials. At the ESRF, much work is taking place to understand the world of magnetism and the dynamic properties of matter, and the Upgrade Programme will boost this field even more.

Despite being at the forefront of high-tech electrical products now, magnetism was first observed by Greek philosopher Thales of Miletos in the 6th century BC, when he studied naturally occurring magnetic lodestone. Today, scientists understand that the electron carries both charge and a magnetic moment called spin. When the electron spins in a material are oriented randomly, there is no effect. However, in a magnet the spins tend to face the same way so that they pull together, creating a strong total magnetic force. Now, magnetism forms the basis of information storage and processing in computers. However, as researchers make everything smaller, they are reaching a limit. In a magnetic area of less than a certain size, the magnetisation or the spins do not align, so the bits (binary digits) are not stable.

One of the scientific challenges today and for the future is to study magnetisation (and its dynamics) in nanoscale materials. In this sense, spintronics is a new field aimed at tiny materials. This emerging technology allows scientists to manipulate electron spins individually, whereas until now the electronic devices have been based on electron movement. The Upgrade Programme will allow researchers to reduce the size of the samples further, thanks to nanofocusing X-ray optic developments, submicrometre-sized and more-stable beams, and an improved energy resolution.

Another aim of the upgrade is to improve experiment timescales. The faster the scientists can track changes in the structure of materials, the more knowledge of the material they will achieve. This has consequences both in fundamental research and in applied technological advancements. The upgrade intends to push the boundaries of magnetic fields by developing environments of 50 T pulsed and 30 T static fields. This will improve the understanding of the interplay between structural, electronic and magnetic degrees of freedom in strongly correlated electron systems. Pulsed magnetic fields, together with faster detectors, will allow scientists to study materials faster.



Energy and momentum transfer. The regions of energy (E) and momentum (Q) transfer are experimentally accessible today. BLS = Brillouin light scattering; INS = inelastic neutron scattering; IXS = inelastic X-ray scattering. The dotted purple lines indicate two typical sound velocities. The blue area corresponds to the planned extension of the E–Q region.

Several other techniques will make it possible to study magnetic samples. X-ray scattering offers bulk sensitivity and average information on the whole. A new method – X-ray detected magnetic resonance – has just emerged and the upgrade will bring this to maturity. It permits measurements of the dynamics of the spin and orbital magnetisation in different absorbing atoms. X-ray photon correlation spectroscopy and nuclear resonance scattering can provide further valuable information.

Entering the dark zone

In fundamental science there is an energy–momentum transfer region that remains a mystery. Thanks to Brillouin and Raman light, inelastic neutron and inelastic X-ray scattering, researchers can access most of the energy–momentum region and some breakthroughs in the determination of vibrational properties of matter have been made. These properties provide information about elastic and thermodynamic properties, for example, as well as relaxation mechanisms in disordered systems. However, there is still an inaccessible zone. The upgrade will enter this zone, providing a better energy resolution and smaller momentum transfer. This offers the possibility of observing phenomena on nanosecond timescales, thus bridging the gap between processes on the picosecond timescale and slower dynamic processes.

Equally, the upgrade will make it possible to measure relevant thermodynamic and transport properties (sound velocity, viscosity) in a class of systems (e.g. low-viscosity fluids and dense gases) with particular interest in geophysical or planetary science. Challenging studies of the collective dynamics in crystalline nanoislands, glassy clusters and liquid nanodrops will become routine.

The ESRF's studies of the dynamic properties of matter will shed light on many scientific questions, but they can be complemented by other tools. That's why the upgrade includes both synchrotron radiation techniques and neutron and muon probes, as well as *in situ* lab-based methods. Theory is also a crucial aspect of improving techniques and facilities in the field. Thus the joint ESRF/ILL Theory Group will provide key input to experimental preparation and analysis of data by developing *ab initio* computer algorithms for the calculation of structural, dynamic and electronic properties, as well as large-scale molecular dynamic simulations. ●

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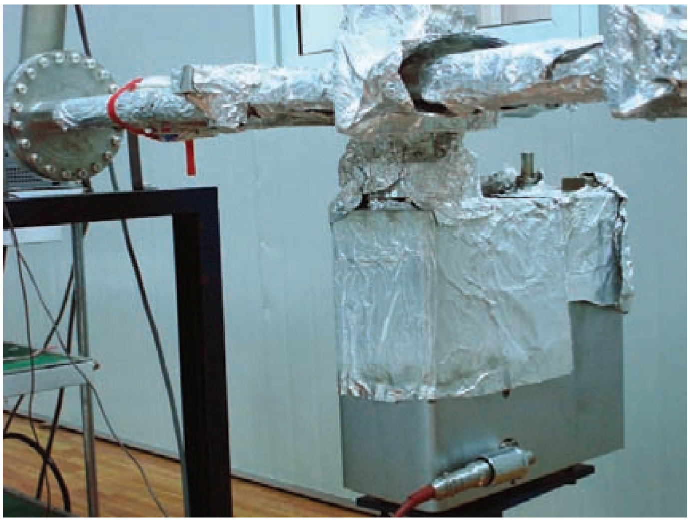
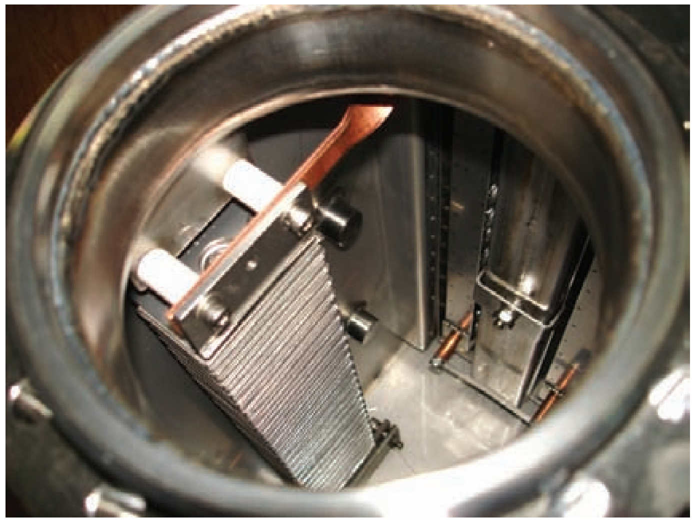


Ion pump with the NEG Module inside, fitted to the SSRF



Mounting detail of Getter Wafer Module inside the ion pump

SAES® Getters' SORB AC Getter Wafer Modules Boost UHV Conditions at Shanghai Synchrotron Radiation Facility (SSRF)

The Shanghai Synchrotron Radiation Facility (SSRF) is a third-generation synchrotron light source designed to meet the growing demand for synchrotron radiation in China.

It consists of a 432 m circumference storage ring operating at 3.5 GeV, a 100MeV electron linac and several beam lines and experimental stations. It will be the largest synchrotron in China and the fourth largest worldwide. Once fully operative, more than 60 beam lines will be made available to users for a variety of studies encompassing macromolecular crystallography, XAFS, hard X-ray microfocus, X-ray imaging and biomedical application, soft X-ray spectro-microscopy, diffraction and small angle X-ray scattering. The synchrotron ring, which is at present under construction at Zhang Jiang High Tech Park in Shanghai, is supposed to begin the commissioning phase by the end of 2008.

