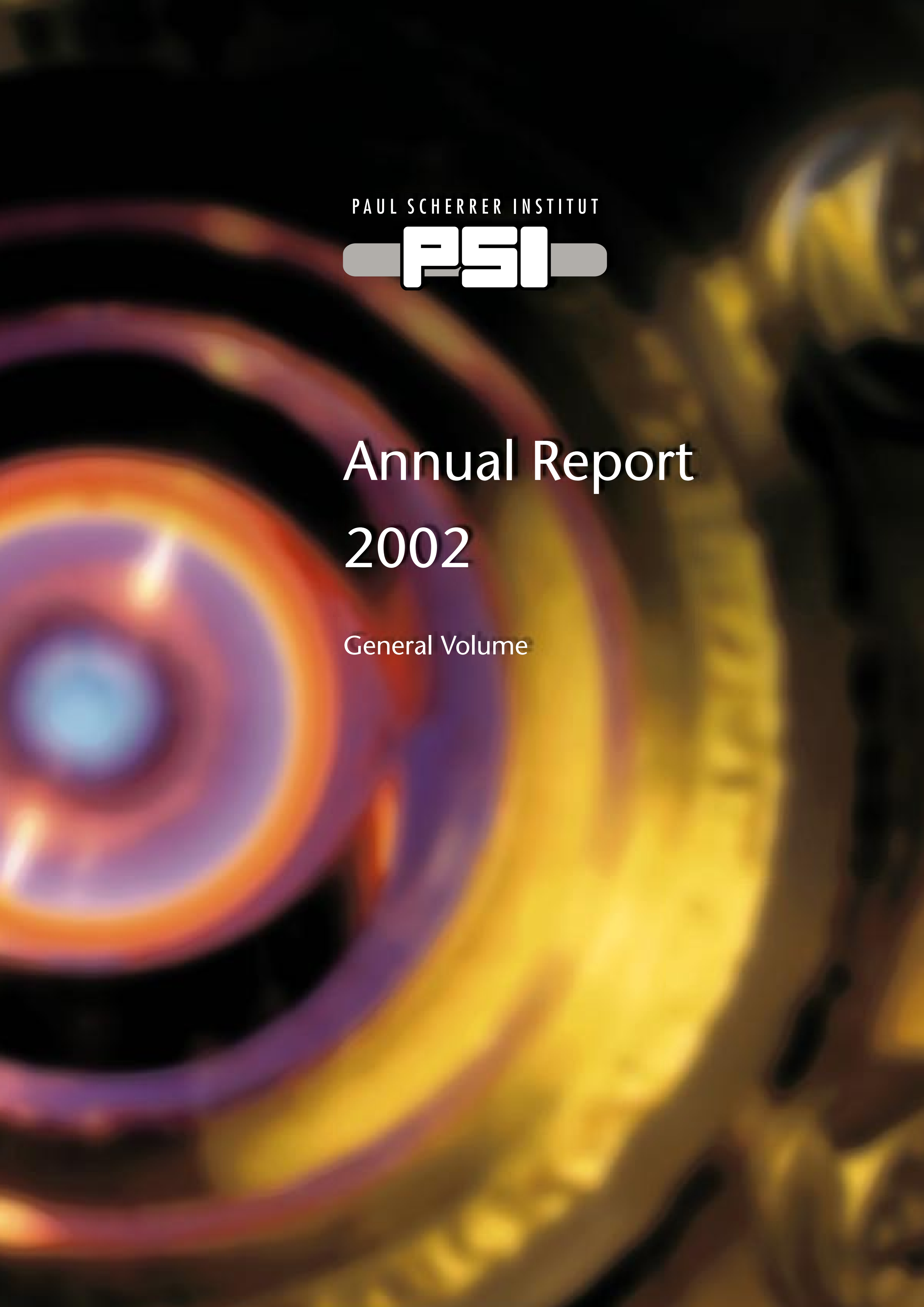

PAUL SCHERRER INSTITUT

PSI

Annual Report 2002

General Volume

Impressum

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General Volume

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Cover photo
Flames in focus: This combustion chamber at PSI permits analysis and optimization of combustion processes in gas turbines (photo H.R. Bramaz).

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PSI Annual Report 2002

Foreword from the Director

Heroes and ultra-short X-ray pulses

Heroes convey simple messages. They divide the world into good and evil, identifying what is beneficial and what is not. Unfortunately, reality is much more complex than this, and it is up to science to understand and describe it. Ingenious ideas and a great deal of patience are required in order to progress basic research into the development of new processes and products. The overall net product is the result of the work of many individuals working in numerous phases of the research process. Only the sudden discoveries of interrelationships or market breakthroughs result in messages that are easy to convey – and the elevation of those who convey them to the status of heroes. This annual report profiles eight PSI researchers – men and women. We have included their profiles in order to show that the long road to understanding complex interrelationships relies primarily on the commitment of individuals and their ability to put together both small and large pieces of the jigsaw.

PSI runs large facilities for national and international users. Four beamlines are now operational on the Swiss Light Source (SLS). The continuous injection of electrons has enabled us to achieve a synchrotron light that is entirely stable in terms of position and intensity – a world first and a major prerequisite for new generation light sources with an extremely small beam spot. The number of users continues to rise and additional beamlines are required. A number of impressive results were recorded during the year under review, for example the decoding of a human membrane protein by researchers from Roche on the protein crystallography beamline – notably only the third protein of this type, which is of major significance for the development of active substances, amongst the thousands that are yet to be investigated. Other user facilities were also very much in demand. The fifth EU framework programme provided financial support for neutron scattering (SINQ) and muon spin resonance (SμS) and it is hoped that the SLS will be included in the sixth programme. As ever, demand for our facilities (including particle physics beams) exceeded supply, which meant that we could only cater for the best experimental proposals.

A sought-after partner in industrial and EU projects

Our knowledge and skills are arousing increased interest in the world of science. Together with the Max Planck Society, the Basel pharmaceutical industry has invested in a second SLS beamline for protein crystallography, the automotive and automotive components supplying industry has indicated an increasing interest in our fuel cells and combustion research for conventional engines. The electronics industry is supporting the development of silicone-based lasers and radiation-hard electronics for applications in particle physics and in space. Part of the operating costs for the Hotlab is being provided by the Swiss nuclear power stations. PSI has also become a sought-after partner in EU projects.

Our primary objective is to encourage the next generation of research scientists – above all at doctorate level – which we run together with the two Swiss Federal Institutes of Technology and the universities in the various Swiss cantons. Of note are the efforts to preserve technical knowledge in the field of nuclear power, where a joint solution is emerging between the Swiss Federal Institute of Technology in Zurich (ETHZ), the Swiss Federal Institute of Technology in Lausanne (EPFL), the nuclear power stations and PSI.

However, PSI is much more than just a successful user laboratory. It is also the largest energy research institute in Switzerland. A central theme is the reduction of CO_2 emissions in energy conversion – in particular in traffic and electricity production. We are focussing our efforts on the generation of biodegradable fuels from wood or wet biomasses using solar chemistry or nuclear energy, the development of environmentally friendly and efficient combustion engines, fuel cell drives for vehicles and safe ways of disposing of spent nuclear fuels. We are able to establish a competitive edge in all these activities by means of the careful application of our large facilities – the SLS, SINQ, SμS, Hotlab and solar concentrator. Research expenditure for nuclear power has been reduced to a minimum acceptable level and will remain constant in the future.

A new Director in the middle of the year

A number of organizational changes were introduced when I succeeded Meinrad K. Eberle as Director of the Institute on July 1, 2002. The SLS changed from project status to a separate research department (SYN) and all our accelerators (cyclotrons and synchrotron) are now run by the Large Research Facilities Department (GFA). Safety is a central issue; the manager of the radiation protection department is also the highest-ranking safety officer with direct access to the Director. However, safety is not only an organizational issue; it must be firmly lodged in the consciousness of every individual. This is why we promote radiation protection training appropriate to all employees.

The separation of Personnel from Logistics and its operation as an independent department has proved worthwhile. The autonomy of the ETH domain and the new Swiss personnel law means that the department now performs an important strategic function in addition to its administrative responsibilities. Amongst its significant duties are the securing of the future of the Institute by means of promoting the next generation of scientists and researchers, career planning and promotions, training and education and even cost transparency.

At this point I would like to thank my predecessor, Meinrad K. Eberle. It was my privilege to take over an institute with motivated employees and huge potential for innovation. Ideas currently being followed range from femtosecond X-ray pulses, ultra-cold neutron sources, advanced X-ray detectors for the SLS and astrophysics to a demonstration facility for producing biodegradable fuels, the development of high-temperature materials for solar chemistry and nuclear power and even the construction of research centre for a proton-based radiotherapy.

I would also like to express my thanks for the external support received by PSI – from the Council of Swiss Federal Institutes of Technology, the Swiss Federal Department of Home Affairs and the Swiss Federal Councils, the Research Commissions who bear the significant responsibility for quality assurance and our customers, for their loyalty and support. I would also like to say a special thank you to the increasing number of sponsors who are supporting the radiation facility for deep-seated tumours which is currently under construction. Finally, my sincere thanks go to all employees of the PSI, to whose efforts the success of our Institute is due.

