A LIGHT FOR SCIENCE

ESRF news

Number 80 December 2018

30 YEARS OF SCIENCE

1988–2018

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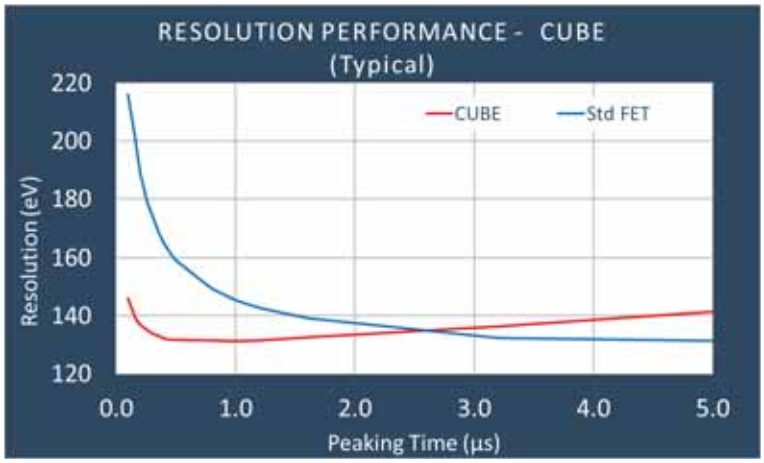
RaySpec Multi-element detectors take advantage of the latest CUBE® and JFET developments in sensor readout and next generation Digital Pulse Processors to offer improved resolution and higher count rates.



CUBE detectors offer improved resolution at shorter peaking times

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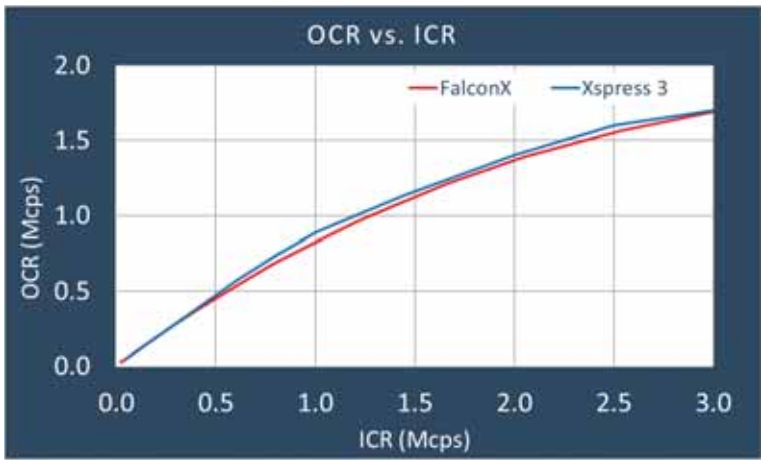

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Single and Multi-Sensor SDD Detectors

Example of single sensor design

Example of multi-sensor design with UHV compatibility

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Examples of Customised Designs

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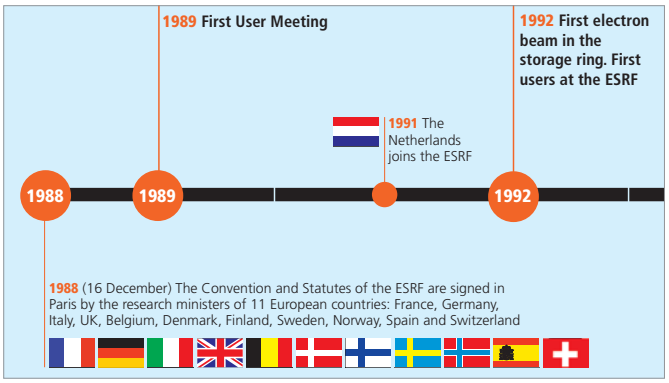
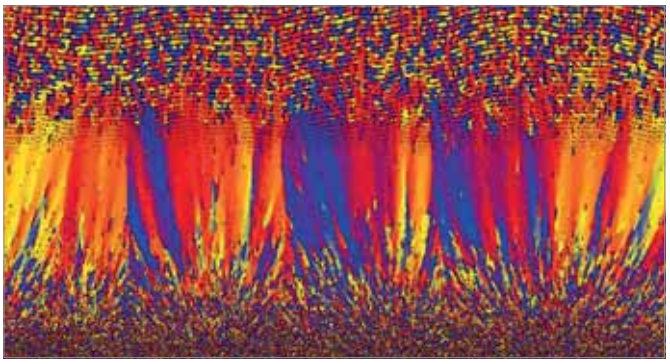
The European Synchrotron



Milestones in the ESRF's 30-year history, p16.

"Twice in my life I've been able to live through exceptional engineering projects." Jean-Claude Biasci reflects on the EBS project, p29.



Model of mollusc growth tested on ID19 and ID06, p34.

On the cover:
30 years of bringing nations together through science, p16

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Happy 30th birthday ESRF

In 1988, 11 countries joined forces to create the first third-generation synchrotron light source: a dream became reality. For 30 years, the ESRF has broken records for the brilliance and stability of its X-ray beams, for its scientific output (more than 30,000 publications and four Nobel prize laureates) and for the strength of its community of users, who are all motivated by the same passion for discovery and new knowledge. The success of the ESRF programme demonstrates what European countries can do when sharing a common objective.

Today, 22 partner countries from Europe and beyond share the same vision: to promote excellence in science, and to embrace international cooperation. Beginning on p16 of this special issue, an anniversary focus section gives a flavour of our collective engagement – past, present and future – with tributes and recollections from members of the scientific community. The variety of stories demonstrates that an interdisciplinary hub is crucial for successfully addressing the complex global challenges facing our society, and that, more than ever, science is a driver of peaceful relations among countries and cultures.

"More than ever, science is a driver of peaceful relations among countries and cultures."

Audacity and innovation have always underpinned the history of the ESRF, and this story continues today. On 10 December, precisely 30 years after the signature of the ESRF Convention, the ESRF's shining light will be paused. The ESRF will then enter a 20-month shutdown, with the aim of returning, in 2020, with a new Extremely Brilliant Source back in user service mode. With a brand new storage ring, and a portfolio of new beamlines, the EBS will enable scientists to bring X-ray science into research domains and applications that could not have been imagined a few years ago. By pushing the frontiers of accelerator technology, it will also pave the way for future synchrotron projects worldwide, and will offer extraordinary new tools for the next generation of scientists and accelerator engineers.

2018 is definitively a turning point for the ESRF, and I would like to take the opportunity in this issue to thank all those who, with their continuous support and engagement with the ESRF, help us to improve our standards and to develop new research opportunities. Thanks from all of us at the ESRF to those from academia and from research labs and institutes; thanks to the whole international community using the ESRF; and thanks to the 22 partner countries that provide the means to make the ESRF such a special place. And finally, on behalf of the management, the user community and myself, thanks to the ESRF staff, whose unique expertise has allowed us to implement new and innovative projects that push the limits of science and technology.

I look forward to keeping you informed on the progress of the installation of the new storage ring, and the restart of the experimental programme in 2020.

Francesco Sette, *ESRF director-general*

STEF CANDE

ESRF–EBS named 'landmark' facility

The ESRF's upgrade, the Extremely Brilliant Source (EBS), has been confirmed as a "landmark" project in the latest roadmap report by the European Strategy Forum on Research Infrastructures (ESFRI).

Published in September, the report describes the ESRF–EBS as a landmark project in the category of physical sciences and engineering, along with other major European facilities such as the Square Kilometre Array telescope, the European Spallation Source, the Extreme Light Infrastructure, the European X-ray Free Electron Laser and the upgraded Large Hadron Collider. A landmark, according to the ESFRI, is a research infrastructure that has reached an advanced degree of implementation, and represents a "major element of competitiveness of the European Research Arena".

In a joint statement, ESRF directors of research Harald Reichert and Jean Susini say that the EBS will address "major challenges facing our society". "It will help develop the next generation of drugs, biomaterials and sustainable materials, and provide deep insights into the complex mechanisms governing living organisms," they add. "What's more, it will elucidate our recent and ancient past, and provide unique opportunities for innovation-driven research."

At a cost of €150 m, and backed by 22 partner countries, the EBS upgrade will transform the ESRF into the world's first fourth-generation synchrotron light source operating at high energies.

The design has inspired more than 10 other light-source projects worldwide, and is expected to serve as a reference for accelerator scientists for at least another decade.

Quake precursors imaged

It begins innocuously enough, with the formation of a few microfractures. But these quickly grow and coalesce into a rupture that swiftly propagates through the rock, generating an earthquake.

Occurring several kilometres under the Earth's surface, earthquakes are not the easiest phenomena to observe. Nevertheless, smaller quakes can be studied by making use of the Hades deformation rig at the ESRF beamline ID19, which allows centimetre-scale rock samples to be imaged at near micron resolution while being subjected to the pressures and temperatures found deep in the Earth's crust. Now, geoscientist François Renard of the University of Oslo in Norway and colleagues, who developed this facility, have used it to document the evolution of microfracture growth, termination, shearing and, ultimately, full-on rupture, with unprecedented resolution.

The researchers incrementally increased the stress on two core samples of monzonite – a granite-like rock that composes most of the continental crust – while imaging them every 1.5 minutes. The images showed that the total damage, as well as the size of the largest microfracture cluster, rose according to a power law of stress; in other words, they rose quicker and quicker until the point of failure, when they diverged. During this transition, the microfractures rotated from being parallel to the direction of stress, to produce the shear fault (*J. Geophys. Res. Solid Earth* doi:10.1002/2017JB014964).

According to Renard and colleagues, the results provide the first visual evidence to support theoretical models of the transition to failure. Importantly, the researchers add, "the dynamics of microfractures – precursors to the main earthquake – display predictable properties".

Austria boosts ESRF ties

Austria has increased its association level to the ESRF from 1.3% to 1.75%, to reflect the increased use of the synchrotron by its scientific community. The ceremony for the new arrangement took place at the Austrian Academy of Sciences (ÖAW) in Vienna in June, with ESRF director-general Francesco Sette and ÖAW president Anton Zeilinger (above, left to right) as signatories. Daniel Weselka, the director of basic research and research infrastructures at the Austrian Federal Ministry of Education, Science and Research, was also present.

Registration open for AfLS2

Registration is open for the second African Light Source Conference (AfLS2), which is scheduled for 28 January to 2 February next year. The first such conference, AfLS1, was hosted by the ESRF in 2015, and led to a roadmap for the development of an African light source, including developing a user base, exchanging expertise, building local infrastructure capacity and raising the political profile. Held at the University of Ghana Legon Campus, AfLS2 will further explore the light source's vision and strategy, and present talks on promising areas of scientific research.

Cryo-EM facility bears fruit

One year after its inauguration, the ESRF's cryo-electron microscope (cryo-EM) facility has delivered its first publication: a study of a protein that is targeted by anti-nausea medication for cancer patients undergoing chemotherapy and radiotherapy.

The protein is a serotonin receptor known as 5-HT3 – an ion channel that is present inside the brain, as well as in the enteric nervous system, which drives the digestive tract. The chemicals used in cancer treatment trigger an elevation in serotonin signalling, prompting 5-HT3 to open its channel and, as a result, causing nausea. For that reason, pharmaceutical companies have studied it extensively as a target for anti-nausea drugs.