One of the key challenges faced during the project has been the achievement and maintenance of a suitable vacuum level, especially at full beam current when large gas load is generated by synchrotron radiation along the ring and in specific areas like the crotch absorbers. A pressure design value of $<1 \times 10^{-9}$ mbar during machine operation and 10^{-10} mbar under static conditions has been set for SSRF.

To ensure this challenging target the vacuum ring is pumped by more than 300 ion pumps, most of which integrate inside their volume a SAES® SORB AC Getter Wafer Module (mainly of the WP 1250-St 707 type).

The integration of SAES NEG Wafer Modules inside ion pumps is a well known and proven approach which has been used in several machines, like Elettra in Italy, the Pohang Light Source in South Korea or APS at Argonne National Laboratory. The Getter Wafer Modules are available with two getter alloys (St 707 and St 101) and come in a range of compact sizes. They feature pumping speed for hydrogen between 400 and 1200 l/s, significantly boosting ion pump performances. Ion pumps, in fact, loose their pumping efficiency for hydrogen in the 10^{-9} mbar range and below. Being hydrogen the main residual gas in UHV systems, this may create inconveniences during the machine operations, especially in the high gas load regions. The Getter Wafer Modules provide therefore a simple and cost effective way to significantly increase speed and capacity for hydrogen (as well as for the other gases) right where this is most required.

A picture of a NEG module mounted inside the ion pump installed at SSRF is showed in the pictures.

Given its compact size, the module can be easily mounted inside the ion pump. Activation is generally accomplished by passive heating, during the ion pump bake-out, or, preferably, by direct passage of current through the module length.

Modules have high capacity for gases and are rugged pumps, so once installed they do not need to be replaced, but just reactivated from time to time or after ion pump venting for maintenance and shut downs. This is possible, as for other getter pumps, a large number of times, generally more than 50. However, if required after extensive operation or for any other reasons, modules can be easily replaced. This provides extra safety and reliability to the entire vacuum system, since the replacement operation is very simple and does not affect at all the ion pump performance.

Extensive testing of Wafer Getter Modules inside ion pumps of different vendors is ongoing in several synchrotron light sources which are being built or designed in Europe and in Asia.

In particular, investigations carried out at SSRF have showed that after getter module activation, vacuum in the 10^{-11} mbar are obtained, fully meeting the demanding vacuum requirements of this light source.

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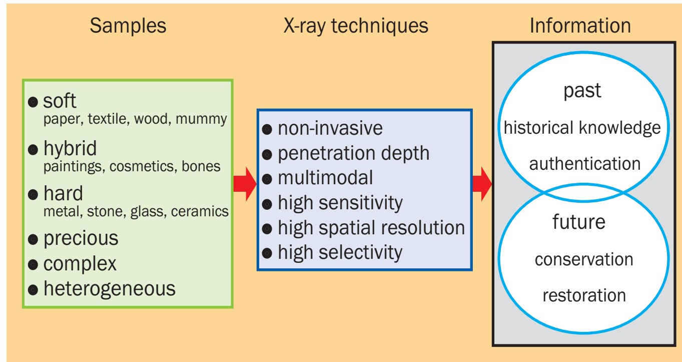
NEW COMMUNITIES DISCOVER THE ESRF'S APPEAL

The features of modern synchrotron beams and the user-support system at the ESRF attract new scientific communities, and this trend will continue with elements of the upgrade catering to these users' needs.

The notion of support and service is intrinsically linked to the ESRF. Staff scientists assist external users in their experiments. This is part of the added value that has made the ESRF attractive to non-synchrotron related communities. No one would have thought a decade ago that art restorers and environmental scientists would become regular users at the ESRF. Today, they are a growing part of the user community, and the Upgrade Programme includes improvements to benefit them.

Restorers examine and work on paintings with an impressive precision. Their work in keeping art alive and in good health makes them record in their minds every brush stroke, every original detail that time is inexorably trying to take away. And then they try to bring it back to its best condition. Their eyes are the best possible allies they could have in this job.

However, their eyesight may not be enough. In a similar way to their eyes, synchrotron X-rays can "look" locally at heterogeneous samples. They can provide researchers with the density and chemical state of each element. This information helps restorers to identify the optimal mechanisms for the conservation of the artwork. A decade ago, no one would have connected synchrotrons with restorers, but today an increasing number of them are asking for beamtime to investigate cultural heritage material.



Cultural heritage items fall into two chronological classes: past and future. They share common technological challenges, linked mainly to the material's nature, value and complexity. The Upgrade Programme will allow an evolution of archaeometry from descriptive to comprehensive studies. This transition will, in particular, involve innovative developments in materials science for *in situ* experiments and time-resolved analysis.

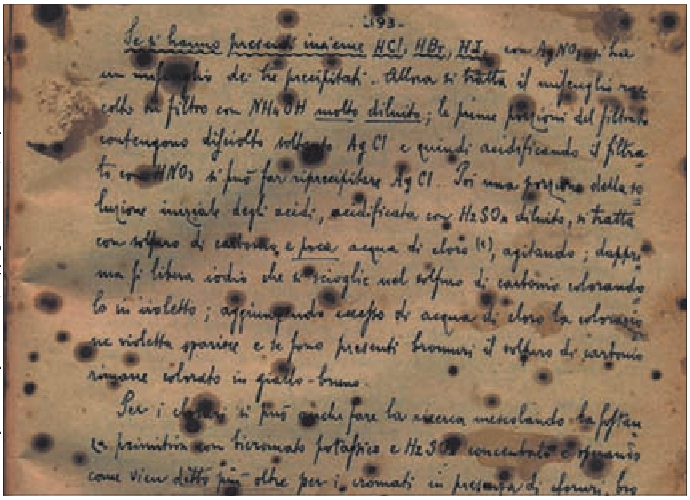
A perfect combination

Over the last 10 years, new scientific communities that were in principle strangers to the concept of using synchrotron light have felt increasingly attracted by its capabilities. However, it is not only the technical part of it, but also the support that they get from ESRF staff to perform experiments, that interests them. Most of these communities have an expertise in their own field but not in X-ray facilities, so the merging of both communities makes an ideal combination for optimal results.

The maturing of research in new fields has resulted in a specific part of the ESRF Upgrade Programme being dedicated to this growing tendency. In archaeological science it will provide improved spatial resolution and detection limits in microspectroscopy, and new beamlines that will allow high-resolution nanoimaging, thanks to improved parallel and coherent beam imaging.

Imaging will help not only archaeologists in their research but also medical doctors. The ESRF is developing different biomedical imaging techniques that will have an impact on basic, clinical and industrial research. For example, those suffering from osteoarthritis may benefit from a better diagnosis in the future thanks to analyser-based imaging. This technique already makes it possible to visualise the cartilage structure, which couldn't be observed previously. With the upgrade, the experiments will be performed *in vivo* with the aim of testing the reconstruction of damaged tissues. The ultimate aim is to translate the upgraded technique to tabletop lightsource facilities, which are being designed for use in hospitals.