Ralph A. Eichler, Director

PSI in brief

The Paul Scherrer Institute is a centre for multi-disciplinary research in the natural and engineering sciences. It collaborates closely with universities, other research institutions, technical colleges, and industry, both at home and abroad. It is the largest national research institute with about 1,200 members of staff, and is the only one of its kind in the country. Its particular areas of specialization are solid-state research and materials sciences, elementary particle physics and astrophysics, biology and medicine, and energy and environmental research.

PSI concentrates on those subjects which are at the leading edge of scientific knowledge, which contribute to the education of the next generation, and which pave the way to a sustainable, environmentally friendly society. It actively pursues the commercial exploitation of new discoveries and, as a national research centre, also offers its services to external organisations.

PSI develops, builds, and operates complex, large-scale research facilities, facing up to particularly high demands in terms of knowledge, experience, and professionalism. It is one of the world's leading user laboratories for the national and international scientific community.

Research 2002

Portraits & Projects from PSI Departments

Synchrotron Radiation (SYN)

Condensed Matter Research with Neutrons and Muons (NUM)

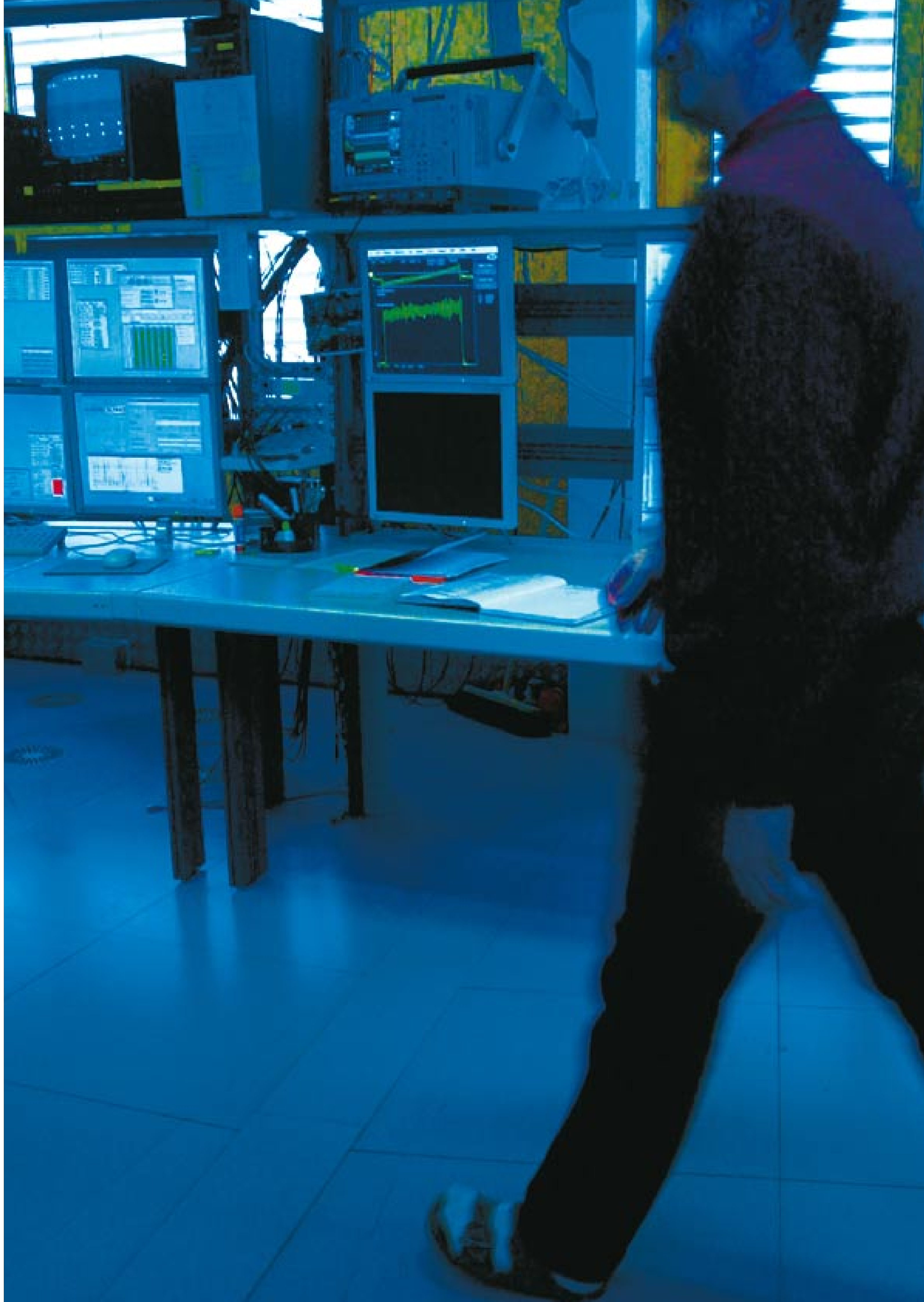
Particles and Matter (TEM)

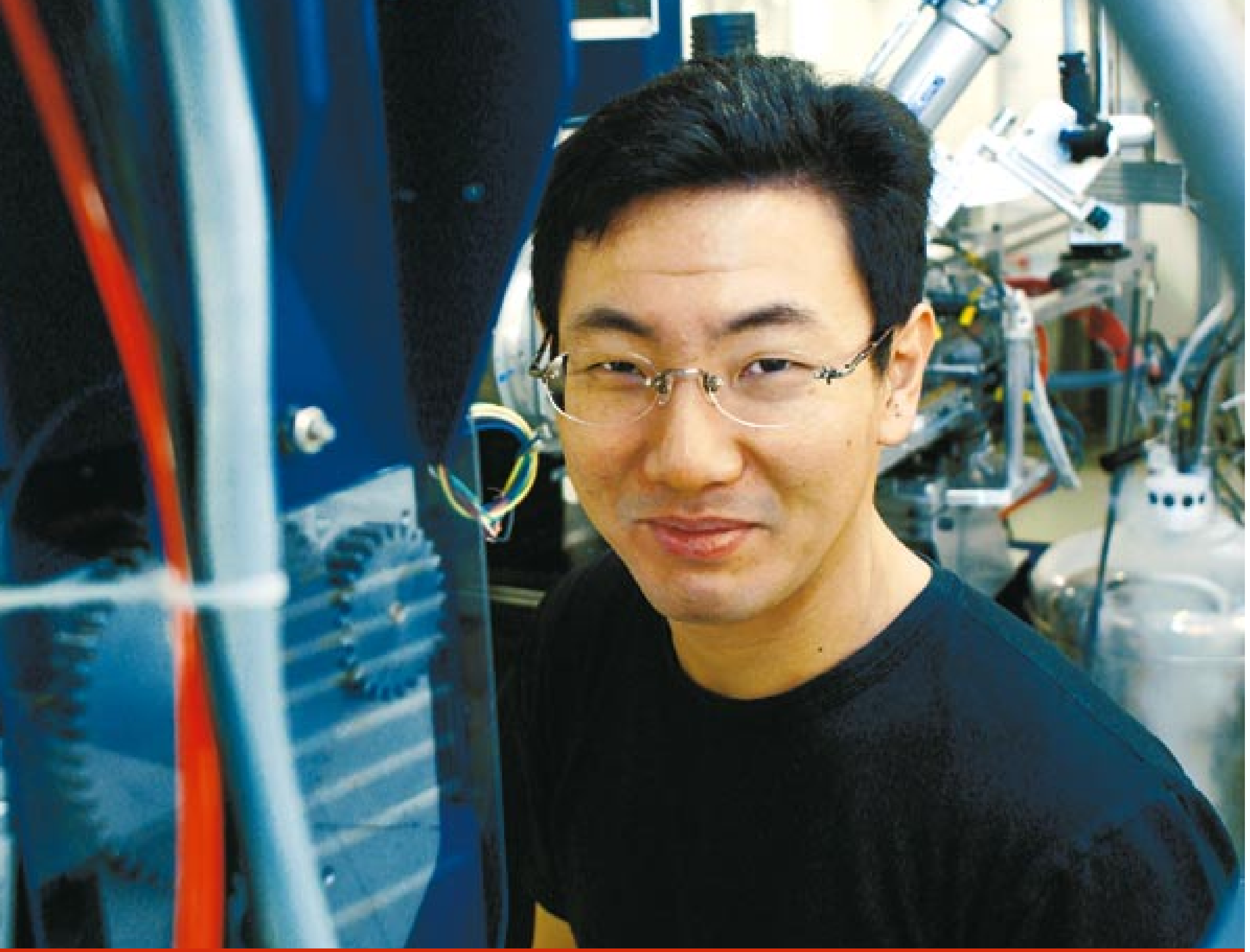
Life Sciences (BIO)

Nuclear Energy and Safety (NES)

General Energy (ENE)

In the control room of the SLS ▶

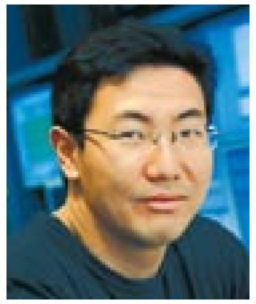




Controlling synchrotron light

Takashi Tomizaki

A system that runs well is "like the air or water", says Takashi Tomizaki. People don't notice it until a problem occurs. His job, he says, is to optimize the SLS software environment so scientists can concentrate on results.