The new study involves researchers from the French Alternative Energies and Atomic Energy Commission, the French National Centre for Scientific Research, the Institute of Structural Biology (IBS) in Grenoble, the Pasteur Institute in Paris and the University of Lorraine in France, as well as researchers from the University of Copenhagen in Denmark, the University of Illinois in the US and the French biotech company Theranyx. Cryo-EM allows biomolecules to be frozen in different conformations with no need for crystallisation, and the researchers exploited this at the ESRF to obtain the structure of 5-HT3 in one of four conformations (*Nature,* in press). (The other three were obtained at the Center for Cellular Imaging and NanoAnalytics in Switzerland.) "Now we see the binding pockets in unprecedented detail, which can help the development of future drugs," says Hugues Nury of the IBS.

"This publication is a true reward for us – our first one in less than a year from inauguration," says Isai Kandiah, who runs the ESRF's cryo-EM facility. "We hope these rewards will grow in number – the more the merrier."

STEF CANDE

The Cryo-EM facility was inaugurated in November last year.

User Meeting coming soon

A flavour of the cutting-edge research that will be possible with the ESRF and its Extremely Brilliant Source upgrade will be provided at next year's User Meeting, which will take place from 4–6 February (www.esrf.fr/UM2019).

Open to all ESRF users, the meeting will kick off with tutorials before progressing on the second day to plenary sessions, the Young Scientist Award, a poster session and the facility report on recent science from new or upgraded beamlines. The final day will feature microsymposia on the subjects of tunable past and time-resolved future at the ID29 beamline, X-ray microscopy in biology, and coherent X-rays for imaging and studies of dynamics. "The ESRF User Meeting is an ideal forum for exchange among users and with the ESRF staff, whether it be to discuss the EBS project and its opportunities or to stimulate new proposals and ideas," says the User Organisation Committee (UOC).

• The UOC has welcomed two new members. Oier Bikondoa of the University of Warwick in the UK, and of the XMaS UK collaborating research group beamline, now represents the X-ray Nanoprobes community. Meanwhile, Beatrice Ruta of the Institut Lumière Matière in Lyon, France, now represents the Complex Systems and Biomedical Sciences community.

Joel Chavanne, head of the Insertion Device and Magnet group, oversees the in-house assembly of the EBS's permanent magnet dipoles.

S CANDE/ESRF

Magnet construction complete

ESRF engineers and technicians have completed the design, construction and measurement of all 1115 magnets for the EBS storage ring, marking a major milestone four years into the project. "It has been five years of hard work, and we're very pleased to have reached this point," says Joel Chavanne, the head of the ESRF's Insertion Device and Magnet group.

The ESRF currently has a storage ring based on a double-bend lattice design, with two bending magnets per cell. For the EBS, however, it will be transformed into a "hybrid multibend achromat" (HMBA) configuration, with seven bending magnets per cell. The result will be an X-ray beam 100 times more brilliant and coherent than before, but it also means twice as many magnets in the existing space. Many magnets have had to be redesigned to be more compact and to generate stronger magnetic field gradients.

"The magnets of the EBS project stand out in terms of innovation."

The ESRF's team of 14 magnet experts began work in 2013, first redesigning the magnets and then selecting companies to manufacture them. Once the magnets were delivered, each had to be tested to ensure that its magnetic field was correct. "It took about one to two hours to measure each magnet, not forgetting the time it took to manoeuvre them," explains Gael Le Bec, head of the Magnet work package for the EBS project. "The quadrupoles weigh nearly 1000 kg apiece!"

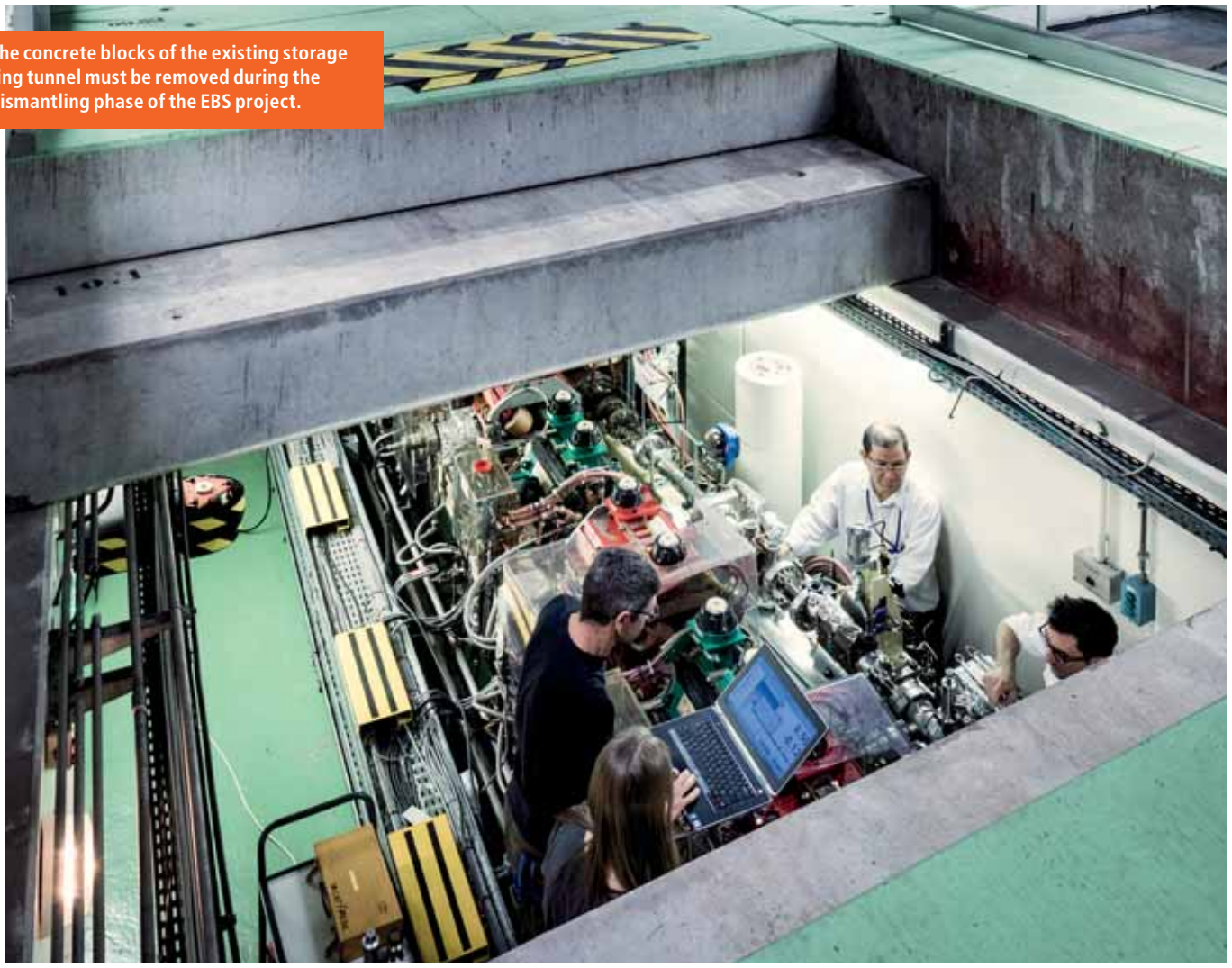
Not all the magnets were manufactured offsite. The 128 dipole magnets were assembled in-house by ESRF staff and required the installation by hand of more than 15,000 permanent magnet bars into 660 magnet modules. The painstaking process took about a year and was carried out in parallel with the measurement work.

Pushing to the limit

Many of the magnets push engineering technology to the limits, taking advantage of modern materials and increased expertise. The dipole magnets, for example, are made from permanent magnets instead of electromagnets, so they will not use any electrical power, unlike the 700 kW used by the old dipoles.

"When you think of a synchrotron, the magnets are often the first components that come to mind," says Pantaleo Raimondi, the director of the Accelerator and Source Division, and the EBS project leader. "The magnets of the EBS project stand out in terms of innovation, and reflect the capacity of the ESRF team to move forward in magnet technology."

This month, the last beam of the current storage ring will fade and teams will have 20 months to both dismantle the existing accelerator and install and commission the new HMBA lattice (see Insight, overleaf). The EBS is expected to come online in August 2020.



The concrete blocks of the existing storage ring tunnel must be removed during the dismantling phase of the EBS project.

SCANDE/ESRF

Insight: the EBS shutdown

What is the shutdown?
On 10 December this year, the ESRF's beam will be stopped and teams will have 20 months to dismantle and remove the existing storage ring and install and commission the new EBS machine, for restart in August 2020.

How do you dismantle a storage ring?
As soon as the beam is cut, teams will spring into action. First, radio-protection engineers will ensure that it is safe to work in the area, then the electrical equipment for the storage ring, booster and radio-frequency cavities will be safely disconnected – a procedure known as lockout-tagout. Next, fluids and cryogenic networks will be drained, and the storage ring and front ends will be brought back up to atmospheric pressure. That is when the dismantling will begin: first with the recovery of components to be re-used in the new machine, then with the removal of pipes and cables. Finally, the concrete roof of each cell will be lifted off in turn and each girder, insertion device and radio-frequency cavity removed with the help of three cranes situated around the ring. This will take about three months.

What happens then?
Each cell will be prepared for the new girders. Old girder supports and concrete pillars will be removed, trenches in the floor will be filled in and two tons of glue will be used to attach steel support plates to the ground for the new girders.

And the installation?
From March to November next year, the girders will be installed in the tunnel. The new girders are too heavy for the existing cranes so specially designed gantries will be used to lift the girders over the tunnel wall and into the ring. There are three entry zones and no room for manoeuvre inside the tunnel, meaning that the girders must be installed in a specific order. Lighter equipment, such as radio-frequency cavities, insertion-device chambers and the injection zone will be lifted over with the cranes. A girder transport module in the ring will roll the girders to within 1 cm of their final positions. Once installed, the girders will be finely aligned and connected together, the front ends installed, pipes and cables connected, and the ring put under vacuum.

Then can you switch it on?
Not yet! Each component must be cabled to the technical zone on the inside of the ring. All in all, around 50,000 connections will be made and tested. Storage-ring commissioning will follow, by debugging the equipment and software, injecting an electron beam, and tuning the machine to ensure that the beam is stable. Three months later, in March 2020, the beamlines will be commissioned to ensure that they can take the beam, with a return to user-service mode expected in August 2020.

What will happen to the old storage ring?
Some parts will be re-used in the new ring, while others will be stored on-site. Each piece will have to be individually dismantled and tested before it can leave the site – and this could take around three years.

ATRON, a new technological platform dedicated to under irradiation studies

In partnership with CNRS and CEA laboratories, ATRON, subsidiary of the ENGIE group developed a rupture technology that aims to abandon the use of radioactive sources to calibrate radiation survey meters

To achieve its project and meet various irradiation needs, ATRON has developed a technological platform equipped with:

- an electrostatic electron accelerator with a removable X target,
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- a measurement and analysis laboratory,
- a team with scientific skills,
- a network of partnerships with research laboratories.