Moving from human health to our planet's health, there have been an increasing number of proposals for beamtime at the ESRF submitted by environmental scientists in recent years. Plants that detoxify heavy



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Foxing spots. With time, external and internal factors lead to cellulose degradation in paper. Degraded papers can exhibit fragility, yellowing and the formation of foxing spots. Foxing degradation is a complex mechanism still not well understood.

Malvina Lak and Paul Tafforeau

Wasp preserved in opaque amber. This was discovered on ID19, thanks to phase contrast radiography (it's impossible to detect these fossils without a synchrotron), then imaged using 5 µm voxel size phase contrast microtomography on ID19. It is 100 million years old and comes from Charentes amber (France).

metals and clean soils, and corals that tell us about past climates, have been the object of environmental research at the ESRF. Today, thanks to the Upgrade Programme's proposal for new beamlines with different complementary spectroscopic techniques, new questions relating to our planet will be tackled, such as how to manage nuclear waste. Nuclear waste includes radioactive material, such as plutonium. Good nuclear waste management requires a profound understanding of the geochemical behaviour of sulphur in the treatment of vitreous waste from incineration activities. The new combination of techniques possible thanks to the upgrade will provide precious and previously inaccessible chemical information about this material.

A prominent field of research that has started profiting from the ESRF's capabilities is paleontology. The non-destructive synchrotron imaging techniques are ideal to access the internal structure of fossils, which can provide information about our past. The experiments on these samples, together with the technique, have evolved dramatically since the first experiment, in 2003.

Today the ESRF acts as the world leader for non-destructive investigations into fossils by providing the highest-quality data and helping to preserve them. The Upgrade Programme includes the creation of a unique database with all of the information provided by synchrotron radiation for the use of the paleontology community. The database will help scientists to study fossils and will also preserve fossils by reducing the number of manipulations.

The main limitation for the constitution of this database would be access to the beamline to perform scans of samples. This is why the upgrade has foreseen a beamline that will be partially devoted to paleontology. ●

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Photonic Science

NEW CCD detector allows continuous Φ-slicing

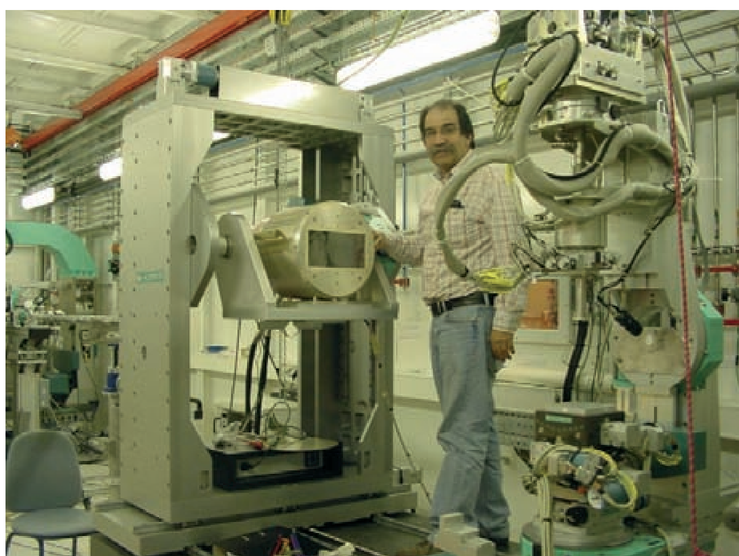
Photonic Science brings a new generation of CCD detectors for synchrotrons that deliver small and bright beams, with the aim of screening micro samples in a more flexible way.

Continuous sample rotation combined with shutterless acquisition brings simpler and more flexible data collection routines.

This requires simultaneous exposure and read out, with 100% duty cycle capability, and allows working at constant goniometer speed with excellent reproducibility when performing fine angular slicing.

Dynamic range and statistics can be then monitored via multiscans at constant speed and/or with dual scans at two different but constant speeds. This can only be achieved thanks to an excellent anti-blooming efficiency that can suppress saturation artifacts when merging dual scans together.

Keeping a small pixel size will maintain a tight PSF response and will also result in smaller working distances making the most of small convergent microbeams.



German Castro at the ESRF BM24 with the new VHR camera system

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The machine

ACCELERATOR AND X-RAY SOURCE GET MAKEOVER

As part of the planned Upgrade Programme there are several vast improvements in the pipeline for the future of the ESRF's accelerators and X-ray sources.

Thanks to the ESRF Upgrade Programme, modifications that would otherwise not be possible are now expected to enhance the accelerators and X-ray sources. These will be achieved by increasing the length of selected insertion device straight sections and canting undulators, increasing the stored electron current, replacing the electron beam-position monitoring system, operating in a "top-up" mode and upgrading obsolete accelerator components. This will provide several key improvements (see box) and achieve a factor-2 gain in spectral flux. Figure 1 shows the associated gain in brilliance.

However, the user community emphasises an important boundary condition for these developments: that the improvements in brilliance and flux must not diminish the reliability and stability of the storage ring. Beam stability, too, is key to the ESRF's success and is essential for the storage ring upgrades. A recurrent demand from several beamline teams is for further increases in brilliance by reducing horizontal emittance. Investigations into new storage ring magnet lattices fitted inside the existing tunnel have yet to produce a satisfactory technical solution, though any change here would entail an interruption of up to two years from shutdown to recommissioning. For the numerous user communities relying on the ESRF, this is too long. As a result, the upgrades to the accelerator and source will be made within a framework that avoids large-scale intervention into the storage ring.

Seven metre straight sections

The lattice of the ESRF storage ring is of the double-bend achromat type, with 32 cells of alternating horizontal high and low beta values. It was designed with two sets of quadrupole triplets on both sides of the 5 m long insertion device straight sections. This provides maximum flexibility and the ability to set a range of beta values in the centre of the straight sections (an option so far never used), though it would be possible to remove one quadrupole on either side and use the space to enlarge the available length for insertion devices from 5 to 6 m. This would require all other quadrupoles and sextupoles of the magnet lattice to be retuned to different values (something already tested and implemented in user mode in October 2006). A further increase in the available length of insertion devices, from 6 to 7 m, is possible by replacing two quadrupoles either side of the insertion device with shorter magnets and by displacing the adjacent sextupole (figure 2).