Among many exciting applications, synchrotron radiation can be used to probe the structure of proteins, not only for what they tell us about how life works but as an aid in designing new drugs. For such investigations, light from the accelerator's storage ring is sent along a beamline to an experimental station, where scientists can work with it. That's where Takashi Tomizaki comes in.

Tomizaki handles the software side of beamline control. Using light to learn about proteins is a tricky business. The protein crystal must be positioned accurately in the beam, and images collected from many different orientations. Not all that long ago, the procedure was done entirely by hand, and photographic films had to be changed and developed.

Now researchers come with protein crystals so small they can't be aligned by hand. Instead, the crystals are rotated automatically and imaged using a digital imaging camera that snaps at every change. What's more, biologists have adapted to the new technology: since they no longer have to worry about manipulating their crystals, they just want to get results as fast as possible. That means automating "everything", says Tomizaki.

Tomizaki hails from Tokushima, a rural community in Japan. His parents worked as farmers, and Tomizaki was preparing to follow in their footsteps when he got a chance to study at the local university. Once there, he was exposed to biology and impressed by the fancy computers used to determine protein structures: "I just wanted to touch the computers", he says.

Software for all cases

As an undergraduate, Tomizaki wrote some programs that contributed to solving the structure of cytochrome c oxidase, a protein essential for breathing. He worked at an accelerator near Tokyo, and then completed his doctorate at the European Synchrotron Radiation Facility in Grenoble before arriving at PSI in 1999. At the time, the SLS still had no roof.

Protein crystals are different from other kinds of crystals, says Tomizaki. They may be hard or soft, as big as a hazelnut or microscopic, and depending on their character, require different treatment and measurement methods. Creating software to handle such a range of conditions is a challenge. The easiest remedy would be to customize the software for each user, "like a formula 1 car", says Tomizaki. But then the user interface would be less friendly.

Tomizaki has developed a one-size-fits-all interface that he adjusts based on the feedback he gets from researchers. It seems to be working. In the old days, solving the structure of a protein took so long that it was possible to sleep or go skiing while the machine was running. Now, says Tomizaki, researchers complain that the process is too short even to have a coffee.

Giselle Weiss

Decoding a major link in the metabolic chain

SLS: The Swiss Light Source, commissioned at PSI in 2001.

Angstrom (Å): A unit of length for measuring light and X-rays (10^{-10} m).

Mutation: Spontaneous or artificially induced change in the genetic structure.

Enzyme: Large organic molecule produced in living cells which plays a role in the metabolism of the organism.

ATP: Adenosine triphosphate, the most important energy carrier in the body. The majority of its energy comes from the decomposition of fat and carbohydrates.

Heme: A general term for metal porphyrin, e.g. unsaturated complex molecules with iron which are able to absorb oxygen, carbon monoxide or nitrogen bases.

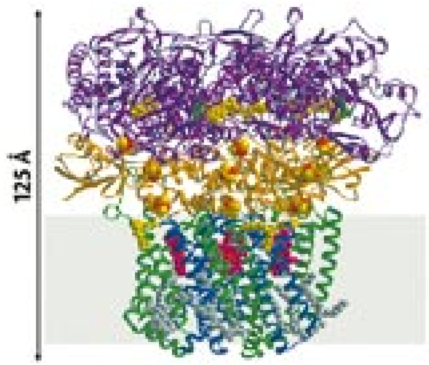
An all-rounder for all living things

Although proteins always comprise the same 20 amino acids, there are millions of different incidences of them which vary in size and function. They can act as tools or building materials as well as managers or transporters. There are no functions in the human body which do not involve at least one protein.

An international team of researchers has been able to decode the structure of the membrane protein common to the respiratory chain and the citric acid cycle.

Due to its central role in the metabolism, the succinate dehydrogenase (SDH) protein is both important to biochemical research and relevant for medicine. It is vital to understand the molecular mechanisms of a range of genetic disorders caused by mutations of this enzyme. The SDH structure was analysed on the SLS at a resolution of 2.6 angstroms.

Mitochondria are tiny cell organelles at the centre of the energy metabolism which actually power cells. In addition to the respiratory chain and the production of ATP which is connected with it, reactions also take place inside these organelles involving the citric acid cycle and the decomposition of fatty acids. Succinate dehydrogenase (SDH), also known as Complex II, is a component of both the citric acid cycle and the respiratory chain.



The succinate dehydrogenase protein, also known as Complex II, is part of the respiratory chain. The energy supplied via oxidation is released gradually and invested in the formation of energy-rich chemical bonds.

Responsible for many illnesses

A range of clinical disorders can be attributed to mutations of Complex II. These include degenerative muscular disorders, childhood tumours and Leigh Syndrome, a rare hereditary metabolic disease. Studies have also identified premature aging and high oxygen sensitivity in SDH-mutated nematodes. An excess of reactive oxygen species is suspected to be the cause in both cases.

So Iwata and his team from Imperial College London analysed the highly resolved structure of succinate dehydrogenase on the SLS protein crystallography beamline. For the first time, they were able to gain an insight into the function and detailed molecular mechanism of the disorders caused by mutations – a real scientific breakthrough.

We can learn a lot from electron transport. It is possible to use the distances measured for the molecules involved to calculate the distribution of electrons following the dehydrogenation (the process by means of which hydrogen is removed) of succinate. The result? A large number of the electrons can be found in the heme group at the end of the electron transport chain. As all known types of succinate dehydrogenase contain hemes, it is suspected that this is preventing the production of reactive oxygen molecules (free radicals) and, as a result, the development of diseases observed as a consequence of mutations. Electron transport is probably not possible in SDH-mutated nematodes, and this is what causes oxidative stress.

Bone failure and brain disease

Technical advances in medicine, biology and materials sciences are based on the knowledge and understanding of microscopic processes. New and very encouraging results are provided by the X-ray microtomography station installed at the SLS.

What effect does osteoporosis have on the structure and load capacity of bones? How does Alzheimer's disease affect the capillaries in the brain? These are just two of many questions to which synchrotron-based X-ray computer microtomography (SRμCT) can provide an answer. The extraordinary features of synchrotron radiation allow us to have a look into a sample in a non-invasive way, i.e. without damaging its structure and chemical composition. In fact, X-rays have a high penetration capacity for lightweight materials and therefore two-dimensional X-ray images of the specimen can be taken easily.

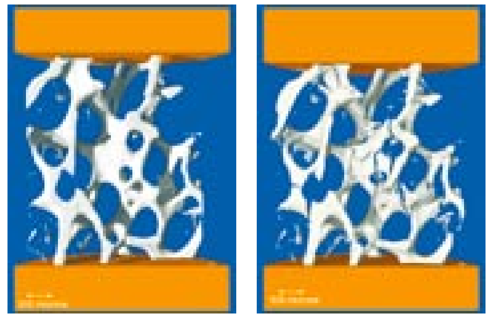
These 2D X-ray projections contain spatial information about the overall volume of the sample. By taking projection images in a number of different directions, we can glean volumetric information. Ingenious software tools and high-performance computers help experts to visualize and analyze data. A SRμCT system has been developed at the SLS to investigate samples measuring a matter of millimetres with a spatial resolution of one micrometre.

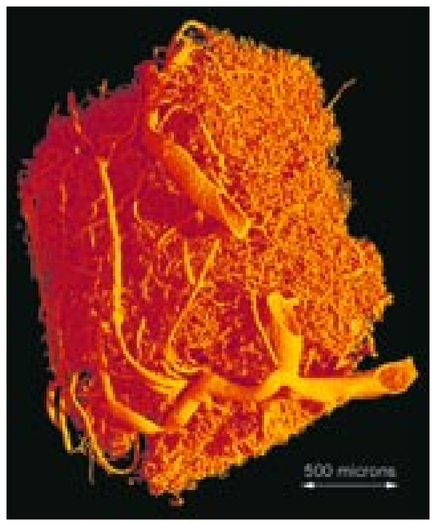
Finding out more about osteoporosis

A research group from IBT and EMPA is currently investigating bone diseases by carrying out loading tests on bone samples. A bovine bone was investigated before and after application of static and dynamic pressure. The damage caused in this test was clearly visible and is an obvious indication of failure. By carrying out a quantitative analysis of this process we can improve our understanding with regard to osteoporotic bone fractures of how damage starts and progresses.

Another research group including scientists from IBT, the University of Zurich and the Scripps Research Institute in La Jolla (California, USA) is currently carrying out research into Alzheimer's disease (AD). The reduction in the circulation of blood to the brain is one of the most resistant physiological deficiencies of AD. The development of mouse models for AD, in conjunction with X-ray microtomography, has made possible extensive research into the temporal progress of the disease and is a world first. New insights are being gained by means of the genetic induction of pathological characteristics together with non-invasive 3D imaging and quantification thanks to improved tomographic techniques.