Calibration of radiation survey meters

ATRON calibrates radiation survey meters with realistic and representative fields connected to a reference source for a better metrological control. Furthermore, the absence of radioactive source leads to a reduction of sanitary and environmental risks and the extended ranges of energy and dose rates allow measurements across the entire energy response range of the instruments.

3.5 MeV electron beam and an X-ray irradiation line

Accelerated aging under irradiation

Materials subjected to irradiation experience structural modifications susceptible to impact their properties. It is therefore essential for manufacturers implementing equipment in hostile environments - in nuclear, space or defense industries - to evaluate these effects in order to establish an appropriate preventive maintenance plan. Due to its ability to irradiate material samples with electron beams or X-ray radiations and at a controlled temperature, ATRON allows a fine evaluation of the effects of irradiation on the material.

Reliability of electronic systems

Likewise, placed in a radiating environment, electronic systems are susceptible of failures consecutive to the interaction of ionizing radiation at the level of their sensitive components. In order to measure the impact of this kind of events on components or on integrated systems, ATRON has a X-rays and electrons source whose characteristics can be adjusted to reproduce nuclear or space environments.

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(+33) 261 819 990 | contact@atron.fr | **www.atron.fr**

EBS workshops in 2019

During 2019, a number of workshops aimed at helping users to fully exploit the properties of the new Extremely Brilliant Source (EBS) once the beamlines restart in 2020 will be organised.

The workshops are listed below and a more complete overview is available at www.esrf.eu/EBSworkshops2019. The dates given are tentative: the information on this web page will be continually updated, as workshop dates are finalised, registration deadlines are set and workshop web pages appear, so please check the link regularly.

Time-resolved science at ID09 and its synergy with EuXFEL programme

4–5 March 2019

The EBS will be a great improvement for laser pump/X-ray probe experiments on ID09. However, the ultimate time resolution in pump-probe experiments is limited by the X-ray pulse length, which will remain 100 ps from the EBS. The FXE beamline at the EuXFEL has similar setups to ID09 but the time resolution is dramatically lower (< 100 fs). The aim of the workshop is to discuss the overlap and complementarity of the two beamlines and to strengthen the collaboration.

Nuclear resonance scattering at the Extremely Brilliant Source

11–12 March 2019

With the new EBS, the nuclear resonance beamline will offer users an order of magnitude improvement in energy resolution (50 μeV) and two orders of magnitude improvement in beam size (200 nm × 200 nm). The aim of the workshop is to discuss and identify key scientific cases that will benefit most from nuclear resonance scattering with the EBS.

Probing low Z elements using hard X-ray Raman scattering spectroscopy

1–5 April 2019

ID20 hosts a worldwide unique spectrometer to study low-energy absorption edges using hard X-rays. The workshop aims to bring together experts and novices in the field to collectively assess and discuss the current status, potential, and future prospects for this emerging inelastic X-ray scattering technique. We wish to strengthen the current user community, define future research directions, and guide the worldwide efforts to build new dedicated end-stations.

Hands-on! High-pressure techniques at the ESRF–EBS (school)

17–21 June 2019

This school aims to give an introduction to high-pressure research at synchrotron radiation facilities and to present the unique opportunities in this field with the ESRF–EBS upgrade. It comprises lectures covering the basic principles of synchrotron-radiation techniques used to explore matter at extreme conditions as well as "hands-on" step-by-step practicals. This school will promote exchange between experts in the field and our future user community on instrumental developments to exploit the EBS upgrade.

Opportunities and challenges for dynamical and structural studies with coherent X-rays at EBSL1

9–13 September 2019

A new beamline (EBSL1) will be constructed to exploit the future revolutionary properties of the XPCS and CXDI techniques for dynamical and structural studies in soft and hard condensed systems. The meeting aims to strengthen the involvement of the ESRF user community in the design of the new beamline through discussions about the future scientific challenges and opportunities that the EBS upgrade will enable.

A coherent future with coherent X-rays at ESRF–EBS

9–13 September 2019

The workshop aims to clarify the current state of the field and identify the opportunities created and challenges posed by coherent X-rays when applied to real-world systems, in terms of *in situ* and *operando* capabilities, precision and resolving power. The outcome will drive the future directions for development and application of the ESRF–EBS upgrade project.

Emerging synchrotron techniques for characterisation of energy materials and devices

24–25 September 2019

The heterogeneous devices that will play a role in the future green-energy economy, such as batteries, solar cells, and super-capacitors, rely on complex interactions over many length scales. This workshop will focus on the application of established and emerging synchrotron experimental techniques to understanding problems from the energy sector, and investigate new opportunities following the ESRF–EBS upgrade.

X-ray spectroscopy of magnetic materials

6–10 October 2019

The workshop will be a fruitful forum for informal discussion of new results and future projects of synchrotron-radiation-based research in magnetism, serving also to form new collaborations. Recent achievements and discoveries based on the application of a large variety of X-ray spectroscopic techniques to materials with intriguing magnetic properties will be highlighted. The emerging new opportunities for magnetism research offered by the ESRF–EBS project will be thoroughly discussed.

Short-pulse experiments with the Extremely Brilliant Source

28–31 October 2019

The dramatic increase in the brilliance from the EBS will be a great advantage for all time-resolved experiments and many experiments will be done with very short or even single-pulse exposures. The aim of the workshop is to discuss how to prepare the beamlines involved in scattering (SAXS/WAXS), spectroscopy (XES), imaging (XRI) and diffraction (XRD) applied to dynamic compression and/or structural dynamics studies for this new era.

Local electronic structure and coordination probed by X-ray emission spectroscopy

2–6 December 2019

Several beamlines at the ESRF have added X-ray emission spectroscopy (XES) to their portfolio and further installations are planned with the EBS. The aim of this workshop is to give an overview of the new possibilities provided by XES and to obtain feedback from the user community concerning pertinent applications that require further instrumental development (e.g. sample environment, time and spatial resolution).

Undesired effects of high photon densities on the sample – analysis and strategies for mitigation

10–12 December 2019

The interaction of X-rays with a sample or its environment may affect an experiment in an undesired fashion. This may concern the atomic structure, crystal structure or chemical state (radiation damage) but also other parameters such as sample temperature and sample environment (gases, liquids). This workshop will provide a forum for discussing our observations and proposing measures that address the problem.

Important dates for your diary

ESRF shutdown for EBS upgrade **10 December 2018**
User operation planned to resume **25 August 2020**
User Meeting (UM2019) **4–6 February 2019**
UM2019 registration deadline **20 January 2019**

Cryo-EM facility

During the shutdown, the cryo-electron microscope CM01 will operate as usual for the structural biology community, with access via rolling applications (no submission deadline).

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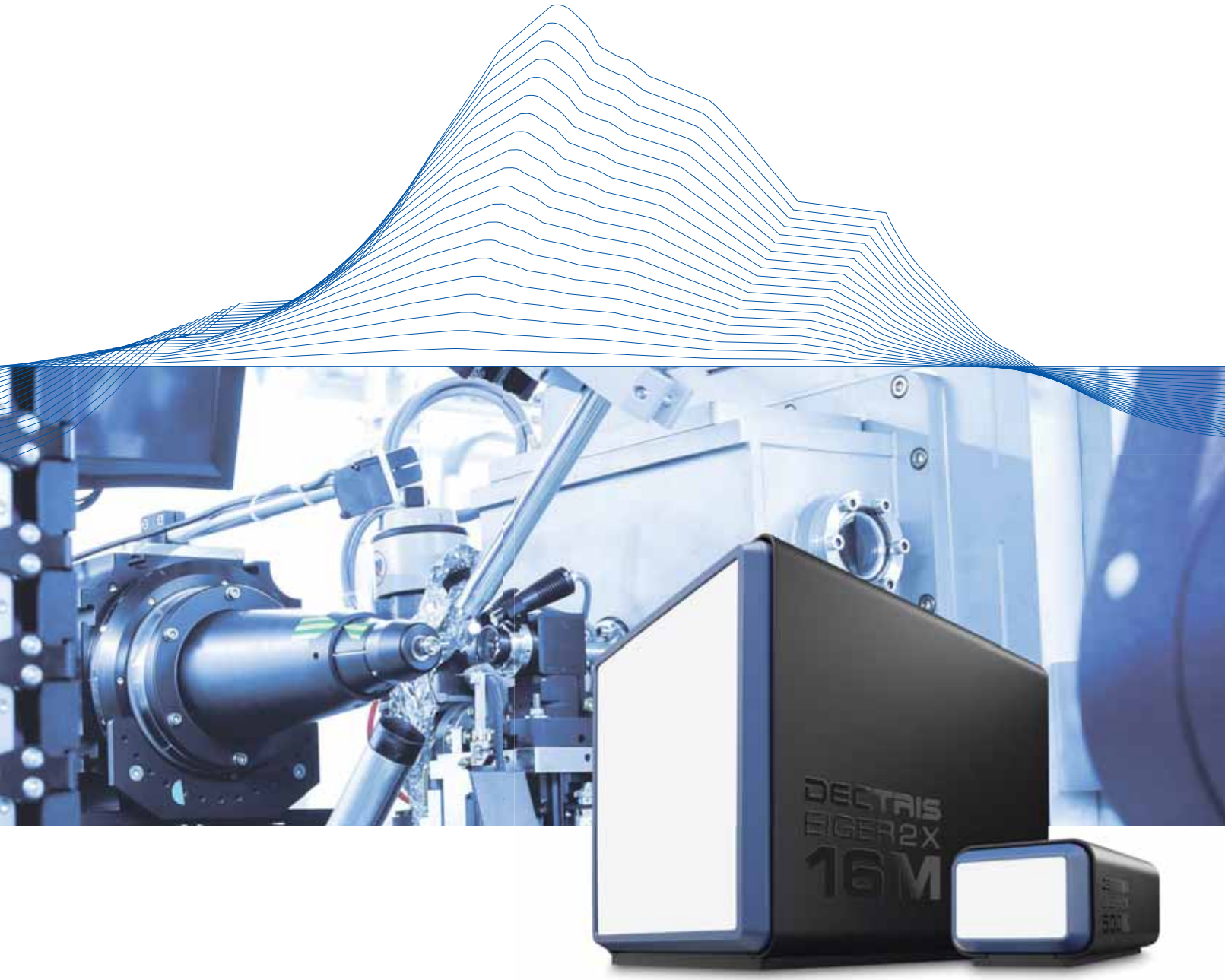

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You are making the invisible visible. To all of you, congratulations on 30 years of success. Here's to 30 more!
Carlos Moedas, European Commissioner for Research, Science and Innovation

Thirty years uniting Europe around synchrotron science for the benefit of knowledge and society is an achievement to be very proud of. Happy birthday to the ESRF!
Fabiola Gianotti, director-general, CERN

The ESRF is the place, the facility, where we collected our best data. This is where we did our real science.
Ada Yonath, winner of the 2009 Nobel Prize in Chemistry

For 30 years, the ESRF has been the model of successful European research infrastructure. Congratulations!
Jan Hrušák, chair, European Strategy Forum on Research Infrastructures

A remarkable return on investment. Happy birthday, ESRF!
Helmut Dosch, chair, Deutsches Elektronen-Synchrotron

The ESRF supports a vast community of researchers, including biologists probing the secrets of life at the smallest scales.
Iain Mattaj, director-general, EMBL

A large international facility can do things on a scale that is not possible by one country. By bringing scientists together, the ESRF has led to a lot of pioneering ideas.
Venki Ramakrishnan, winner of the 2009 Nobel Prize in Chemistry

Thanks to the ESRF, and the scientists Gebhard Schertler, Christian Riekel, Manfred Burghammer, for introducing the field of G-protein-coupled-receptors to microdiffraction.
Brian Kobilka, winner of the 2012 Nobel Prize in Chemistry

The breathtaking speed with which the ESRF rose to become the world-leading synchrotron facility allowed the EPN campus to become one of the leading international hubs for materials research.
Helmut Schober, director, Institut Laue-Langevin

SESAME is grateful to the ESRF for its continued support. Without it, many of our achievements would still be dreams!
Khaled Toukan, director, Synchrotron-light for Experimental Science and Applications in the Middle East

The APS congratulates the ESRF on 30 years of excellence as our two facilities travel together into the bright future of synchrotron X-ray science!
Stephen Streiffer, director, Advanced Photon Source

30 YEARS OF BRINGING NATIONS TOGETHER THROUGH SCIENCE 1988–2018

"There are three things that make me incredibly proud that Europe hosts the ESRF," says Carlos Moedas, the European commissioner for research, science and innovation. "First, the ESRF is a beacon of excellent science. Second, it is a powerhouse of international scientific collaboration. And third, it has created an interdisciplinary hub where scientists of all disciplines come together to exchange their knowledge."