The alternating low- and high-beta undulator source points (a desirable and successful feature of the ESRF lattice) will be kept. The implementation of a number of these 7 m straight sections should be possible with minimal adverse effects on their injection efficiency and ultimate lifespan. The available 7 m length can then

BENEFITS OF THE ENHANCEMENTS:

- Higher brilliance
- Higher flux
- Increased capacity for further beamlines
- Higher photon beam stability
- Increased insertion device flexibility
- Enhanced durability of the accelerator complex

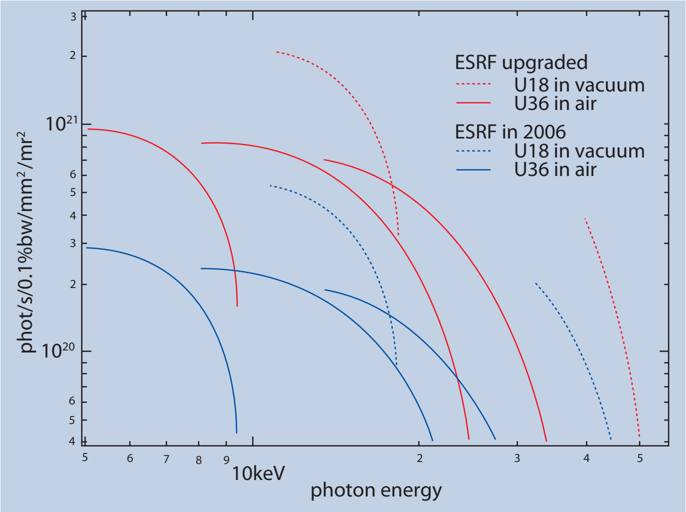


Figure 1: Brilliance of typical ESRF undulators before upgrades (blue curve) and after upgrades (increase in current to 300 mA, 7 m-long insertion devices and lower vertical emittance) have been implemented (red curve).

be used to install longer undulators and increase the available brilliance, or to increase the flexibility of the insertion devices. Alternatively, the undulators inside such a long straight section could be canted (figure 3).

In a set-up such as this, two of the existing 1.65 m sections (simple or revolver type), or a 3 m long in-vacuum undulator, can be installed on each of the two segments of the chicane. As has always been the case at the ESRF, specific insertion device segments will be developed and optimised for each beamline (polarisation, photon energy range, harmonic content, etc) and installed on the newly rebuilt straight sections.

The storage ring has been injected with 200 mA in multibunch mode for many years. A bunch-by-bunch feedback system, currently under construction, has allowed stable operation at 300 mA in uniform filling mode for short periods of time during machine tests. This mode of operation still requires further tuning and optimisation, but it will become the standard operation mode in the years to come. All multibunch modes will be delivered with a stored current of 300 mA (including uniform), 2 × 1/3 filling and the recent 7/8+1 mode.

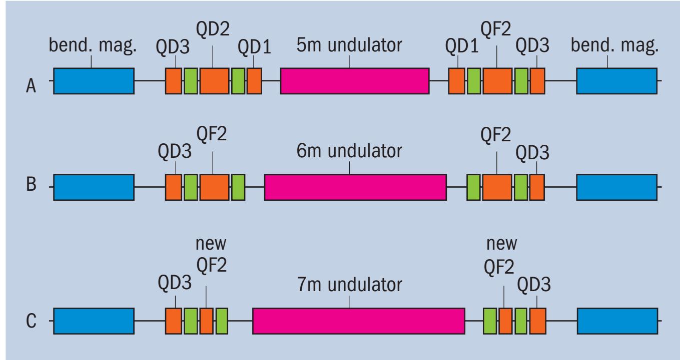


Figure 2. Schematic of a high beta straight section. The blue, red and green elements are bending magnets, quadrupole and sextupole magnets, respectively. Case A represents the situation in the first part of 2006, with a triplet of quadrupole magnets on both sides of a 5 m long undulator. Case B shows the first phase of modification consisting of the removal of the QD1 quadrupoles on both sides of the undulator, allowing the undulator length to be increased to 6 m. Case C shows the next step, replacing QF2 with a shorter quadrupole and moving the adjacent sextupoles closer, leaving a further 1 m (giving a final available length of 7 m) for the undulator(s). Similar alterations can be used on a so-called low-beta straight section.

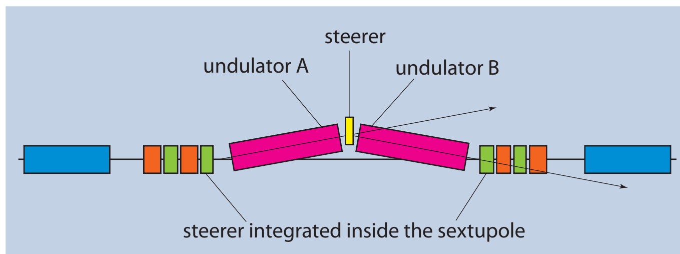


Figure 3. Schematic of undulator canting. The angles are exaggerated to improve readability. The maximum angle between the beams from undulator A and undulator B will be close to 2 × 2.7 mrad. The canting is produced by three steerers at the entrance, middle and end of the straight section. The entrance and end steerers will be implemented inside the existing sextupole magnets.

High-power, solid-state RF amplifiers

High-power klystrons constitute the heart of the existing RF power transmitter system. As demonstrated over 15 years of operation, klystron instabilities constitute a significant and unpredictable contributor to RF trips and downtime. Unfortunately, the two manufacturers that supplied the most stable klystrons have since stopped production, leaving only one supplier. Confronted with these uncertainties over the klystrons, all of the new light sources developed in Europe (SOLEIL, DIAMOND, ALBA), as well as some existing ones (ELETTRA, SLS), have been, or are, developing alternatives based on inductive output tubes (IOT) or high-power, solid-state amplifiers. IOTs are not yet commercially available at the frequency of 352 MHz needed. Therefore the only alternative to klystrons is solid-state power amplifier technology. Following the pioneering results of SOLEIL, it is planned gradually to replace the klystron-based transmitters with solid-state amplifiers. These will also suit the required redundancy for the 300 mA ring current.

The reliability of day-to-day operations at 300 mA could suffer if it ever had to rely on the delicate combination of higher-order mode (HOM) detuning of the RF cavities through precise temperature regulation and optimum tuning of the longitudinal bunch-by-bunch feedback system. Thus the existing five-cell copper cavities will be replaced with a set of single-cell HOM damped cavities kept at room temperature. This will provide longitudinal stability over the full range of current (0 – 300 mA), even without feedback. The new cavities will be optimised for high beam power transfer and fit into the existing RF-dedicated straight sections of the ring. A normal conducting 352.2 MHz cavity with HOM damping is being designed in collaboration with BESSY and ALBA.

The implementation in 2003 of injection with front ends open has improved the stability of the beamline optics. Thanks to the continuous availability of the X-ray beam, and the machine's current configuration in multibunch mode, it only needs two short refills each day and results in a longer lifespan. The beam is delivered for 12 hours between each refill, with a current change of 15 – 20%. In contrast, this larger current variation during decay makes frequent injection (top-up) attractive for time-structured modes (16 and 4 bunch), while increasing the average current and photon beam stability.

Clean machine

These time-structured modes (and hybrid mode) must be delivered with a high contrast of 10^9 between the filled bunches and the empty bunches. The process of removing the low populated bunches, which is needed for a 10^9 contrast, is known as "cleaning". This is currently achieved in the storage ring immediately after injection by selectively exciting and intercepting the low current bunches in the vertical plane – making use of the variation of the vertical tune with the bunch current. Solutions are being investigated as to how to perform the cleaning process in the booster in a way that avoids undesirable excitation of the beam each time storage ring refilling takes place. This includes the operation of a 1 Hz injection cycle of the booster synchrotron following an upgrade of the booster power-supply system.