A bovine bone before (left) and after (right) static and dynamic pressure has been applied. The damage caused in this test is clearly visible.





Blood vessels in the brain of a mouse – a world first: The image of the organ investigated at the SLS clearly shows the complexity of the vessel structure. These types of image can be used to carry out research into how diseases develop and may lead to the discovery of new methods of diagnosis.

Osteoporosis: Loss of solid bone tissue.

Alzheimer's disease: Brain disease named after the German neurologist Alzheimer, results in almost total memory loss.

Micrometre (micron): One thousandth of a millimetre (10^{-6} m).

IBT: The Institute for Biomedical Engineering at the University of Zurich and the Swiss Federal Institute of Technology in Zurich.

EMPA: Swiss Federal Laboratories for Materials Testing and Research, based in Dübendorf.

X-ray powder diffraction

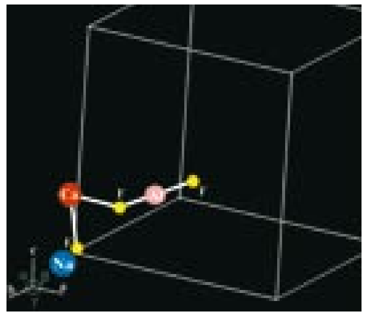
Synchrotron light through thousands of crystal grains

The instruments at the SLS can be used to decode structures in powder form in a flash and are broadening the horizons of material sciences.

Crystal structure analysis is probably the most common – and certainly the oldest – area of application for X-ray diffraction (XRD). As long ago as 1913, Sir William Lawrence Bragg was using the technique to identify structures such as common salt NaCl. The periodic arrangement of atoms in a crystal determines how an X-ray is scattered through the crystal atoms in a small number of specific directions and prevents it from being scattered in all other directions.

In almost all materials, XRD patterns not only provide information about crystal structure but also indicate the presence of structural phase transitions, flaws, the preferred ordering of crystals, all of which have a significant influence on the mechanical and electrical properties of materials. However, single crystals (e.g. pharmaceutical organic molecules) are not always available, and in these cases, XRD patterns are then based on materials which are present in powder form. A perfect powder sample consists of thousands and thousands of crystal grains, which we call crystallites.

It is much more difficult to analyze the structures of powders than those of single crystals. The high angular resolution of the experimental station at the SLS materials science beamline has made this process significantly easier. The extremely fast XRD data detection (XRD patterns can be captured in milliseconds) has also made it possible to carry out time-resolved experiments and is paving the way for new exciting applications in materials science.



The crystal structure of sodium calcium aluminium fluoride ($Na_2Ca_3Al_2F_{14}$ or NAC for short): The powder diffraction data were collected at the SLS and the EXPO program developed at the University of Bari in Italy was used to decode the structure.

2D X-ray waveguide

Radiation sources in nano dimensions

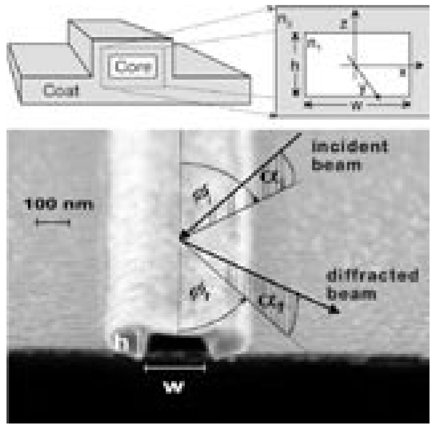
Nano science, nano technology deals with objects measured in nanometres (nm). One nanometre is equal to one millionth of a millimetre (10^{-9} m).

Coherent light: Light sharing the same wavelength and mode of oscillation.

A two-dimensional waveguide has been produced for the first time at PSI. It is able to generate the world's smallest spot for hard X-rays.

Numerous fascinating experiments in condensed matter and surface research would require an intensive, almost completely coherent X-ray source with dimensions in nanometres, yet it is extremely difficult to focus very hard X-rays in a small spot. An alternative method is to introduce a waveguide with an appropriately small cross-section. However, until now, the production of such a device appeared unrealistic due to the interfacial roughness and fabrication tolerances required.

An international joint venture carried out at the Laboratory for Micro and Nanotechnology (LMN) at PSI has succeeded in producing suitable structures for this type of application for the first time. The waveguides comprise a polymer core inside a thin chromium cladding layer. The exit aperture beam cross section of the waveguide at 12.4 keV photon energy has been measured at 68.7 nanometres across and 33 nanometres high, making it the world's smallest spot for hard X-rays.



As close as possible to a point source: The above diagram illustrates an X-ray waveguide with a core width w and a core height h. The image taken by the scanning electron microscope below shows a waveguide where w = 120 nm and h = 60 nm. By selecting appropriate angles of incidence α_i and ϕ_i, hard X-rays can be coupled efficiently into various resonant modes of the waveguide.

Quantum cascade lasers

Tailor-made light from silicon

An experiment carried out with cascaded quantum layers of silicon and germanium has succeeded in generating light for the first time by exciting electrons – the basis for the development of what are known as quantum cascade lasers (QCL).

Unlike conventional lasers, QCLs allow the wavelength of the light to be customized for the application in which they are being used. If an electrical voltage is applied, the electrons cascade down an energy staircase, emitting photons (particles of light) after each step. The wavelength of these photons depends on the height of the step, which can be controlled. By calculating layer thicknesses in advance, it is possible to create a staircase with steps of different heights, each of which will therefore emit light of the required wavelength.

In an experiment carried out recently at PSI with cascaded quantum layers consisting of silicon (Si) and germanium (Ge), it was possible to demonstrate for the first time that light can be generated by applying a voltage to the quantum structures (electroluminescence). These types of cascade structure, which were demonstrated for the first time in 1994 at Bell Labs in Murray Hill (New Jersey, USA) can be used to produce infrared laser light sources or even a QCL.

Revolution in microelectronics

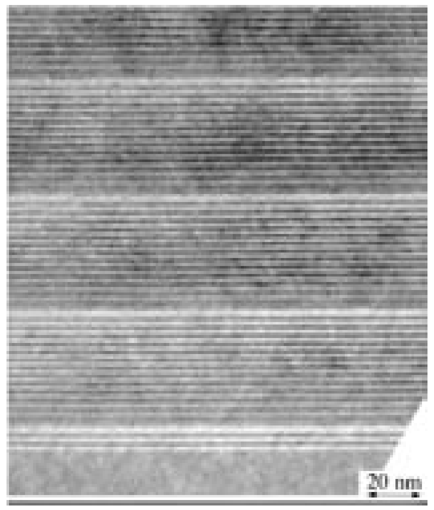
The development of laser light sources based on silicon, the material which is used to make PC processors and practically all types of electronic components, has the potential to revolutionize modern microelectronics. If electronic and optical components can be connected on a single silicon chip, i.e. with all components made from the same material, production will become more cost-effective and more compact.

Picking up on work carried out in preliminary experiments, a joint venture between the Laboratory for Micro and Nanotechnology (LMN) at PSI and a European research association is currently working on the application of the QCL concept using Si/SiGe layers. For the first time, an attempt is being made to generate laser light from a material which has always been considered to have poor emission characteristics (due to an indirect energy band gap). However, the implementation of this concept is pushing our understanding of material production and metrology as well as process technology to the limit.

The quantum structures comprise an alternating sequence of hundreds of thin layers of Si and SiGe with thicknesses of less than 1 nanometre (see image). The carriers are captured in the SiGe layers (quantum wells). If an electrical voltage is applied, electrons are be transported from cascade to cascade. During this process, they emit a photon, which, in suitable structures, will initiate the amplification process of a laser. In order to be amplified, the light must be guided through an optical waveguide (see image) with virtually no loss. The research group at the LMN is now working to optimise the various components and match them to one another. This is the final obstacle on the way to demonstrating an Si/SiGe quantum cascade laser.

Quantum leap: Transition of the (quantum) state of a system to a higher or lower energy level. The difference in energy is either absorbed or emitted by a γ-quantum or photon (particle of light) in quantized format.

Clean room in the Laboratory for Micro and Nanotechnology (LMN) at PSI.



An electron waterfall: Multi-cascade structure of silicon and germanium (electron transmission image, 1 nm = 10^{-9} m)

Low-loss light transmission: Chip with optical waveguide (waveguide: actual transmission line; golden colour: contact pads; SiNx: insulating layer).

Discovering interplays of forces

Joël Mesot

Along with the rest of his colleagues, Joël Mesot longs for the day when he will see a superconductor at room temperature. Together with his team, the French-speaking Swiss hoping to gain a greater understanding of how neutron spectrometers can be used for resistance-free current flow has developed a device for use in this field.

In euphoria for superconductivity

Joël Mesot's enthusiasm is apparent as he describes the way in which superconductors exploded onto the scene little more than 15 years ago. "It really was a revolution." This progress was triggered off by Georg Bednorz and K. Alex Müller of IBM's laboratory at Rüschlikon near Zurich. In 1987 – just a year after publication – the two scientists were awarded the Nobel Prize for Physics in recognition of their sensational achievements with superconducting metal oxides.