Moedas's words sum up what most people feel about the ESRF, which for 30 years has brought scientists together to push the frontiers of X-ray science. It was in 1988 that the research ministers of 11 European countries signed the Convention and Statutes of the ESRF, bringing the facility formally into existence. Just four years later it was up and running – on time and on budget – generating X-rays of energy and quality that exceeded even the designers' expectations. It was the world's first "third-generation" synchrotron light source, surpassing the capabilities of earlier second-generation sources through its use in the storage ring of devices known as undulators and wigglers. These intensified the production of X-rays, providing users with the most powerful microscope ever to understand the microscopic nature of matter.

In this anniversary issue of *ESRFnews*, we delve into the ESRF's three-decade journey at the forefront of X-ray science with a special fold-out timeline, featuring recollections from people who witnessed the key events (pp17–20). We also look at how the ESRF has helped to revolutionise 10 areas of science, from the basic building blocks of life to some of humanity's most important industrial processes (pp23–26). Finally, we look to the future, with the upgrade to the Extremely Brilliant Source (EBS), which will turn the ESRF into the world's first high-energy fourth-generation synchrotron source (pp29–30).

"The ESRF is, and will be, the leader in synchrotron science, thanks to its governance and its ability to attract the best minds worldwide," says Francesco Sette, the ESRF's director-general. "As long as X-rays are needed, the ESRF will be there to supply the best service."

Jon Cartwright, editor of *ESRFnews*

1989
THE FIRST USER MEETING

In late 1988, just before the signature of the ESRF Convention, the directors decided that it was essential to prioritise the scientific areas to focus on and the beamlines to build. We wanted to involve the whole community, so we risked calling a meeting of potential users. Would enough scientists come to make it a credible consultation? It was still many years before the first experiments, and many people thought that the ESRF beams would be too hot to handle – that they would pose formidable challenges for optical elements and instrument design. For that reason, some of us at the ESRF doubted that many scientists would be willing to drop their experiments at their current synchrotrons and travel to Grenoble. But I remember in March 1989 being on the entrance steps of the amphitheatre of the Institut des Sciences Nucléaires (above) with Andrew Miller, the director of research for biology, and being elated as scores of participants from Europe and the US showed up for this, the first ESRF User Meeting. And it wasn't only quantity: the true crème de la crème of X-ray scientists had come to share their ideas. The durable bond between the ESRF and its users had been forged.

Massimo Altarelli, *senior scientist, Max Planck Institute for the Structure and Dynamics of Matter (ESRF research director 1987–1993)*

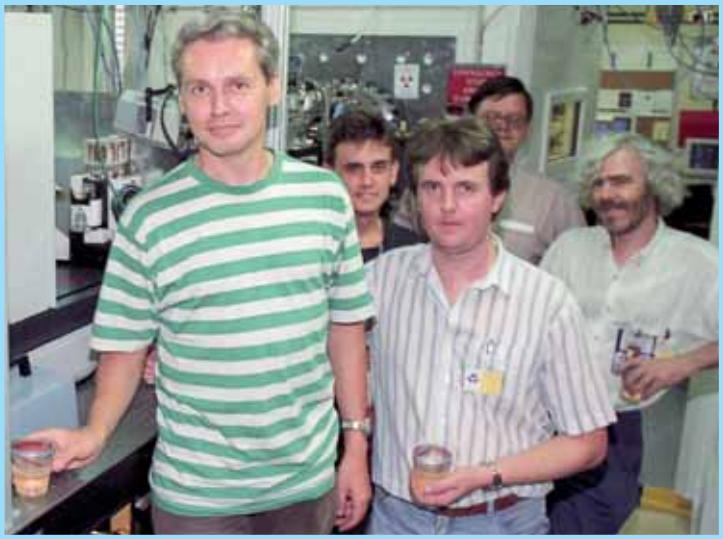
1992
THE FIRST EXPERIMENTS

I first came to the ESRF with two colleagues and armed with crystals of bovine enterovirus – a small non-pathogenic virus. The results from the microfocus beamline, which helped us solve the virus's structure, showed so much potential for addressing previously intractable systems that I was soon back with several other colleagues and crystals of bluetongue virus, a highly pathogenic cattle virus. We established high-throughput methods on an adapted small-angle scattering beamline, analysing up to 600 crystals in each 48-hour beam-time slot, to reveal what was then the most complex structure ever seen in atomic detail. Carl Brändén, the ESRF director of life sciences, arrived at the beamline with champagne!"

Dave Stuart, *director of life sciences, Diamond Light Source (below, far right)*

As early users of the ESRF, we were interested in the atomic structure of diamond surfaces. Our experiment at the surface diffraction beamline was successful thanks to numerous cups of coffee keeping us awake during the long shifts, although the coffee vending machine was a 20-minute round trip during which no data could be taken. Based on the ESRF's operating costs, I estimated that this unused beam time raised the price of a cup of coffee to 490 Dutch guilders (€220)! Expensive indeed, but it was worth it.

J Friso van der Veen, *emeritus professor of experimental physics, ETH-Zürich*



1989 First User Meeting

1992 First electron beam in the storage ring. First users at the ESRF

1994 The ESRF creates a synchrotron industry office

1991 The Netherlands joins the ESRF

1988 | 1989 | 1992 | 1994 | 1995

1988 (16 December) The Convention and Statutes of the ESRF are signed in Paris by the research ministers of 11 European countries: France, Germany, Italy, UK, Belgium, Denmark, Finland, Sweden, Norway, Spain and Switzerland

1994 Inauguration of the ESRF. User operations begin with 15 beamlines. The storage ring current is raised to 150 mA; X-ray brilliance reaches 10^{19} photons/mm^2/mrad^2/0.1%bw

1994
THE FIRST INDUSTRY OFFICE

The Industry Coordination Office (as it was then called) was set up by scientist Jean Doucet (above, bottom row, far right) at the end of 1994. In that year, he had only one industrial client, who performed one macromolecular-crystallography experiment on the ID02 beamline. But the following year there were seven industrial clients and 11 experiments, and interest began to snowball: more than two decades later, we have some 150 commercial clients who carry out experiments on thousands of samples every year. Over that time, the industry office has undergone several changes. I joined Jean in 2000, and one of my first achievements was to overhaul and streamline the industrial statistics from 1994 to 2000 – a process that sometimes retrospectively boosted our income! Shortly after, Manuel Rodriguez-Castellano took over from Jean to create the Industry and Commercial Unit, which began taking on contracts and European projects; in 2010 he was replaced by Ed Mitchell, who renamed the office the Business Development Office, reflecting its purer connection to industry, with contracts and legal support kept separate. Meanwhile, a new income stream has opened up, in the form of technology transfer and the sale of instrumentation and related services. We now have a core team of six, with an extended circle of industry-dedicated scientists and key legal, contract, finance and comms support.

Katherine Fletcher *(above, top row, far right), ESRF business development administrator*

1995
THE FIRST ESRF HIGHLIGHTS

It was clear early on that the ESRF could not follow the tradition of other laboratories by producing an annual report: with 25 beamlines and one page per project, it would be over 1000 pages. You could hardly imagine a visitor taking that back on an aeroplane! Fearing that few people would actually read it, in 1995 we decided to publish the full annual report only on the web, and in print publish only a select report on research and technical developments, called *Highlights*. There was another benefit of doing things this way. Together with the scientific directors Massimo Altarelli and Carl Brändén, I had already rejected the calls from some countries that the ESRF be a service laboratory without any in-house research. The *Highlights* justified this stance to the ESRF Council, exhibiting the unprecedented science that had emerged from in-house research in the first two years of operation: inelastic scattering with meV resolution; phase-contrast and coherent imaging; pressures in the range 100–300 GPa; protein crystallography (on 10–20 μm crystals or very large proteins) thanks to the development of the technique of multi-wavelength anomalous diffraction. To this day, the annual ESRF *Highlights* (below) continues to showcase the very best of the ESRF.

Yves Petroff, *director, Brazilian Synchrotron Light Laboratory (ESRF director-general, 1993–2001)*

1995 Publication of the first ESRF *Highlights*, promoting the results from 11 public and four collaborating-research-group beamlines

1998 The number of ESRF beamlines reaches 40

1998 Israel joins the ESRF

1997 *Science* magazine includes synchrotrons as one of its annual breakthroughs

1997 Portugal joins the ESRF

1996 Storage ring current is raised to 200 mA; X-ray brilliance reaches 10^{20} photons/mm^2/mrad^2/0.1%bw

2002 The Partnershi
the ILL, the EMBL ar
comprises more than
platforms for state-o

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2009
NOBEL PRIZES IN CHEMISTRY FOR ESRF USERS

I clearly remember when the first structural results on the ribosome – the molecular machine responsible for producing proteins – started to appear at the turn of this millennium. Although crystals of this large complex of proteins and RNA had been available for some time, many scientists believed that it would be an almost insurmountable task to obtain diffraction data from them, at a quality sufficient to glean some understanding of its function. It would be an achievement worthy of a Nobel prize, so I was not surprised when one was awarded to the successful ESRF users Ada Yonath (above right) and Venkatraman Ramakrishnan (left), shared with their late US colleague Thomas Steitz (centre), in 2009. The structure of the ribosome would not have been possible without synchrotron radiation and the rapid development of the beamlines for macromolecular crystallography at synchrotrons. At the start of the ESRF, there was half a beamline dedicated to macromolecular crystallography; about a decade later, when I started working at the ESRF, there were six beamlines, and their impressive development continued with automation and micron-sized, highly brilliant beams. There is no doubt that biologically important and challenging projects like the ribosome were instrumental drivers in this development.