Several more improvements to the accelerator complex will be carried out, such as the replacement of the electron beam position-monitoring system with a modern digital system. This will increase the accuracy of the position measurements and beam stability, which will also enable further optimisation of the lattice. Studies will be carried out to find a suitable scheme for producing X-ray pulses that are shorter than the 100 ps fwhm currently achieved in four-bunch mode. Lattice studies will continue targeting the longer term (beyond the ESRF upgrade), including the design of a new lattice with reduced horizontal emittance that can be implemented inside the existing tunnel. Studies will also explore the conceptual design of an ultimate high-energy source with ultra-low horizontal emittance. •

PASCAL ELLEAUME

Feature news

GOOD INGREDIENTS AID EXPERIMENTAL SUCCESS

The success of the ESRF upgrade depends not simply on the quality of its scientific programme but also on aspects relating to its instrumentation, such as developments in optics, detectors and beamline engineering.

A better-performing ESRF needs better-performing instruments. The ESRF's upgrade will offer the scientific community a more brilliant X-ray light and 10 nm nanobeams, but this has a price: a large effort in instrumentation development.

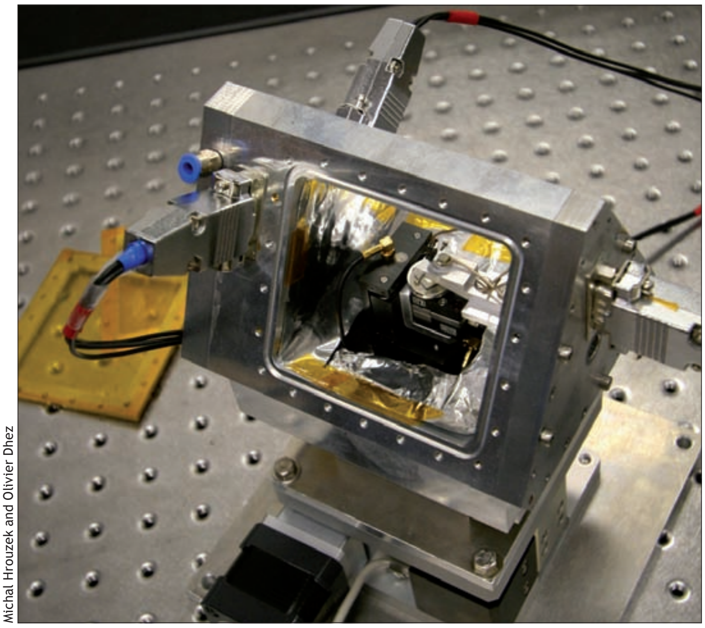
High heat loads produced by the increased brilliance of the source are one of the challenges that the ESRF engineers will have to face in the future. To manage this heat, engineers will increasingly use diamonds in monochromators as well as in attenuators. They will also develop new cooling schemes for classic crystal monochromators and new multilayer-based, white beam mirrors. High-power large-aperture refractive lenses need to be developed further as well. Further development in optics will also take into account coherency preservation.

The development of nanofocusing optics based on diffraction, refraction and reflection show that there are no physical barriers in pursuing sub-10 nm resolutions. This will be accomplished through new developments in Kirkpatrick–Baez mirrors, compound refractive and multilayer Laue lenses providing high-efficiency, high-resolution focusing of medium-energy X-rays.

The problem of sample and beams monitoring, plus alignment and steering at nanometre precision, will demand a huge effort to integrate the development of all of the instruments at the same time.

Detecting sneaky photons

Today the experiments are limited by the existing detectors. In some cases they waste photons in the incident beam because of their lack of detection efficiency. In other cases they don't perform well enough to provide all of the required information about the sample. Thus the potential for new science through the development of better detectors is enormous. The Upgrade Programme foresees dedicated X-ray detectors specialised for a given type of experiment so that they produce the maximum impact. This variety of detectors should offer a number of improved features, such as higher efficiency, high resolution and larger areas. Also, the availability of fast detector pixel arrays will allow experiments to be performed on shorter timescales than are possible with the current technology.



Michal Hrouzek and Olivier Dhez

A beamline atomic force microscope. This instrument was developed recently at the ESRF for imaging surfaces with nanometric resolution while performing X-ray scattering.

The engineering challenges that the ESRF faces are shared by all of the next-generation synchrotron sources. Conceiving, manufacturing, integrating and validating a variety of instruments can only be done if appropriate test benches are available to assess innovative instrumentation. The Upgrade Programme thus plans two stations dedicated to instrumentation development.

Another project beneficial to the lightsources community in general is the creation of an integrated beamline control platform for common protocols and standards for instrumentation on the one hand, and for integration at the sequencing level on the other.

The detector strategy will include promoting or participating in ongoing joint development programmes, involving European light sources, detector development laboratories and detector manufacturers.

MC

EXPERTS SHARE THEIR VIEWS ON THE UPGRADE

The Upgrade Programme is designed to keep the ESRF at the forefront of synchrotron science, so that it can provide the best possible tools to the scientific community, but what does the synchrotron "family" think of it?

INGOLF LINDAU

Professor Emeritus at Stanford University (USA); professor at Lund University, Sweden

What do you think of the Upgrade Programme?

I am very excited about it and consider it absolutely essential for the ESRF to keep its well established position as a world-leading lab in synchrotron radiation research. No other synchrotron radiation lab is better positioned to implement the proposed and challenging advancements described in the programme.

Is it good timing?

Yes. Many beamlines have been in operation for a long time and have reached peak performance. To meet the challenging scientific problems that we are facing over the next 10–20 years or so, it is the right time to make drastic improvements to accommodate new capabilities and increase capacity. With a well planned upgrade in phases over a long period, this can be done without a drastic impact on users' access. If implemented over 10 years, the ESRF will have consolidated its position as a world-leading lab, considering the facilities now being commissioned or planned to be in operation.

How can the scientific community in general benefit?

The main reasons for my enthusiasm are the new scientific opportunities. From my point of view, these concern studies of nanostructures, complex materials and matter under extreme conditions. Much important work is being done on nanostructures at the ESRF and other synchrotron facilities, but the upgrade will, in my opinion, revolutionise X-ray absorption, scattering and imaging studies on a true nanoscale.

This will require developments of more advanced optics, extreme stability of the beamlines, and high operational reliability of the storage ring. The ESRF has the world's foremost expertise to meet all of these challenges and I am confident that it will be successful.

MARCO GRIONI

Professor at the the Institut de Physique des Nanostructures in Lausanne (Switzerland); ESRF user

What do you think of the Upgrade Programme?

I think the ESRF has made the right move by choosing to develop a high-profile, long-term vision, based on its uniquely strong points. National facilities already offer very attractive performances at the lower-energy end of the spectrum, and free-electron laser sources in a few years will open up new possibilities. The upgrade guarantees that the ESRF will remain the best place in the world to do most of the really innovative and exciting experiments with X-rays.