The success of Bednorz and Müller inspired hundreds of research laboratories all over the world to start working with similar materials. Some groups recorded amazing results: the superconductivity transition temperature suddenly rose to minus 110 degrees Celsius – a massive leap of more than 120 degrees within just a few years. Studying physics at the Swiss Federal Institute of Technology (ETH) in Zurich at the time, Joël Mesot also became caught up in the euphoria. He had a sudden realization that he too would one day carry out research into high-temperature superconductivity.

"In order to make scientific progress, we wanted to understand the phenomenon right down to the very last detail", Mesot explains, outlining his ambitious goal. Since October 1999 he has been in charge of the neutron spectroscopy team at PSI. The team is part of the Condensed Matter Research with Neutrons and Muons Department (NUM) and sometimes works in partnership with the ETH Zurich. Work remains to be done on the superconductivity mechanism and the theory still has to be developed. Mesot's team has built a spectrometer which it uses to measure the energy states of the magnetic components of electrons in superconducting copper oxides. The researchers hope to gain information about magnetism, which could play an important role in superconductivity.

Joël Mesot's pioneering spirit is breaking new ground in terms of research. The 38-year-old is fascinated by the interplay of complex forces, triggered by molecular lattice vibrations, by interactions between electrons and magnetism – a physical realm which exceeds the capacity of conventional powers of imagination. Mesot's fascination for the untapped microcosm set him on the right path for a successful career as a scientist. Having completed his studies at the ETH, he joined the Institut Laue-Langevin in Grenoble to write his doctoral thesis in close collaboration with the ETH Zurich. A native of Fribourg, he then returned to PSI for five years before leaving to expand his research horizons at the Argonne National Laboratory in Chicago.

Having already received several awards – in November 2002 he won the coveted Latsis prize awarded by the ETH Zurich – Mesot looks to the future with confidence. He hopes to use a new beamline at the Swiss Light Source (SLS) to go further into the secrets of superconducting structures. A football fan (Servette FC, Geneva and FC Basel), he attributes his motivation for his work to his family – his two sons and his wife, who is also a physicist. The origins of Mesot's calling to natural sciences can be traced far back to Geneva, where he grew up. He was inspired by a high school teacher to dedicate himself to the study of inanimate matter. And Mesot was not alone as four of the 17 pupils in his class went on to study physics – an unusually high percentage.

Beat Gerber

Microscopic probes for measuring magnetism

Phonon: A quantum of vibrational energy in a crystal lattice.

Coherent: Sharing the same wavelength and mode of vibration.

Magnetic fluctuations: Dynamic movement of electron spins.

Spin: Rotational motion of an elementary particle.

Muons: Elementary particles similar to but 207 times heavier than electrons and unstable.

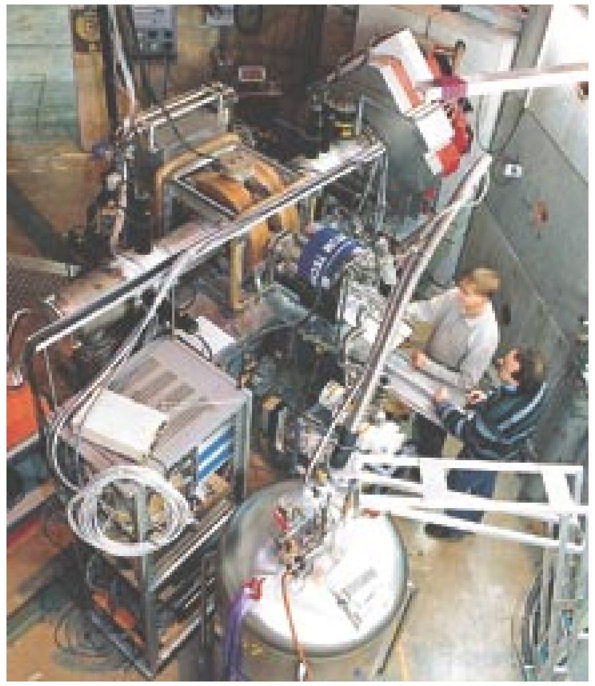
Muon spin spectroscopy: A method of analysis in which muons act as probes to gain information about properties (e.g. magnetism) of a sample.

$YbPd_2Sn$ (Ytterbium-Palladium-2-Tin): Intermetallic compound which crystallises and is superconductive in what is known as the Heusler structure.

An international research team led by PSI has verified a new explanation for no-loss current transport under experimental conditions.

Superconductors are materials which are able to conduct current below a certain temperature with no resistance, i.e. without any energy loss whatsoever. A theory known as the BCS theory has been used until now to explain how conventional superconductors work. It demonstrates that under certain conditions, electrons are drawn to one another by means of interaction. The electrons are linked by phonons, which are coherent vibrations of atoms in the crystal lattice.

For electrons involved in superconductive processes, it is better in terms of energy that they combine to form pairs than return to their previous state as individual entities. According to the BCS theory, a number of pairs, known as Cooper pairs, will combine to form a highly ordered ground state called condensate. The condensate is highly coherent and has a long span, the basic conditions for superconductivity: if an electric field is applied to a superconductor, the individual pairs of electrons will not be able to react to it separately but will flow as one (as condensate) without resistance through the entire sample. That's the conventional theory, anyway.



Use of muons as magnetic probe: General Purpose Surface-Muon Instrument (GPS).

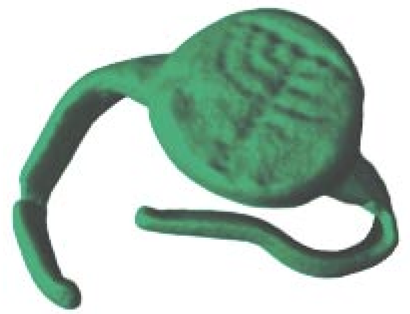
Magnetism instead of phonons

Recent interest has concentrated on the possible existence of what is being called unconventional superconductivity – in the sense that other mechanisms can generate the formation of Cooper pairs. The most obvious possibility is that superconductivity in most materials is due to magnetic fluctuations rather than phonons. Although countless reports have been produced laying claim to the existence of such a state in various system classes, until now there had been a lack of microscopic analytical proof to support these theories.

By using the features of muons and neutrons as microscopic probes for magnetism in matter, a research group headed up by PSI scientists recently succeeded in observing close interplay between superconductivity and magnetic fluctuations. Magnetic fluctuations appear at the exact point in time at which the intermetallic compound $YbPd_2Sn$ is cooled to below its superconducting transition temperature of 2.3 Kelvin.

The result is the perfect complement between two microscopic techniques which are available to in-house and visiting researchers at PSI, muon spin spectroscopy and neutron scattering. The work has benefited from international co-operation between PSI, CEA/ILL in Grenoble and Tokyo Metropolitan University.

Taking care of our past



Found near Kaiseraugst: A Roman ring (tomography) with a Jewish symbol (diameter approx. 12 mm; weight 2.3 g)

Non-destructive methods must be applied to protect expensive objects under investigation. Neutron radiography is an alternative and seldom used method which can benefit many applications.

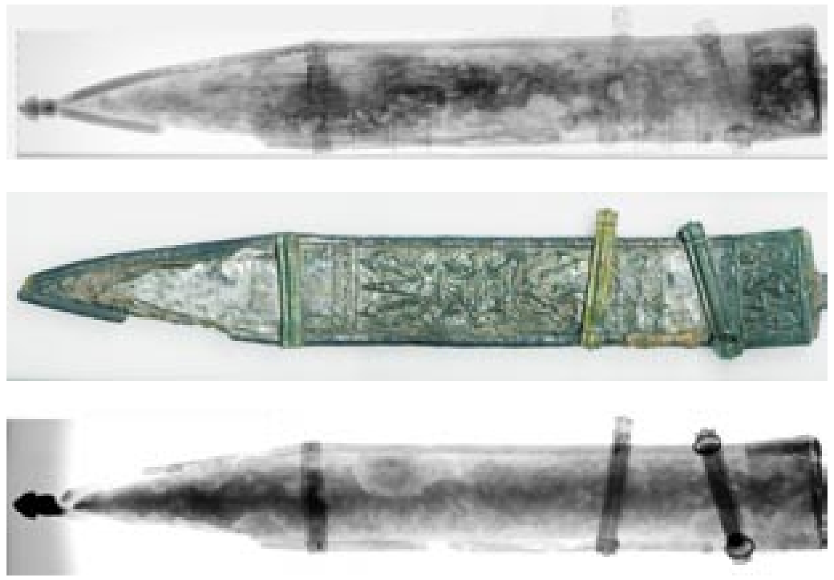
Archaeological finds provide unique information about how our ancestors lived hundreds or even thousands of years ago. Analysing them in detail usually leads to new insights into relationships or expert hypotheses previously considered valid. Spurred on by a European research initiative (COST G8), archaeologists and museum curators from Swiss institutions were invited to visit the Swiss Spallation Neutron Source (SINQ) to take a look at current research projects. As even large museums such as the Swiss National Museum in Zurich only have limited access to non-destructive analysis and testing methods, the large PSI research facilities provide a unique basis for specialist high-value studies. The enforced synergy between natural science and the arts can be mutually beneficial.