Sine Larsen, *professor of chemistry, University of Copenhagen (ESRF director of research for life sciences, 2003–2009)*

2009
UPGRADE PROGRAMME PHASE I LAUNCHED

I chaired the ESRF Council during an exciting period for the ESRF, with the accession of Centralsync (the Czech Republic, Hungary and Slovakia) and the hiring of Francesco Sette as director-general. It was also when we began to seek financing for the Upgrade Programme Phase I. But with the implementation plan not yet finalised, and the world entering an economic crisis, not all members were ready to support additional contributions. By the time of a decisive Council meeting in 2008, some budgetary issues were still unclear for some delegations, including France. I postponed a formal discussion until the second day, hoping that exchanges over dinner would prove fruitful. Indeed they were. At about 10.00 p.m., the head of the French delegation, Michel van der Rest, returned smiling: a positive statement had been given by the French Ministry! This removed remaining uncertainties, and a positive statement was given by all. Eight years later, one of the first decisions I made as chair of the Council of the European X-ray Free Electron Laser was to insist that Council meetings extend over two days, so that we have dinner to solve thorny issues. It's worked so far.

Robert Feidenhans'l, *chair, European XFEL (chair, ESRF Council, 2006–2010)*

2009 Nobel Prize in Chemistry for ESRF users

2009 Upgrade Programme Phase I launched

30 years of science

2009

2004 Poland joins the ESRF

2003 Austria joins the ESRF

p for Structural Biology is launched with
d several local institutions. Today, the PSB
n 300 active scientists and some 20 technical
of-the-art integrated structural biology

2008 The Czech Republic, Hungary and Slovakia join the ESRF

2014
RUSSIA JOINS THE ESRF

By an original combination of circumstances, I was a signatory at both the beginning and the end of the process of Russia's accession to the ESRF. In 2011, at the beginning, I co-signed the memorandum of understanding in Moscow between the ESRF and the NRC Kurchatov Institute as chair of the ESRF Council; then in 2014, I co-signed the intergovernmental Protocol of Accession in Grenoble as representative of Belgium. Those three intervening years involved an exemplary and enormous amount of work by all the stakeholders – including making sensitive financial agreements on the transfer of shares between the owners of the ESRF company (or "Société civile") – all of which was even more remarkable considering the less-than-easy political relations between the EU and Russia during this period. But the ESRF wanted to strengthen its international character (especially as it implemented an ambitious upgrade programme), while the ESRF member countries and Russia both saw the benefits of increased cooperation to their scientific communities. In the end, everyone won.

Jean Moulin *(above), honorary general advisor, Belgian science policy office (chair, ESRF Council 2011–2013)*

2015
EBS LAUNCHED

I remember well the groundbreaking ceremony for the first phase of the ESRF Upgrade Programme – we had to use a pick axe on the frozen winter ground. From then on, as French Minister for research and higher education, I followed closely all stages of that innovative and ambitious project. Now, 30 years after its creation, the ESRF is undergoing an even more ambitious metamorphosis, with the creation of a new-generation storage ring (below). A world first, initially adopted by the international board in 2015 and with significant public support and investment, the Extremely Brilliant Source (EBS) will be constructed from 2019 to 2020. It will generate X-rays that are 100 times more brilliant than those of today, allowing us to image matter at details down to the nanometre. It is a tremendous improvement – a true revolution – and one that will benefit many fields, from basic science up to more specific applications such as archaeology and industry. More than ever, the ESRF is investing for the future of science and technology. Congratulations to all the regional and international scientific teams, and all the smart contributors to this wonderful project!

Geneviève Fioraso, *French minister for research and higher education 2012–2015*

STEF CANDÉ

2014 Russia joins the ESRF as a Member State, bringing the total number of countries backing the ESRF to 21: 13 Members and eight Scientific Associates

2015 Launch of the Extremely Brilliant Source (ESRF–EBS) project

2018 Assembly of the EBS girders begins

2011 X-ray brilliance reaches 1 x 10^{21} photons/mm^2/$mrad^2$/0.1%bw, some 500 times brighter than the ESRF's original design specification

2017 India joins the ESRF

2011 Inauguration of ID24, the first of eight new beamlines to be built within the ESRF Upgrade Programme Phase I

2012 The ESRF designs a revolutionary storage ring

2012 Nobel Prize in Chemistry for ESRF users

2013 South Africa joins the ESRF

2014 Inauguration of ID30A, also known as MASSIF-1, the world's first fully automated beamline for the collection of data from crystals of macromolecules

2017 Inauguration of the Titan Krios cryo-electron microscope (cryo-EM), completing a world-leading suite of synchrotron-radiation beamlines dedicated to structural biology

2017 The number of ESRF beamlines reaches 44. Meanwhile, the number of publications in peer-reviewed journals tops 30,000

2014 2015 2018

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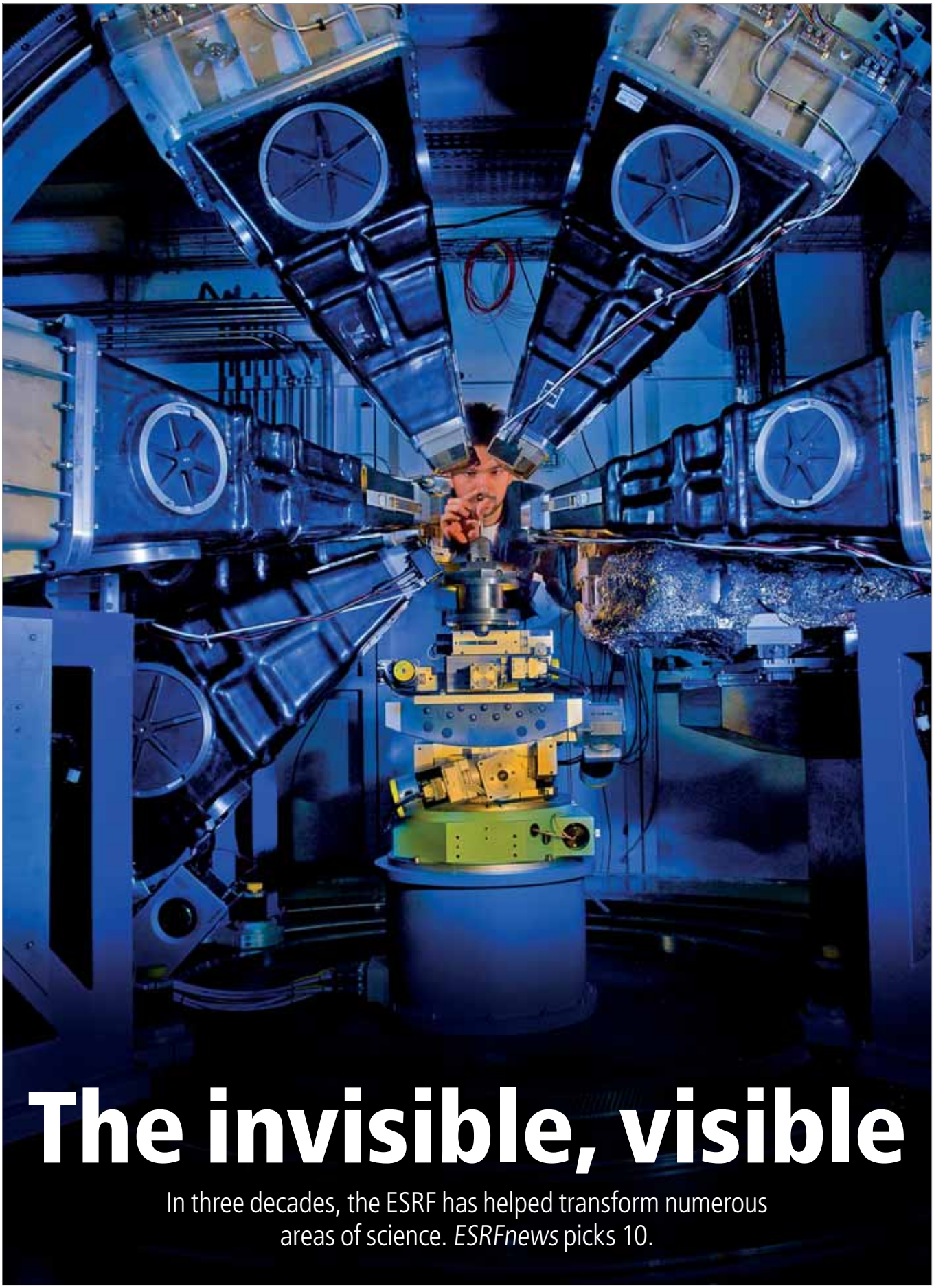
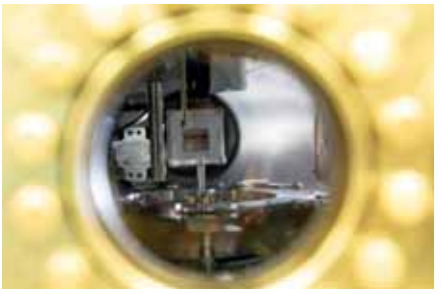


The invisible, visible

In three decades, the ESRF has helped transform numerous areas of science. *ESRFnews* picks 10.

1 The nano world

Thirty years ago, synchrotron X-rays were lauded for their ability to determine the bulk properties of materials – the word "bulk" here meaning averaged over millimetre-sized regions. How times have changed. Peerlessly bright to begin with, and now being upgraded to be a hundred times brighter still, the ESRF's X-rays have enabled scientists to zoom in to ever finer details, down into the nano world. At this scale of molecules, atoms and small atomic structures, there is such a diversity of science that new applications are emerging all the time. X-ray nano-probes can distinguish living cells, for example, to track the efficiency of new medical treatments. Meanwhile, nano-imaging can uncover the local atomic structure of tomorrow's micro- and nano-electronic devices, to check their likely performance. "There's plenty of room at the bottom," as the famous physicist Richard Feynman once remarked of the nano world: the ESRF is helping scientists explore it.



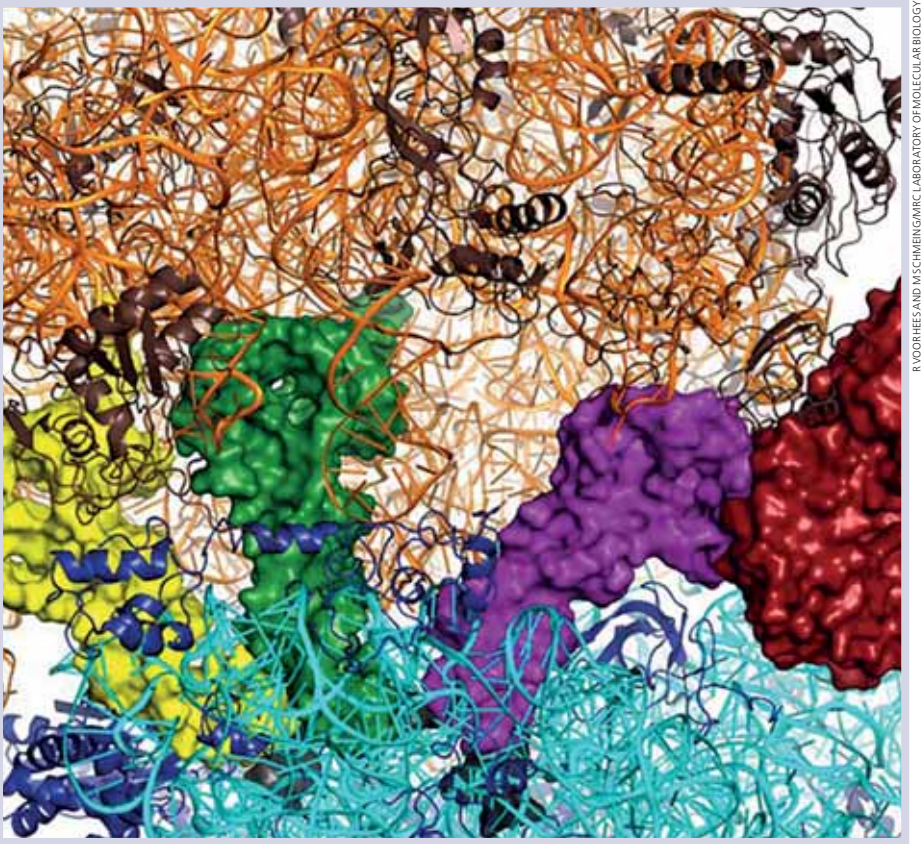
"The ESRF's X-rays have enabled scientists to zoom into the nano world – the world of molecules, atoms and small atomic structures."