Are there any negative aspects?

Users who already run successful scientific programmes at the ESRF may be concerned about the forthcoming perturbations of the machine's operation. In a way, the facility is a victim of its own success. However, I believe that this concern is taken seriously and that the real shutdown will be minimised.

How will you benefit as an ESRF user?

Experiments exploiting nanofocus conditions and very short X-ray pulses will be the great winners. On the other hand, my research into electronic excitations in solids will also take advantage of the improved brilliance. I am thinking of experiments under extreme conditions of pressure, magnetic field and temperature, which will also need the special infrastructure that the ESRF plans.

How can the scientific community in general benefit?

Directly, because new experiments will be possible in physics, materials science, chemistry, etc. Indirectly, because new technical advances developed for specific needs will then be made available to scientists in distant areas of research. Detectors are an obvious example.

CHRISTIAN VETTIER

Science director at the European Spallation Source in Sweden; adviser to the ESRF's director general

What do you think of the Upgrade Programme?

Users' needs have evolved, new scientific fields are developing and other facilities are creating their own areas of excellence. The ESRF must stay in the lead.

It is timely because new facilities are appearing that could compete with the ESRF, because the sister institute on the joint site (the ILL) has launched a similar project, and because the joint site is to be developed to become a European Science Campus. It is also ambitious because it focuses on future scientific trends.

Are there any negative aspects to the upgrade?

Being ambitious means taking risks, and taking risks is not negative. The reliability and predictability of the machine are key for users.

How can the scientific community in general benefit?

The ESRF will confirm its position as the leading light source in Europe. Pushing beamline instrumentation to the limits means faster data acquisition during more demanding experiments. New methods will open up avenues to new science.

Do you have any other thoughts?

The scientific environment on the ILL-ESRF site should be developed, to offer lab space and interface facilities (similar to the Carl-Ivar Brändén Building: soft matter, gas handling labs, extreme conditions, etc) for preparing experiments and optimising the scientific output from ESRF (and ILL) beamtime. A computer-modelling lab would allow virtual experiments in parallel with real ones for deeper data analysis. Links between the theory groups of both institutes should be strengthened too.

EVA PEBAY –PEYROULA

Director of the Institut de Biologie Structurale and professor at the Université Joseph Fourier; ESRF user

What do you think of the Upgrade Programme?

The ESRF has a huge impact on several scientific fields. It was conceived to be at the forefront to allow the most extreme experiments. It has to remain there, so the upgrade is key.

Is it good timing?

After 10 years of user operation, yes. Science has evolved, as have experimental requirements. The facility has two roles: to perform "routine" experiments that still need high-quality beams, and to permit new and challenging experiments. The upgrade is necessary for the ESRF to compete internationally.

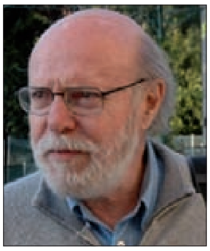
How will you benefit as an ESRF user?

In biology there is a need to work with smaller samples. Automation and beam performance will help to handle them and to get enough signal. In addition to structure determination, structure-function analyses need other approaches than crystallography to bridge several scales and to understand larger (and softer) macromolecular assemblies.

How can the scientific community in general benefit?

Automation and easy access to the beam with possible data treatments will open up the use of the ESRF to non-specialists (e.g. in protein crystallography). In addition, the possibility of sending crystals to the ESRF for study will also contribute to it. However, it is important to keep good contact (not only by e-mail) between the beamline scientist and the users, in particular to maintain constant development for new and challenging projects. Partnerships, such as the Partnership for Structural Biology, will help to integrate the experimental possibilities offered by the ESRF into the scientific community in general.

LUCIO BRAICOVICH



Professor in physics at the Polytechnic of Milan; ESRF user and former chairman of the ESRF-SAC

Is it good timing?

Yes. Not only to propose the upgrade but also to start implementation. I see several good reasons to start as soon as possible. The quality of the measurements done at the ESRF has been improving continuously due to learning through process and refurbishment. However, major improvements cannot be done during the normal life of a beamline because this would interfere too much with its operation. Thus some improvements have been postponed to a time of major rebuilding, thus allowing the whole facility to be updated.

There is also a "political" issue. In recent years we have seen the expansion of the projects on free electron lasers (FELs), which will become increasingly important and will offer fantastic new opportunities. In the scientific community there is a general consensus that these new sources will be complementary to synchrotron radiation facilities and will cross-fertilise with them by allowing new physics to be done. However, I am not sure that this is fully understood at the political level. There is the risk that policy makers think of FELs as substitutes for synchrotron radiation sources and will not put enough resource into storage ring activities. To avoid this, it is timely to present and support the Upgrade Programme. Moreover, the complementarity with FEL projects is particularity true in the case of a high-energy storage ring at the ESRF, because the new FELs will not cover the whole range of photon energies delivered there.

How will you benefit as an ESRF user?

The possibility of having a better focal point on the sample will be a real breakthrough. Smaller spots at micro- and nanofocusing levels are obviously important in the era of nanotechnologies. There are also other key reasons: there is a very large number of samples that cannot be prepared as big objects (typically 1 mm or a fraction of that) but only at the scale of the tens of microns. This is not the typical nanoscale but will enable a great number of important investigations — both structural and spectroscopic.

JEROME HASTINGS

LUSI (ultrafast science instruments) project director at Stanford Linear Accelerator Center (USA)

What do you think of the Upgrade Programme?

It focuses on the strength of third-generation X-ray sources: brightness. There is a push for long beamlines that enable reasonable working distances for diffraction-limited nanometre-scale focusing. Combined with the lattice upgrade, this is an exciting opportunity.

Is it good timing?

The ESRF has always had a variant of the ILL approach to instrument upgrades, and this has served the scientific community well. However, this cannot provide the necessary infrastructure that is laid out in the Upgrade Programme. With the start of construction of PETRA III, this is an appropriate time to begin the civil construction and lattice upgrade so that the build-out of beamlines can commence.

Are there any negative aspects to the upgrade?

We should focus on the opportunities specific to nanoscale beams and brightness-limited experiments and not look on the upgrade as a 'super' beamline refurbishment.

How will you benefit as an ESRF user?

In science it is becoming clear in a number of areas that inhomogeneity is an intrinsic property. With nanoscale focus the nature of these inhomogeneities, their role in understanding complex materials can be investigated. ●

MC


A changing panorama. The layout of the ESRF as it is now (left) and an artist's impression of the facility following the upgrade.

NEW AND IMPROVED LOOKS IN STORE FOR THE ESRF

The Upgrade Programme will significantly change the ESRF landscape. A total area of 21 000 m^2, equivalent to four football pitches, will be created to accommodate long beamlines, plus new laboratories and offices.

On a clear day you can see the doughnut shape of the ESRF from the tops of the surrounding mountains. It is a near-perfect ring nestling in the junction where the Drac and Isère rivers merge. This familiar view is now set to change, with a planned upgrade adding to the ring and other nearby buildings. The new area will total 21 000 m^2, which is one-third of the ESRF's total existing space.