Radiographers and archaeologists

In recent times, it has been possible to counter the initial reluctance of museum experts and many successful investigations have been carried out. Direct dialogue between specialists on both sides has been the most important factor in the success of all investigations carried out. While neutron radiographers simply view the objects they are investigating as combinations of different materials, the samples are "alive" from the archaeologist's viewpoint due to his knowledge of their historical background and origins.

Investigations carried out on the NEUTRA facility (beamline 32 on the SINQ) on museum samples are constantly providing new challenges for the specific method to be used in each case. It has been possible to analyse and test not only huge objects like the so-called Zürcher Klumpen (a Celtic coins find) and extensive samples such as the Roman sword but even very delicate objects like antique rings. In addition to direct transmission methods, neutron tomography, which enables objects to be modelled in three-dimensional format, has even been used in some cases.

Direct comparison with analogue investigations using X-rays which are also available at PSI can extend still further the information that can be gleaned from museum objects. Work is set to continue on collaborative projects with expert archaeological groups, some on a pan-European basis.



A Roman sword (gladius) from the Vindonissa Museum in Brugg (centre). Non-destructive analysis and testing was carried out using neutrons (top) and 150 keV X-rays (bottom). X-ray testing supplies information about metallic components (iron, bronze) and neutron scattering identifies organic components (wood and leather in addition to resin and paint used in restoration).

Proving a theory which is almost 50 years old

Muons: Elementary particles similar to but 207 times heavier than electrons and unstable. The tiny compasses can provide information about magnetic fields in and around the surface of a material.

A muon spin rotation technique developed at PSI has made it possible for the first time to detect directly non-local effects in a superconductor.

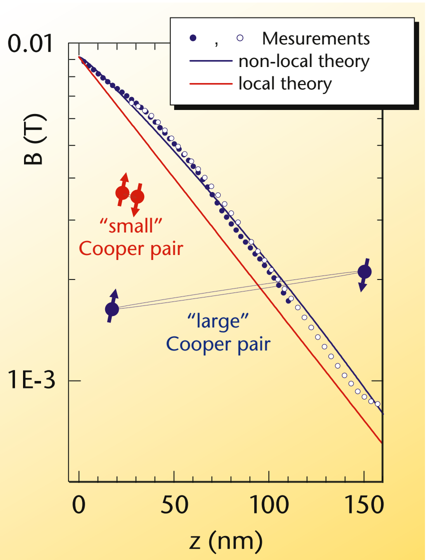
Electrons in simple metals often behave as if they were hardly aware of their mutual existence. However, under certain circumstances, these electrons combine to form pairs which are known as Cooper pairs. This pairing occurs at very low temperatures and radically changes the macroscopic properties of the metal. It becomes a superconductor, which means that it is able to transmit electrical currents without losses. If you place a superconductor in a magnetic field, it will attempt – unlike a normal metal – to screen it. The screening takes place at the surface of the superconductor within a depth of several to a few hundred nanometres (millionths of millimetres).

In most superconductors, the extent of the Cooper pairs is much smaller than the magnetic penetration depth (type II superconductors), which is responsible for a local relation between current and magnetic field. In this situation, the magnetic field decays exponentially from the surface of the superconductor towards its interior. However, if the size of the Cooper pairs is larger than the magnetic penetration depth (type I superconductors) the simple local model is no longer valid and the theoretical explanation becomes more complex. As a result, we expect to see a non-exponential dependance in the magnetic penetration profile.

Magnetic profile over nanoscale

Although theories in this field date back as far as in the 1950s, until now it has not been possible to test them directly in experiments due to the lack of a technique with microscopic sensitivity. This is now possible thanks to the low-energy muon spin rotation technique developed at PSI. Extremely slow, completely spin-polarized muons are implanted into the material under investigation, where they act as local magnetic field probes and enable magnetic profiles to be measured with nanometre sensitivity.

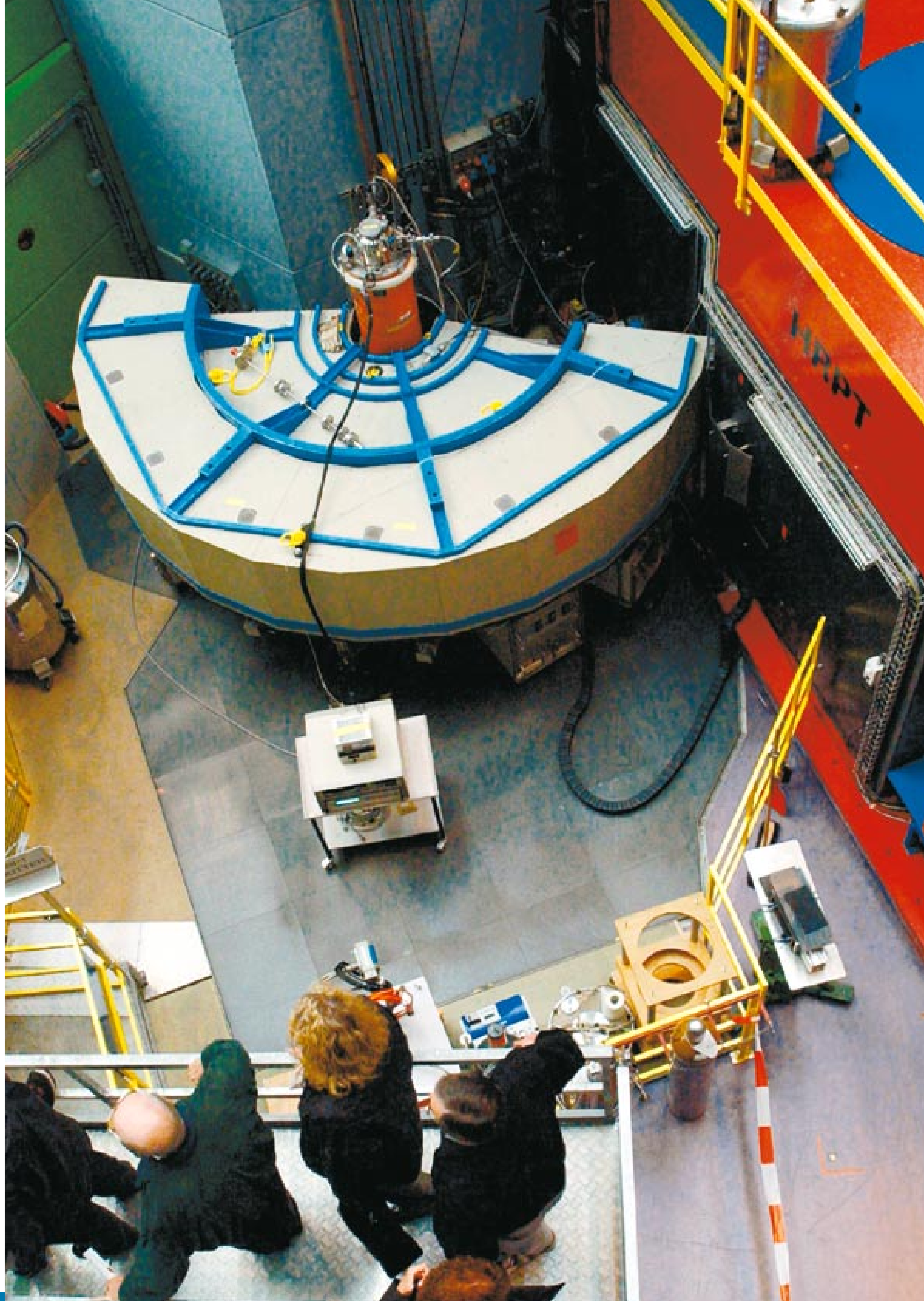
Initial investigations carried out on lead and niobium films found clear evidence for a non-exponential decay of the magnetic field. This is the first time that has been detected in a direct microscopic way non-local effects in superconductors. By carrying out a detailed analysis of the curve shape, we were able to identify important model parameters, e.g. the extent of the Cooper pairs or the magnetic penetration depth.



Magnetic field on the surface of a lead film: The curve traces the interplay between the size of the Cooper pairs and the magnetic penetration depth.
Blue: measurements and non-local theory ("large" Cooper pairs);
red: local theory ("small" Cooper pairs);
B: magnetic field strength (in Tesla);
z: penetration depth (nm = nanometre).

UHV cryostatic temperature regulator: The new ultra-high vacuum temperature regulator with sample tray (small image) has been developed in-house at PSI and allows measurements to be carried out on superconducting lead and niobium films.

In the SINQ ▶



Enchanted by a world of ice

Margit Schwikowski

This native of the lowlands only discovered her passion for glaciers and high mountains by chance. Today, she wouldn't be without the adventurous element of her daily research.