2 Consumer products

It's amazing how much science goes in to the products that we use every day, and a lot of that science is performed at synchrotrons such as the ESRF. Over the years, the facility has helped companies to innovate and develop new products, from the effectiveness of pharmaceutical drugs to the healthiness of food; from the eco-credentials of washing detergent to the performance of car fuel; from the safety of electrical fuses to the speed of silicon chips; from the silkiness of hair conditioner to the grip of tyre rubber: the list goes on and on. Having pioneered the collaboration between synchrotron light sources and industry, the ESRF now has 30% of its public research linked to industry, and in the past five years alone has welcomed more than 150 clients, from small start-ups to multi-billion-turnover multinationals.

3 The building blocks of life

Figuring out the structure of proteins and their complexes – the building blocks of life – is a key step to understanding how they work. It involves a process known as X-ray crystallography, and the more powerful the X-ray source, the quicker and better a protein's crystallographic data can be recorded. With the unprecedented brightness of its X-rays, the ESRF was a turning point for protein crystallography when it came online in 1994, since it allowed the structures of even large, complex proteins to be obtained in realistic time frames. The best example is the determination of the structure of the ribosome (image, right) – the molecular machine that oversees the synthesis of other proteins in living things – for which ESRF users Ada Yonath and Venkatraman Ramakrishnan (along with the late US scientist, Thomas Steitz) were awarded the Nobel Prize in Chemistry in 2009. Today, the ESRF is a world-leading facility for determining the structures of proteins, and determining them quickly, with a suite of specialist and often highly automated tools, including the recent installation of a cryo-electron microscopy facility.



R VOORHEES AND M SCHMEING/MRC LABORATORY OF MOLECULAR BIOLOGY

4 Sustainability

Sustainability encompasses a huge range of technologies, and a diverse set of scientific questions. Yet with 44 beamlines, and in particular those functioning at high energy (see #10, p26) , the ESRF is well placed to tackle this increasingly important field of research. By exposing uranium compounds to X-rays, the synchrotron has been able to study the long-term effects of storing nuclear waste in underground repositories. With an ability to run experiments in harsh, yet realistic working conditions, it has been able to investigate the performance of the catalysts involved in major industrial processes, such as those converting biomass into renewable fuels. The presence of minute levels of toxic compounds in industrial waste streams can be detected with instruments that operate at different length scales. And then there is the ESRF's ability to track the performance of the materials involved in alternative energy devices, be they solar cells, fuel cells or batteries. Whatever the target of sustainability, the ESRF almost certainly has a way of hitting it.

5 Health

Understanding how our bodies work does not always involve reducing tissues to their tiniest components. Often the key questions are about how these tiny components cooperate and function synchronously to affect the behaviour of their composite structures. Exploring such hierarchical events in a single experiment is challenging, but the ESRF has made it possible. Take research on muscle contraction, for example. Before the ESRF, scientists were just uncovering the molecular mechanism that governs how the muscle protein filaments slide over one another within a sarcomere – the basic structural unit of a muscle fibre. Nowadays, however, the whole pathway of muscle activation from the sarcomere down to the molecular motors can be probed. This has already helped explain the molecular basis governing heart regulation, whose failure can lead to cardiomyopathies, and in the future these studies could help scientists understand genetically inherited muscle diseases.

6 Superconductors

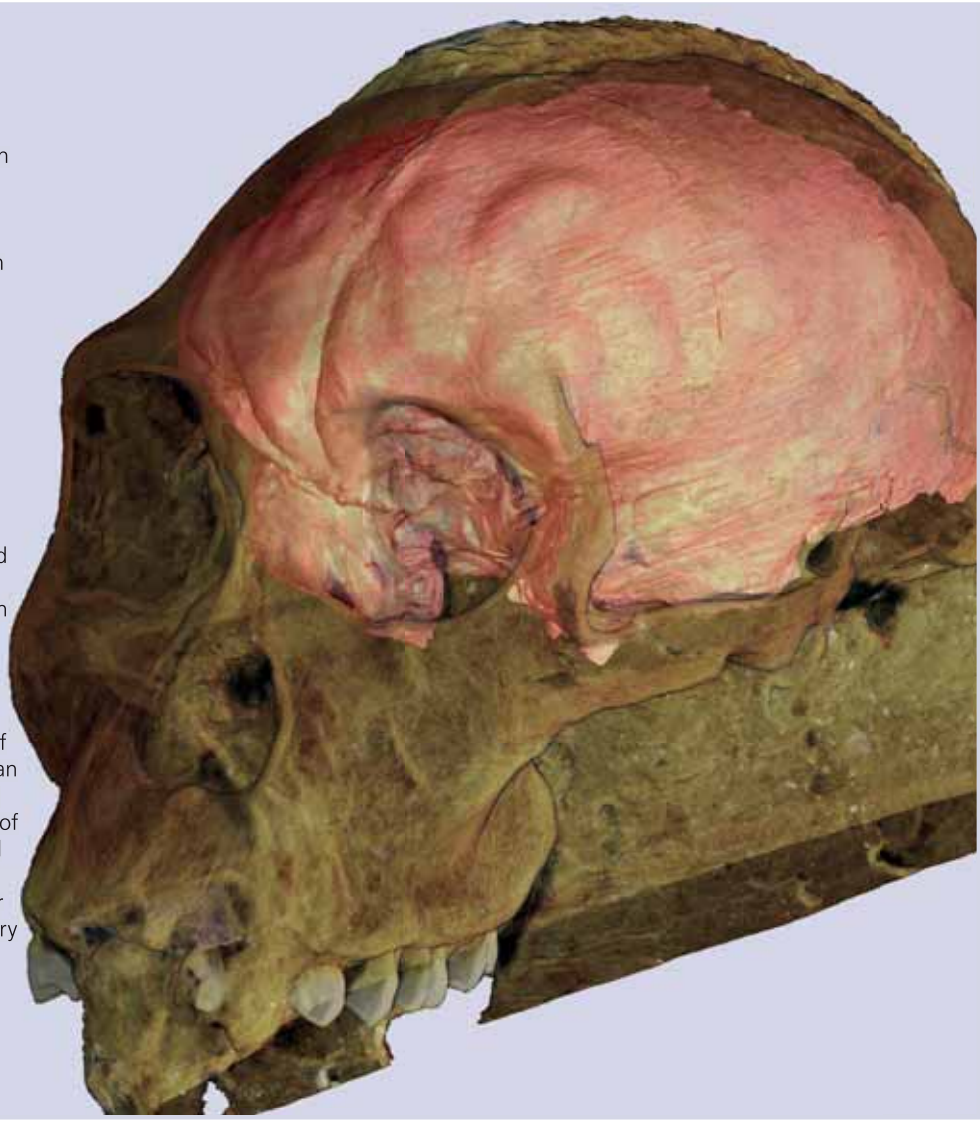
Immediately after the first "high-temperature" superconductors were discovered back in 1986, the field of condensed-matter physics was in a frenzy. Not just because of the potential applications – lossless transmission lines and levitating trains were two of the most exciting – but because no one could agree how the materials worked. The disagreements were so heated that a meeting of the American Physical Society in 1987 was dubbed the "Woodstock of physics" in reference to the infamously chaotic pop-music festival. Thirty years on, there is still no accepted overarching theory of high-temperature superconductivity, but the field is vastly more cooperative – and this is largely down to the development at the ESRF and elsewhere of experimental techniques such as resonant inelastic X-ray scattering (RIXS), which have given a much clearer view of the materials' atomic environment. "RIXS is capable of probing several facets of their complex and mysterious electronic and magnetic structure," says ESRF user Giacomo Ghiringhelli.

7 Cultural heritage

Thirty years ago, the words "cultural heritage" would have featured in few synchrotron scientists' vocabularies. The idea of subjecting a near priceless painting to such a gigantic machine would have seemed exotic, even scary. But in the past 15 years or so, attitudes have changed, as scientists have realised that fragments of museum pieces provide an opportunity to study the very long-term evolution of materials, while curators have realised that scientific analysis at synchrotrons and elsewhere can provide valuable insights into the preservation and restoration of rare objects. In that time, the field has evolved rapidly, with analyses at the ESRF sometimes overturning conclusions drawn previously in the lab. Indeed, the ESRF has seen samples of numerous famous cultural pieces in its beamlines over the years, including fragments of paintings by Van Gogh, Rembrandt and Leonardo da Vinci, not to mention fragments of Egyptian glass, ancient Afghan cave paintings and the Dead Sea Scrolls (image below).

8 The origin of humanity

When examining the fossilised specimen of a possible human ancestor, palaeontologists have a host of questions. Why did it die? How old was it when it died? How did it move? How clever was it? The answers to such questions often lie inside the fossil – the microstructures of the teeth, for example, can indicate the age of a specimen, just like tree rings can be used to age a felled tree. In the past, studying the insides of fossils meant either breaking them apart, or placing them in a conventional computerised tomography scanner, of the kind used in hospitals, which give some ability to image the insides but at low quality and resolution. In 2000, however, the ESRF pioneered non-destructive synchrotron imaging of fossils at very high quality and resolution, and since then has seen a host of unique specimens grace its beamlines, such as the impressive two-million-year-old skull of *Australopithecus sediba*, an early human ancestor (image, right). Arguably, even more important from a scientific point of view was a large survey of Neanderthal teeth in 2010, which revealed that individual Neanderthals matured faster than modern humans, their evolutionary cousins. This ongoing line of research is helping paleaonatologists to answer another big question: did our early ancestors develop slowly like us, or did they grow up faster and with a shorter lifespan like apes?



P TAFFOREAU/ESRF

9 Earth's history

The intense heat and pressure inside the Earth drives volcanic eruptions, plate tectonics and even the magnetic field. Understanding how our planet came to be like this is a challenge, because it is impossible to drill through the Earth's crust to study the inner conditions directly. Seismic data from earthquakes provide some clues, but since these are only mildly affected by changes in temperature they do not provide accurate information about how the temperature varies with depth – a key profile known as the geotherm. An alternative is to use synchrotron X-rays to probe the states of mineral samples while they are being subjected to extreme temperatures and pressures. Even so, the uncertainty of results has led to decades of controversy. From 2015, experiments at the ESRF have helped to settle this with two new techniques to estimate the melting point of iron at pressures over 100 GPa, by blasting a pressurised sample with a laser and recording the subsequent absorption or diffraction of X-rays.