The new long beamlines will occupy most of the added surface area. Research at the nanoscale is one of the central features of the programme, and the new space will allow as many as 16 beamlines to be increased in length between the source and the sample, from 55 m to (in most cases) between 120 and 140 m. For reference, 140 m is about double the length of the new Airbus 380.

The long and the short of it

The raison d'être for the long beamlines is to have either very big or very short beams. The beam sizes for topography, tomography and medical imaging may have to reach several centimetres, and the need for long beamlines lies in the fact that the length of the transverse coherence increases linearly with the distance from the source. Nanobeams also require long beamlines because the source is focused by the ratio of the distance from the lens to the sample, and the distance from the source to the lens.

The jump to nanometre-range experiments will have significant consequences for the sample environment. The design of the extension must minimise additional ground vibrations being transmitted to the sample and provide an environment with a stable temperature.

One of the star projects of the ESRF upgrade is the creation of a high magnetic field facility, with 50 T pulsed field coils on the ID06 and ID08 beamline, on site. Measuring approximately 1200 m^2, this will be demanding in terms of electrical power supply and cooling needs.

With all of these new beamlines and new technology, the ESRF is certain to produce a lot of new data over the next decade. These would be impossible to store in the existing computing rooms, which are already close to saturation. To cope with this, a 500 m^2 computing centre is also included in the framework of the upgrade.

All in all, the ESRF will change looks in a fashionable way. The new buildings will be neatly integrated into the ESRF structure and the construction process will be smooth, with disruption of the facility being minimised. ●

MC

Interview

Robert Feidenhans'l: professor at the Niels Bohr Institute and chair of ESRF Council.

"When there is a flagship like the ESRF, all of the national facilities want to compete. But if you want to keep ESRF at the front, you need to give it a new injection for developing new capabilities."

'NATIONAL FACILITES GAIN A LOT FROM THE ESRF'

He has a very tough job. As the chairman of the ESRF Council, Robert Feidenhans'l, professor at the Niels Bohr Institute at Copenhagen University, tries to reach a consensus between the delegations of the 18 countries represented in the council meetings. Despite the challenge, he asserts that there is a very good working atmosphere and common understanding, which facilitates his job. This is especially important now that discussions about the Upgrade Programme are taking place.

What is your take on the upgrade?

We need it to keep the ESRF at the forefront of science. The facility has explored nearly every new scientific field in synchrotron radiation-based science, such as time-resolved research, protein crystallography, inelastic scattering and nanobeams. When there is a flagship like the ESRF, all of the national facilities want to compete. But if you want to keep the ESRF at the front, like we do, you need to give it a new injection to develop new capabilities.

Is it good timing?

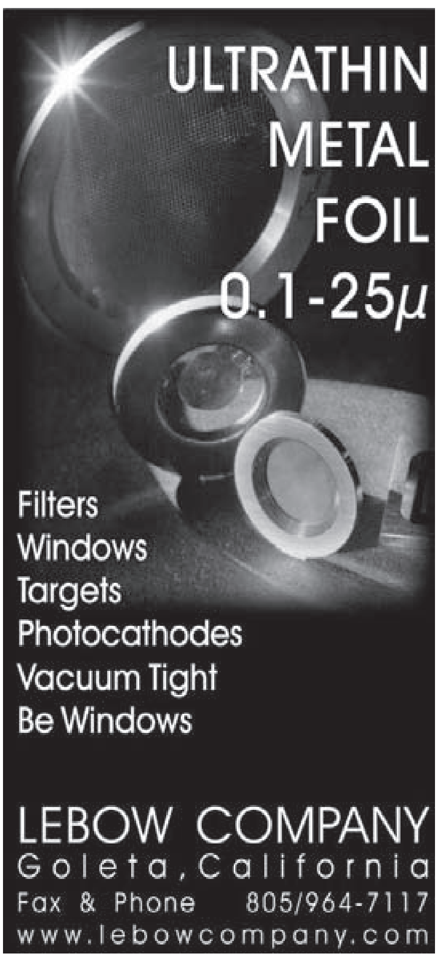
It is very good timing now, but very soon it will be too late. The US and Japan have already started upgrading their machines and in their case it is easier because they only need the agreement of one decider. At the ESRF there are different partners with different traditions and economic situations, so the decision process is more complicated. However, I think we are still moving at a good pace, but we can't delay it now.

Are members of Council convinced about it?

Some countries' representatives wanted to know what they would get from the upgrade in return for the money that they invest. What are the new possibilities that are only offered by the upgrade? We – the ESRF management and I – have visited different agencies and ministries to investigate whether the ideas behind the upgrade are what their user communities are asking for. At the end of the day, this is a user facility, so you have to have backing from the individual countries. You also have to argue why new funding must be injected

POWERS OF COUNCIL

ESRF Council meets twice a year to make important decisions about company policy, which must be approved at different levels depending on the issue. For example, unanimous approval is required for the admission of new members, the transfer of shares among members, an increase in capital, changes to the financial rules of the ESRF or the amendment of the ESRF statutes. Matters such as the annual budget, the medium-term scientific programme, the policy for the allocation of beam time, the election of the chairman of Council or the appointment of the different ESRF directors only need a qualified majority.



into the ESRF rather than only into the national facilities.

A lot of Council members are actively involved in the national facilities. Is there a conflict of interests?

I think that there will always be some conflict of interests, due to the competition between the facilities. But what keeps facilities at the forefront is the competition. On issues like detectors, for example, facilities can work together, but in the scientific field you have competition between light sources. That is where the conflict of interests may come in. However, the national facilities gain a lot from the experience of the ESRF, such as in optics or detectors, or even in training for future staff. This is the way the partners can gain.

What are the negative aspects of the upgrade?

At some stage of the upgrade there will be no beam for a while. This will be a critical point because the users won't get beamtime. They will go somewhere else and will only come back again if the facility is significantly better than what is offered elsewhere. The shutdowns need to be relatively short, which is feasible with the planning as it is today.

How can science in general benefit?

One of the areas that will have an impact is research on the nanometre scale. There is a wide community that is aiming to look at matter in that scale, not only materials science but also life sciences and medical research *in vivo*, for example.

How ambitious is it?

It is reasonable; it is not at the scale of doubling the contribution, it is only 20% more for 10 years. It is necessary if you want to keep the ESRF leading synchrotron science.

How does Council make decisions?

Normally there is a consensus. Sometimes you need to have a vote, but it is really rare. Budget is always the difficult subject: at the moment, Europe is doing quite well, but in the past there have been countries that have had financial difficulties. On a few rare occasions, voting has been necessary.

You must gain a lot of experience in management in these meetings.

Yes. One of the big challenges is to keep to the agenda. You can never predict which are the easy points and which are the difficult ones, and you only have two half-days to sort everything out. The most important thing about the council meetings is that we respect the breaks, in particular dinner breaks, because at dinner you can solve many of the difficult questions.

Have you considered having meetings through videoconference?