Drilling into climate archives

Standing 60 metres high on the banks of the Elbe, Süllberg was the name of the only mountain Margit Schwikowski ever knew in her youth. Yet all that changed when Schwikowski, who hails from Hamburg, landed up at PSI or, to put it more precisely, spent two months at the Jungfraujoch observatory, where she signed up for a project to study the transfer of trace elements from the atmosphere to snow.

The chemist tells us that this plan was not that far removed from the subject of her doctoral thesis: the entry of nitrogen compounds into the North Sea. This was the subject that really roused Schwikowski's interest in field research, albeit under rather unpleasant circumstances. She took her air and rainfall samples out at sea – on a ship, from a plane and from a platform. There's no disputing her predilection for the extreme! A glacier drilling specialist, she is known to spend anything up to several weeks on mountain expeditions with her tent and sleeping bag. Destinations have included the Alps, Andes and the Altai mountains in Siberia. The heights she has scaled in her profession at PSI also make her one of a selected few.

As the assistant manager of the Radiochemistry and Environmental Chemistry Laboratory, Schwikowski is one of the few women at the very top of the career ladder. «I've only been able to pursue my career by swapping roles completely with my husband», she says. He stays at home with their 11-year-old daughter whilst she supports the family. It's a practical, if not ideal, way of life.

There's no doubt that Schwikowski's presence in the Analytical Chemistry Group has left its mark. When she joined the group in 1990, she was its only female member. Today, more than half of the scientists are women. However, the increase in the number of female personnel is not something that Schwikowski has consciously promoted. "Maybe it's simply more attractive for female students to work in a mixed team."

Schwikowski's team spends most of its time analysing drilled ice cores. The team intends to use the chemical data stored in the glaciers to reconstruct the climate of centuries gone by. For many years, this area of climate research only used cores from Greenland and the Antarctic. The much smaller glaciers found in mountain ranges were ignored. Schwikowski takes up the story. "A new trend has emerged recently. We have come to realize that regional archives are essential to our understanding of how climates work."

It's a good job then that PSI's glaciologists developed their own drilling technique early in her career. They use a lightweight device that is easy to handle and, as well as functioning at extreme heights, can also be used in one of the world's most inhospitable locations: the Patagonian Ice Cap, where Margit Schwikowski plans to carry out the first-ever glacier drilling expedition. This woman really has been blessed with a sense of adventure!

Kaspar Meuli

Nitrogen shining over the Aare

Radionuclide: Atomic nucleus (nuclide) which emits radiation and thereby changes into other nuclides.

Target: Material onto which high-energy beams are directed in order to generate nuclear reactions and/or release new particles.

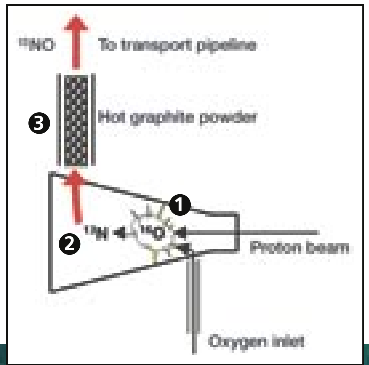
The particle accelerator on PSI's West site is used to produce short-lived radionuclides. Under the umbrella of the PROTRAC project, a radioactive nitrogen isotope is being developed in gaseous form to be used for experiments in atmospheric chemistry.

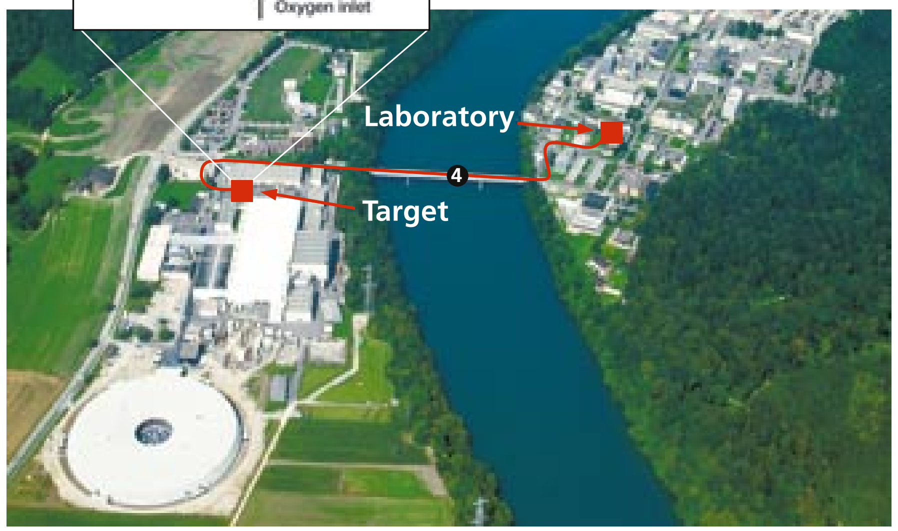
A radioactive isotope can be used for an external observation of how labelled molecules interact with a surface under experimental conditions. This makes it possible to study processes under realistic conditions in model experiments. The Laboratory for Radiochemistry and Environmental Chemistry at PSI has spent the past ten years developing this technique using the ^{13}N nitrogen isotope in order to investigate surface processes in the atmosphere – for example how different types of nitrogen oxide molecules interact with ice and aerosol particles found typically in the atmosphere – with the aim of gaining an insight into the effect of these surface chemistry processes on the ozone budget and the climate.

The end of the line in the laboratory.

So far, experiments have been carried out during beam times at the Philips Cyclotron. However, it became clear that it would only be possible to continue developing the method if we could carry out our experiments on a stationary and routine basis. It was therefore decided to relocate the production from the Philips Cyclotron to the proton accelerator (injector 2) and to transport the ^{13}N isotopes to the new lab building on the East site along a gas pipeline 580 metres in length. This would make the isotopes available on a regular basis and provide an ideal means of integrating these activities into our standard experimental infrastructure.

The pipeline, a plastic tube with an internal diameter of 4 mm in triplicate form is housed inside a protecting tube which is 30 mm thick. All other connectors and valves are jacketed. The jacket flushed with nitrogen, which is permanently monitored so that leaks can be detected immediately. Before the facility was put into operation in mid-December 2002, it underwent extensive tests on the West site with a shorter pipeline. The entire PROTRAC facility is now available for research purposes.





From the proton accelerator to the research lab: 1. A proton accelerator beam (injector 2, PSI West) colliding with oxygen molecules in the target. A nuclear reaction takes place in which the ^{13}N isotope is generated from oxygen. **2.** The ^{13}N reacts with the remaining oxygen molecules and various radicals to create $H^{13}NO_3$. **3.** The gas is passed over powdered graphite at a temperature of 300 °C. This causes a surface reaction which reduces $H^{13}NO_3$ to ^{13}NO. **4.** The gas is then blown together with the traces of ^{13}NO through a pipe 580 m in length across the Aare Bridge into the new research laboratory where experiments are carried out.

Powerful solar eruption

Equipped with instruments developed at PSI, HESSI is supplying images with significantly increased high-sensitivity resolution and at higher temperatures than other satellites.

We know from previous investigations that strong magnetic fields are prevalent in the solar atmosphere. The magnetic field, which is loaded with matter, behaves like a mechanical spring, whose extremities are stretched across the surface of the sun and twisted by convection motions. The potential energy accumulated is discharged in the form of powerful eruptions, which accelerate the whole of the plasma, whereby it reaches temperatures far in excess of 10 million degrees. The energy released is 30,000 times that of the electrical energy produced annually in Europe. These processes are difficult to understand in scientific terms and are being monitored by HESSI (see also page 80).

Taking a look around: The HESSI satellite, 600 km above the earth.

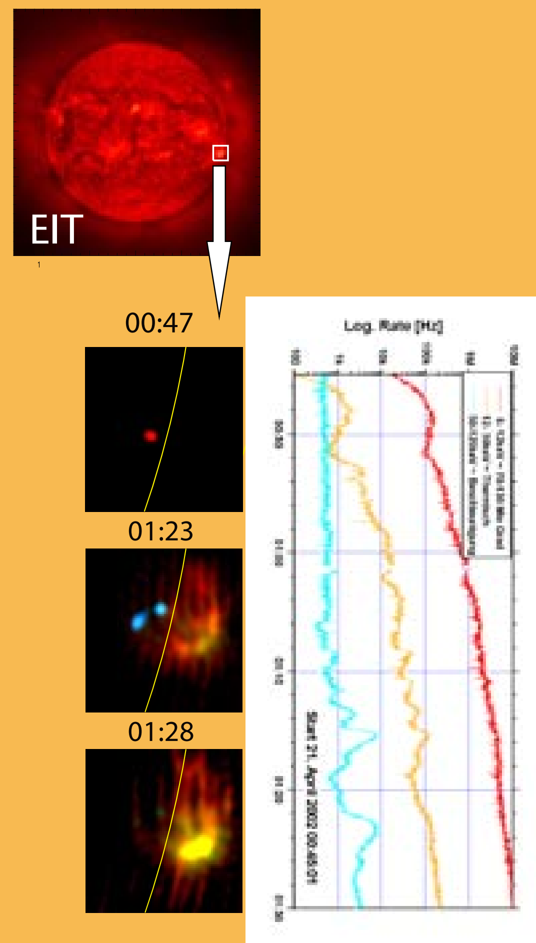
Collapse of the solar magnetic field structure

On April 21 at around one o'clock in the morning, a particularly interesting event took place which was recorded by the EIT instrument on the SOHO satellite. The image of the whole of the sun (approx. 60,000 degrees) indicates that the eruption took place at the sun's edge (small square).