10 High energy

Hard X-rays delve deep into a sample, revealing physics that would otherwise be totally buried. Before the 1990s, they were mostly produced by radioactive sources for medical applications, but the ESRF was one of the first light sources to offer a dedicated high-energy beamline for all scientists. Back then, most of the research was fundamental, but over the years the emphasis has shifted to applied science, particularly by industrial users, who appreciate the ability to study devices with world-leading instrumentation in real working conditions. Today, the ESRF's high-energy X-rays allow users to probe for defects inside huge industrial objects such as turbine blades; and to check the stability of pharmaceutical compounds inside pills or solvents, to give just two examples. Naturally, ESRF X-rays can also image the human body, yet in far more detail than hospital scanners: the higher energies mean that features can be observed not just in bone, but in surrounding tissue too.

UHV Design advances bellows-free drive for critical beamline applications at CERN

Spring-loaded magnetically-coupled device provides a fail-safe solution that could reduce unscheduled downtime due to loss of ultra-high vacuum.

Innovative design

A customer enquiry for a linear power probe – a magnetically-coupled actuator that can operate remotely in vacuum – has led to a new fail-safe design that could improve the operability of beamlines around the world.

"CERN explained that they were looking for a product that would avoid using bellows", says Jonty Eyres, engineering director at UHV Design. The UK-based firm specializes in the design, manufacture and supply of motion and heating products specified for use in high- and ultra-high vacuum conditions.

"Bellows-sealed devices have been the go-to space for moving things in and out in a clean manner and with minimal outgassing", Eyres explains. Depending on the type of bellows used, and their application, their service life can reportedly range from 10 000 up to as many as 2 million actuations. But they won't last forever. And when they fail it can lead to an unexpected loss of vacuum and costly delays.

The challenge for Eyres and his colleagues was to come up with a solution that reproduced the clean operation of a bellows-sealed device, but in a fail-safe manner.

Over the past 20 years, the firm has developed considerable expertise in magnetically-coupled devices. Their bellows-free approach features an arrangement of magnets located inside and outside a rigid tubular vacuum envelope. Moving the magnetic housing on the outside advances and retracts an actuation shaft held centrally inside the device.

The team used specialized software to optimize both the magnetic coupling between the inside and the outside, and the screening of the device.

Online meetings allowed the client – in this case CERN – to voice the product criteria that were important to them. "We used the sessions to discover their feedback, the pros and cons and where we think the scope is in terms of performance", Eyres explains.

Compact, bellows-free actuator.

"Once we are confident in a prototype, the next stage is to put it on a vacuum rig and start running rigorous tests on performance and precision", says Eyres.

This includes carrying out residual gas analysis using a mass quadrupole device to examine how the mechanism affects the vacuum pressure. A major benefit of the firm's design is that there are no bellows to fail. But instead the team has to contend with moving parts in vacuum.

The engineers tackled this by keeping the contact areas to a minimum and using rolling parts, not sliding parts, to limit any pressure rise during operation. Preserving ultra-high vacuum conditions is critical.

Designed for cleanliness

But having rolling contacts isn't the end of the story. In addition, the materials combination must be inert to prevent the mechanism from bonding or sticking over time. And the requirement for absolute cleanliness means that all of the bearings have to be designed to operate without lubrication.

The company's solution was to use silicon nitride (a hard ceramic) ball races that pressed against two extremely tough shafts made out of tungsten carbide. This arrangement keeps the internal push-rod centrally supported, paving the way for precise movement into and out of the beamline. Furthermore, external constant force springs retract the in vacuum mechanism should any failure occur in the pneumatics driving the unit. In this fail-safe position, the linear actuator has no effect on the beam.

A system of flexures ensures that no undue stresses are placed on any of the critical parts during bake out as they expand at different rates according to their composition.

The firm's bellows-free solution brings together creative design, smart materials selection and precision operation. Now that the linear drive is in its final prototype phase the team is working towards fulfilling multiple orders from CERN for what will be a bolt-on solution pre-wired with all of the necessary cables and switches.

"Every beamline in the world needs beam diagnostics," Eyres comments. "And off the back of this project we're ready to work with more clients who are also looking to move away from bellows in critical areas."

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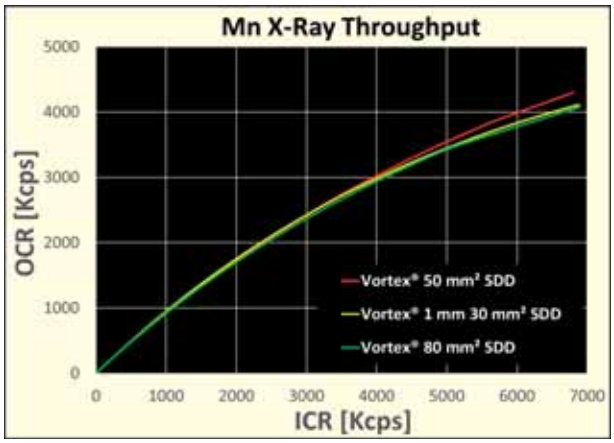

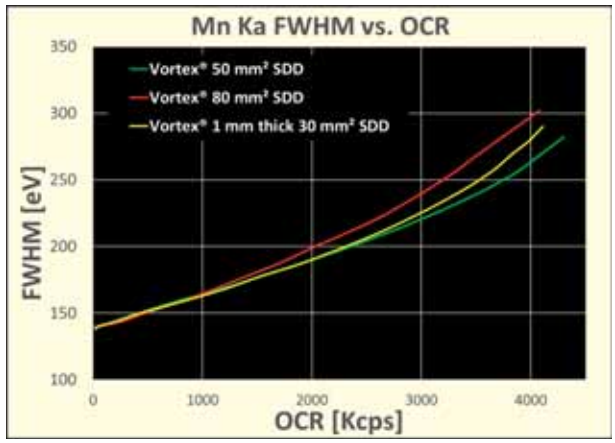

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Vive l'ESRF

The ESRF upgrade, the Extremely Brilliant Source, will drive 30 more years of scientific progress.

The inside of the ESRF01 building is no ordinary production line. There is no noisy machinery, no piles of ready components, certainly no greasy overalls. To one side, three engineers are systematically checking the alignment of a sextupole magnet on one of several huge, Ferrari-red girders, with a laser-tracking system. Every week, the engineers complete the assembly of four of these girders, which glisten like sports cars in a showroom. "The outsides we can touch, but the insides have to be clean," explains Jean-Claude Biasci, the manager of the Extremely Brilliant Source (EBS) project assembly. "If we want to generate a vacuum in the 10^{-10} millibar range, there has to be no dust, no fingerprints, nothing."

Biasci knows a thing or two about building synchrotron light sources. In the early 1990s, as a young man, he helped construct the ESRF's original 844-metre electron storage ring – the world's first "third-generation" synchrotron light source, distinguished from earlier second-generation sources by the unprecedented brilliance of its X-rays. The EBS project is doubly challenging, however. Not only is it a transformation to a fourth-generation source, but it will also have to be constructed within the ESRF's existing architecture. Both theoretically and practically, there is very little room to manoeuvre.

"Twice I've lived through exceptional engineering projects – first with the ESRF, and now with the EBS."

Fourth generation

To demonstrate what makes the EBS a fourth-generation source, Biasci points me to one of the triangular poles of a red quadrupole magnet. On the existing machine, he says, the tips of these poles are a few millimetres from the slender vacuum chamber that runs inside. Now there are but tenths of a millimetre

C ARGOUD/ESRF

Jean-Claude Biasci, the manager of the EBS project assembly, runs a tight ship.

– barely enough room to slide a thin film of plastic. That reduced gap means that the magnetic field inside the chamber will be much stronger, squeezing the cloud of electrons inside (in the horizontal plane) by a factor of 100. Ultimately, that will mean X-ray beams 100 times brighter than at the current ESRF. "The user will have a lot more flux of useful photons," says Biasci. "It's like taking a picture – the brighter it is, the clearer you can see."

Endless possibilities

The ESRF–EBS's X-rays will be so brilliant that its staff and users are still contemplating their future potential. Among hundreds of new scientific possibilities will be the ability to film the microsecond dynamics of biological and synthetic systems across vastly disparate length scales; the ability to capture three-dimensional, microtomographic images of huge objects such as dinosaur skulls and car engines; the ability to capture the crystallographic structures of even the tiniest biological macromolecules; the ability to study the electronic and magnetic behaviour of materials at previously unseen temperatures and pressures; and the ability generally to study samples faster and with more detail than ever before (see *ESRFnews* December 2017, pp15–25).

The EBS is an extraordinary feat of engineering, with each component machined to within a tiny 30 µm of design specifications.

"It's like taking a picture – the brighter it is, the clearer you can see."

Such tolerances are occasionally reached on industrial-scale production lines, but these often rely on the benefit of statistics: manufacturing lots of components, and afterwards selecting those that fit together best and discarding those that don't fit at all. With the EBS, on the other hand, components have been manufactured in such small quantities, and with so little redundancy, that this process is simply not possible, and pretty much everything has to be right. "In terms of machining, what we're doing is really very good," says Biasci.

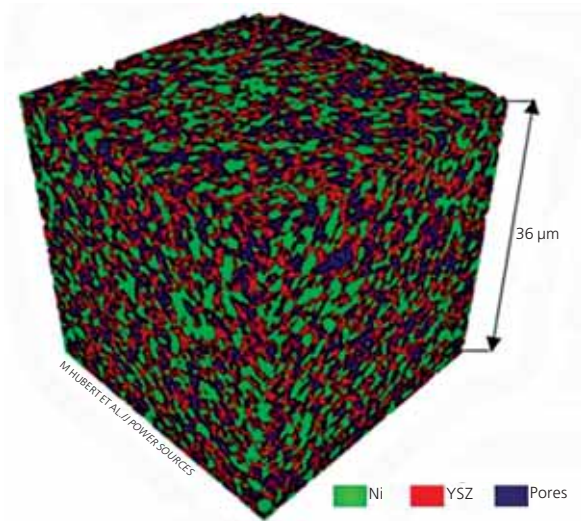
That fact of the EBS being a one-off raises the question: how does Biasci know how long its construction will take? In the beginning, he says, he and other project staff spent weeks estimating the upgrade duration, but this could only amount to a guess – a guess that consistently has to be re-evaluated. Yet with only 20 months of shutdown from 10 December this year allotted to remove the existing storage ring and construct the new one in its place, time is another inflexible factor. To minimise the risk of problems, Biasci runs a tight ship. From the smallest bolt to the heftiest girder, every component is assigned a serial number and checked in and out. Every time a job on the production line is completed, an e-mail is automatically sent to alert the engineers performing the next job. Meanwhile, three-dimensional computer drawings are tacked onto walls, to avoid any communication problems that might arise with the 12 Russian project staff who have been drafted in to work on the construction. "Everything is super well planned, in order to keep the shutdown time to a minimum," says Biasci.