You have to have the person in front of you…and besides, how can you have a dinner through a videoconference?

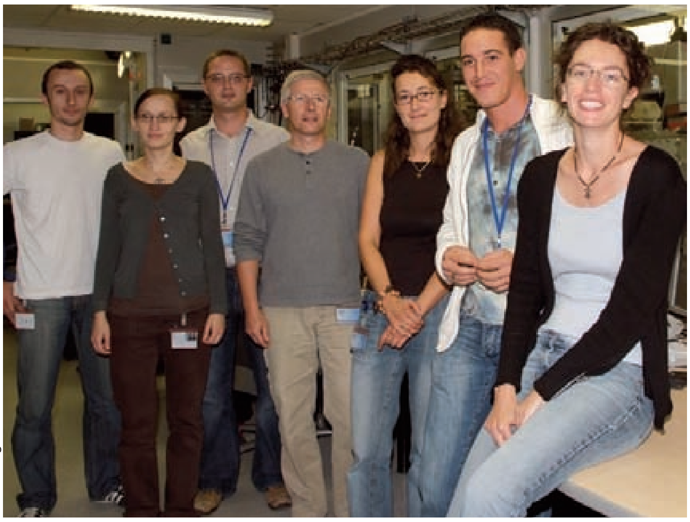
MC

Visiting a beamline

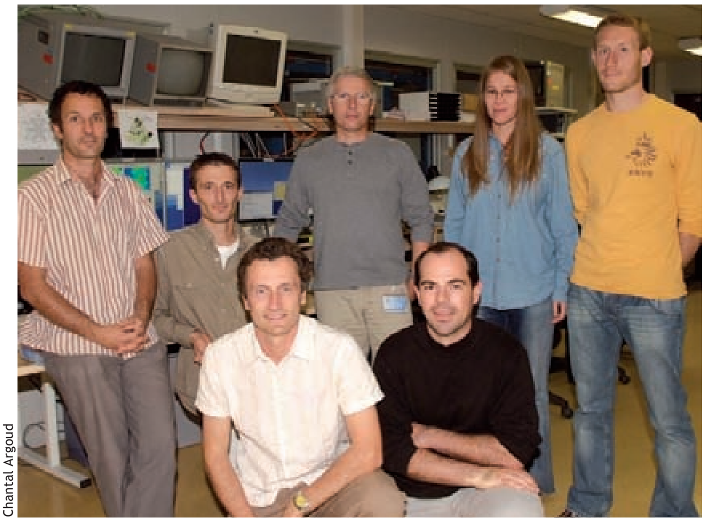
ID21 AND ID22: PLAYING THE FIELD FOR THE FUTURE

A good team spirit is what lies behind the success of the integrated X-ray spectromicroscopy beamlines ID21 and ID22, and now the collaborative teams working on their development have their eyes firmly fixed on the future.

Chantal Argoud



Chantal Argoud



ID21 team. From left: Vincent De Andrade, Malgorzata Rak, Jakub Szlachetko, Jean Susini, Murielle Salomé, Franck di Chiaro, Marine Cotte. Absent: Emilie Chalmin and Gilles Berruyer. **Right: ID22 team.** Remi Tucoulou-Tachoueres, Pierre Bleuet, Sylvain Laboure, Jean Susini, Sylvain Bohic, Gema Martinez-Criado, Sylvain Petitgirard. Absent: Peter Cloetens, Cyril Guillaud, Isabelle Letard-Kieffer.

Jean Susini likes to see his job like that of a football coach. The coordinator of the ID21 and ID22 beamlines says that his role is to "attract the best player, develop a style of game where they can really expand and put them in the best position on the field".

This analogy is not too far off, considering that ID21 and ID22 – along with ID18F – were specifically designed to work together on X-ray imaging as part of a 'team effort'. Like any good sports team, the beamlines are managed centrally and their energy ranges complement each other. A key feature is that they are organised as a coordinated microanalysis platform – the only one in the world that offers a hard X-ray microbeam, soft X-rays and infrared microscopy as a suite of available techniques all within the same structure.

If Susini is the coach, then the beamline staff and users are definitely the team's players. The X-ray imaging team – consisting of a Cuban scientist and two Polish post-docs, a Belgian and several French – lists friendship, mutual aid, good coaching and conscientiousness as personal qualities that ensure a good team spirit across both beamlines. "The integration between the two gives more opportunity for people to collaborate and interact together in the same location, whether on the beamlines or at the coffee machine," Jean believes.

The multidisciplinary ID21 and ID22 have been operational for 10 and 12 years, respectively, taking images of a variety of samples that range from comet grains to human hairs, and from nano-objects and cells through to fragments of paintings. The main techniques that they use are X-ray fluorescence, X-ray diffraction and absorption spectroscopy. Scientists can access almost any element in the periodic table and adapt the energy to the targeted elements. ID22 runs at atmospheric pressure and uses a Kirkpatrick–Baez focusing device, whereas ID21 runs in a vacuum and uses Fresnel zone plates as a focusing lens.

The versatility of sharing

This duality offers the ultimate convenience and flexibility, and it works very successfully. Gema Martínez-Criado, a beamline scientist on ID22, agrees: "The best thing about working in our group is the versatility and complementarity of the shared instrumental conditions. For example, you can analyse a sample on ID21 at the micrometre scale, then go next door to examine it in more detail using the hard X-ray nanoprobe."

The facility's typical users are non-experts in

"The integration gives more opportunity for people to collaborate and interact in the same location, whether on the beamlines or at the coffee machine."

synchrotron light, as well as geochemists, geophysicists, archaeologists, biologists and medical doctors. Today, for example, a group of Italian biologists at ID21 is studying the distribution of gadolinium in cells. The local contacts or beamline scientists usually act not only as the interface between the beamline and the users but also as collaborators, so they are often well integrated and involved with external experiments.

The strength of this support system is reflected in the fact that ID21 and ID22 are the beamlines in greatest demand, receiving more than 195 proposals between them on average and accepting an average of 28 and 29 last year, respectively. In fact, they are so oversubscribed, particularly from the environmental science and cultural heritage communities, that a new beamtime allocation panel had to be set up to select proposals of this nature.

The future is bright for these teams. They are currently commissioning a new nano-imaging end station – the ID22NI (located at the back of ID22) – with the target of reaching resolutions of 50 nm spot size. Peter Cloetens, the ID22NI coordinator, believes that the project will help to bridge the gap between the truly nanoscale techniques and the microscale techniques that are currently available. "X-ray imaging and microanalysis are very successful today at the ESRF, but the spatial resolution is most often limited to typically 1 µm," he explains. "As X-ray nanofocusing will play a major role in several of the Upgrade Programme activities, the new endstation is an important pilot project for us."

As a result, the two beamlines – along with ID13 – will be pioneers in a number of techniques that will drive the development of high-tech instrumentation forward. One aim of the upgrade is to improve the synergy between beamlines, so the integration and team spirit between ID21 and ID22 (and ID18F) could be a shining example of how the ESRF is already embracing the future. ●

ANYA POPE