ESRF01 is quiet when Biasci and I leave, as the engineers have set off for lunch. I ask him whether he is excited about the project finally coming together, but it is clear from his expression that his mind is still working overtime. "Twice in my life I've been able to live through exceptional engineering projects – first with the ESRF, and now with the EBS," Biasci says. "But the EBS is the greatest challenge."

Jon Cartwright

Why fuel cells degrade

Nanotomography at the ESRF helps the company SOLIDpower develop solid-oxide cells.



Post-mortem characterisation of the hydrogen electrode of a solid-oxide fuel cell by X-ray nanotomography, depicting the nickel regions (green), the yttria-stabilised zirconia regions (red) and pores (blue).

Solid-oxide cells are a type of fuel cell that can be used both to generate electricity, in a chemical reaction involving hydrogen, or to use excess electricity to generate hydrogen, via electrolysis. Such flexibility makes solid-oxide cells attractive for applications in a future hydrogen economy, and they often work more efficiently than rival fuel-cell technologies because of their high operating temperatures. The catch is that they degrade rather quickly, losing voltage at constant current.

"If the performance losses were limited to roughly 1% per 1000 hours, it would be economically viable to use them," says Maxime Hubert, a post-doctoral researcher at the ESRF. "Unfortunately, current degradation rates are higher than that, especially in electrolysis mode."

Understanding why solid-oxide cells degrade is therefore vital to the technology's development, and this is why Hubert, together with partners from the French Alternative Energies and Atomic Energy Commission (CEA) and the European fuel-cell company SOLIDpower, have made use of the ESRF beamline ID16A to perform highly sensitive X-ray nanotomography. The researchers believed that processes like electrode poisoning, material instabilities, inter-diffusion and reactivity – all caused by high operating temperatures – could be behind the degradation of the cells. In particular, the researchers suspected that the material of the hydrogen electrode – nickel-yttria stabilised zirconia – changes its structure during operation.

Backed by EU funding, the researchers performed durability tests on solid-oxide cells at the CEA before taking samples of the aged hydrogen electrodes to ID16A, where, aided by Peter Cloetens, the scientist in charge of the beamline, they could characterise the surfaces with a spatial resolution of a few tens of nanometres. The 3D analysis of the data obtained by nanotomography revealed that heat caused nickel to agglomerate on the electrodes after operation. Indeed, it was the reorganisation of this nickel phase that induced a loss of electrochemically active sites, leading to worsening fuel-cell performance. Computer simulations suggested that micro-structural changes in the hydrogen electrode can explain some 30% of the total degradation in fuel-cell mode, and some 25% of degradation in electrolysis mode, at a temperature of 850 °C after 1000–2000 hours of operation (*J. Power Sources* **397** 240).

Montserrat Capellas Espuny

"Current degradation rates are too high, especially in electrolysis mode."

Movers and shakers

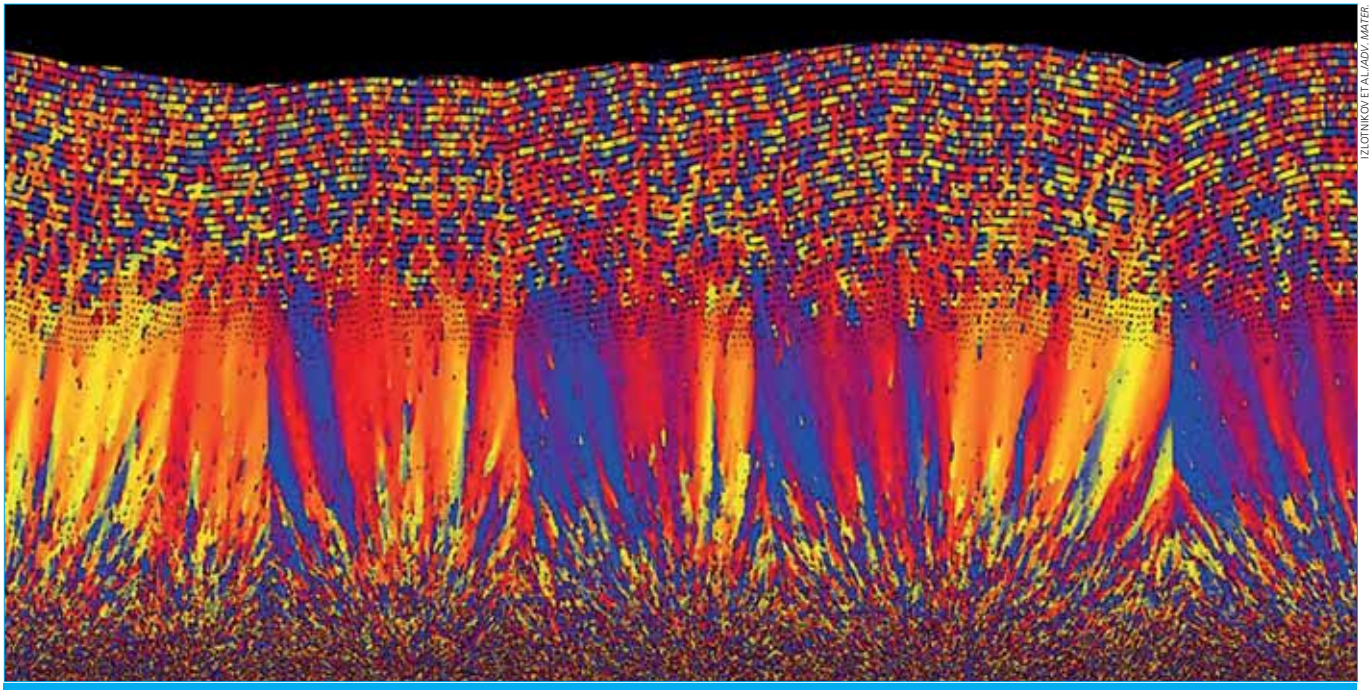
Yves Petroff took up his post as the new director of the Brazilian Synchrotron Light Laboratory (LNLS) in August. A physicist by training, Petroff has previously held senior positions at the (now decommissioned) ACO and LURE synchrotron light sources in France, the Advanced Light Source at the Lawrence Berkeley National Laboratory in the US, and the ESRF, where he was director-general between 1993 and 2001. Petroff was the scientific director of the LNLS between November 2009 and March 2013.

Sine Larsen, the former ESRF director of research, has been awarded the Max Perutz Prize from the European Crystallographic Association in recognition of her multifaceted contributions to crystallography, including crystal structure analyses of organic molecules and proteins, charge density studies, and the development of synchrotron radiation facilities. Now an emeritus professor of chemistry at the University of Copenhagen in Denmark, Larsen's research has focussed on structural chemistry and structural biology, using X-ray crystallography.

Steve Kevan, the division deputy for science at Lawrence Berkeley National Laboratory's Advanced Light Source (ALS), has been named as the ALS's new director. Kevan – who has been standing in as interim director since January when the preceding director, Roger Falcone, stepped down – takes over the reins at a pivotal point in the facility's history, when it takes its first steps towards a major upgrade, dubbed the ALS-U, based on the ESRF's Extremely Brilliant Source upgrade. The ALS celebrates its 25th anniversary this year.

Maria Faury became the new chair of the European XFEL council in July. Faury is the director of international affairs and large research infrastructures at the fundamental research division of the French Alternative Energies and Atomic Energy Commission (CEA), and has represented the CEA, one of the two European XFEL partners in France, on the facility's council since 2014. She succeeds Martin Meedom Nielsen of the Technical University of Denmark, who will continue on the council as vice-chair.

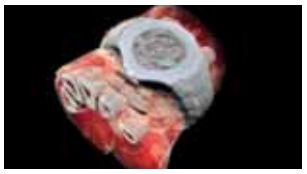
Beauty of science



I.ZLOTNIKOV ET AL./ADV. MATER.

The colour of magic: Scientists have long been mystified as to how molluscs grow their shells. In cold, wet conditions, and out of a single chemical compound, calcium carbonate, come the amazingly distinct shapes of calcite and aragonite – structures that cannot yet be synthesised. The image above, however, is a prediction of a new physical model to describe the biomineralisation of mollusc shells, by Igor Zlotnikov of the Technical University of Dresden, Germany, and colleagues. From bottom to top, it depicts the morphology of a mollusc shell as it grows according to gradually changing boundary conditions, with the colours representing different crystal orientations. The researchers have tested the model by taking data from real mollusc shells at the ESRF's imaging beamline ID19, and ID06, a diffraction beamline that is serving as a prototype for one of the flagship beamlines of the ESRF's upgrade, the Extremely Brilliant Source. "We are still very far from reproducing what nature does in bioinspired materials," says Zlotnikov, "but our research provides a model that can greatly contribute to the general knowledge in this field, and provide new clues about how to reproduce nature in the future." (*Adv. Mater.* doi:10.1002/adma.201803855).

In the corridors

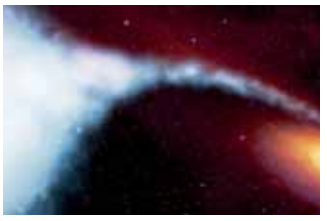


First 'colour' X-ray

Scientists from the University of Canterbury and the University of Otago in New Zealand have taken what they claim is the first three-dimensional "colour" X-ray of a human, by adapting a technology developed by CERN in partnership with the ESRF and other research institutions. The original technology, Medipix, detects and counts individual X-ray photons as they strike the pixels on a detector; the adapted version, called MARS, exploits this to generate images for medical purposes that clearly distinguish different material components, such as fat, water and bone, rather than simple density changes. One of the scientists, Phil Butler of the University of Canterbury, was the first to be scanned.

BepiColombo launches

The European Space Agency (ESA) – one of the ESRF's partners in the European infrastructure group EIROforum – has celebrated the successful launch of a pair of probes to Mercury. Developed in conjunction with the Japanese space agency JAXA, the BepiColombo mission will spend seven years travelling to the Solar System's innermost planet, where it will help scientists to answer how Mercury formed, and why it has an unusually large iron core. The last mission sent to Mercury was NASA's Messenger, but BepiColombo is expected to get closer and for longer.



X-rays expose black hole

Scientists in Japan and Sweden have used a technique known as X-ray polarimetry to determine the geometry of matter around a black hole. The X-ray data, which were collected on a balloon flight, provided evidence that the corona – a band of energetic particles – surrounding the black hole Cygnus X-1 is large and spread out, not compact and closely bound as another physical model had suggested. The results should help to constrain other characteristics about black holes, such as their spin, which has a strong effect on the nature of the surrounding space-time (*Nat. Astron.* **2** 652).

ESRF celebrates in Taipei

In June, Yu-Han Tsou, the vice-minister of science and technology in Taiwan, and the directors of many leading light sources, were among the delegates who celebrated the ESRF's 30th anniversary at the 13th International Conference on Synchrotron Radiation Instrumentation (SRI 2018) in Taipei. The conference, which was organised by Taiwan's National Synchrotron Radiation Research Center, was an opportunity for the ESRF to showcase the instrumentation that it has planned for the Extremely Brilliant Source upgrade – including new optics, detectors, software, control and mechatronics – as well as its upgraded beamlines.

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