HESSI is however able to provide images of this region with significantly increased high-sensitivity resolution and at a higher energy (temperature). The small images taken by HESSI and the graphic trace the progress of the eruption at various stages. The diagram illustrates all of the hard X-rays detected by HESSI in three different energy bands. The same colour scheme is used in the adjacent images on the left (Energy of X-ray – low: red; medium: yellow; large: blue). HESSI entered the earth's shadow at 1:31 a.m.

The HESSI images show that in the early stages of the eruption, only a small number of clouds were indicating temperatures of approximately 10 million degrees (red) (12:47 a.m.). Later (1:23 a.m.) two high-energy localized sources (blue) can be seen lighting up, which have been interpreted as the roots of a magnetic arc. The fact that both sources lit up at the same time suggests a shared acceleration mechanism.

The pulse at 1:23 a.m. also coincides with the occurrence of radio emissions, subsequently drifting to lower frequencies. This type of behaviour is usually associated with the emission centre moving to higher levels of the solar atmosphere – a scenario which can be confirmed directly by the HESSI image at the bottom. At around 1:28 a.m., a wide, hot source at approximately 50 million degrees (yellow) was captured some 30,000 km above the sun's edge. Such an intensive X-ray source at this height could indicate acceleration in the magnetic-hydrodynamic wave field induced by the collapse of the solar-global magnetic field structure. An alternative model suggests magnetic reconnection (short circuit). HESSI's unique high-sensitivity and spectral resolutions means that these types of models can now be verified for the first time.



40 million pictures per second

CERN: European Laboratory for Particle Physics in Geneva, where a gigantic particle accelerator, the Large Hadron Collider (LHC), is currently being built.

PSI is taking part in a collider experiment at CERN for which it is developing a new type of pixel detector. In 2002, a major milestone was reached on the long road to completion.

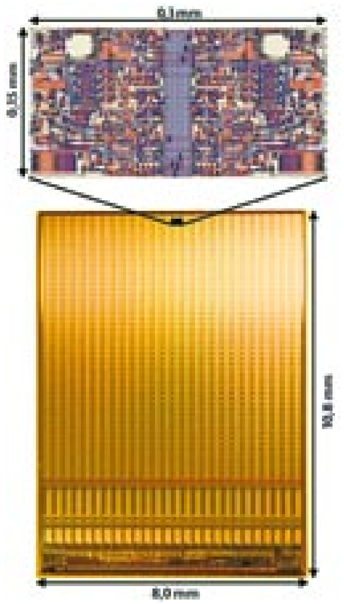
The term pixel is often used in relation to digital cameras, which capture pictures point-by-point on an electronic chip which is segmented into numerous small areas (pixels). A similar method is to be applied in the CERN experiment to record the flight paths of charged particles using high-resolution detectors. When a particle flies through the detector, it induces an electrical signal in the segment which was hit (pixel). Using several detector layers the flight paths of the particles can be reconstructed.

This detector has very challenging specifications. It has to be able to capture 40 million particle hit patterns per second and buffer them in the detector in compressed form. Every thousandth or so picture is considered useful for subsequent analysis and is forwarded for data processing. Any pixel that was hit by a particle will notify this automatically so that the hit can be recorded as point in the correctly assigned picture. The point is also assigned a "colour" (indicating the strength of the signal). One of the most demanding requirements to be met is that the pictures must be captured and stored as well as selectively forwarded simultaneously.

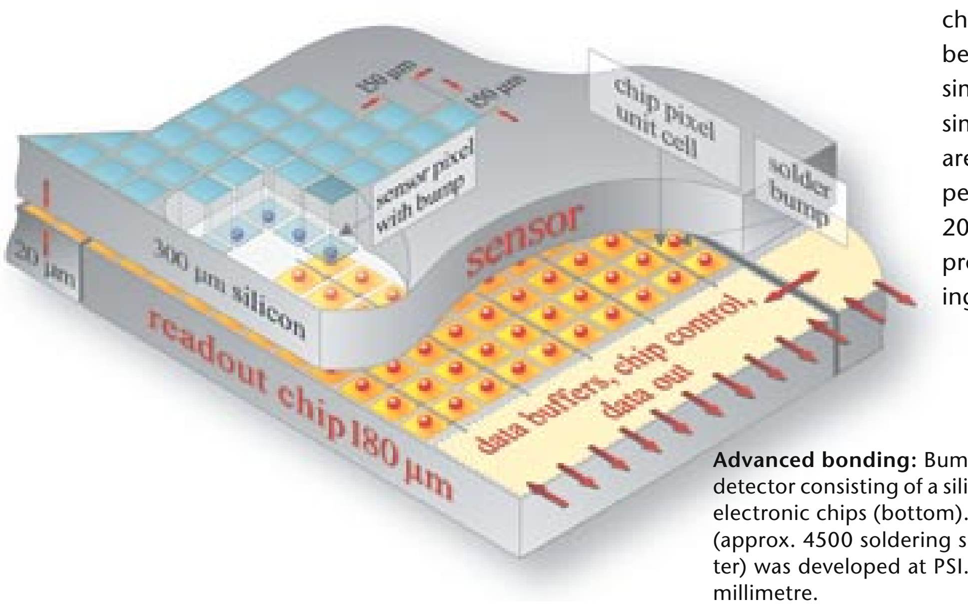
From simulation to reality

The PSI pixel detector consists of thin segmented silicon disk where the hit signals are generated and a complex electronic chip which registers and processes the hit signals (see illustration). We have been concentrating our efforts on this readout chip for the past five years. Its development has been split into a number of stages, from the simulation of the experiment and determination of hit frequencies (in order to dimension the memory on the chip) to the selection of a chip architecture with minimum data loss and the layout of the chip at the transistor level until its manufacture by an external company (see also page 67). The result is a chip with 430,000 transistors on an area measuring just short of one square centimetre (figure on the left).

In summer 2002, a prototype of the chip was tested successfully in a particle beam at PSI. Experimental conditions similar to those expected at CERN were simulated. Some 12,000 of these chips are needed for the detector, which is expected to be ready for operation in 2007. This corresponds to an area of approximately one square metre containing a total of 32 million pixels.



Readout chip: The lower section houses the data memory and control elements along with 40 connection pads. The upper section houses 52 x 53 pixel cells. The cross-section shows the transistor layout of a pair of pixel cells. The signal from the detector pixel is transmitted to the two light coloured areas via soldering spherules.



Advanced bonding: Bump bonding is applied to assemble a pixel detector consisting of a silicon disk segmented into pixels (top), and electronic chips (bottom). The high-density connection technique (approx. 4500 soldering spherules/cm^2; 15 micrometres in diameter) was developed at PSI. 1 micrometre (µm) equals to $^1/_{1000}$ of a millimetre.

New directions in Radiocarbon dating

^{14}C or Radiocarbon method: Based on the radioactive disintegration of the ^{14}C carbon isotope, this method can be used for dating objects between 300 and 40,000 years old.

Units of energy: 1 electron volt (eV) is the unit of energy equal to the work done on an electron accelerated through a potential difference of 1 volt (k: kilo = thousandfold, M: Mega = millionfold).

The Ion Beam Physics Laboratory at PSI is taking the radiocarbon method to a new plane and, as part of a joint venture with the Swiss Federal Institute of Technology in Zurich, has built a novel mass spectrometer.

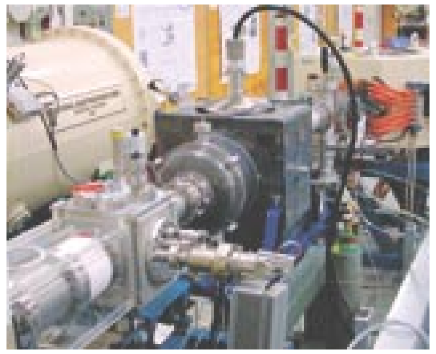
Reliable dating is essential in many research projects in the fields of environmental and natural sciences. Most successful is the C14 method, which is based on the radioactive disintegration of the carbon isotope ^{14}C. Nowadays, the ^{14}C content of a sample is determined using accelerator mass spectrometry (AMS). PSI runs one of the world's best AMS facility together with the Swiss Federal Institute of Technology in Zurich on Hönggerberg.

The very low concentrations of ^{14}C atoms make it extremely difficult to detect radiocarbon. The biggest problem is caused by molecular ions ($^{12}CH_2$, ^{13}CH) whose mass is almost identical to that of ^{14}C atoms. Only one ^{14}C atom exists for every 10 thousand million molecular atoms in the ion beam. In order to release the ^{14}C atoms, the beam is accelerated and penetrates a volume of low gas pressure. In ion-gas collisions electrons are stripped away. Once molecules have lost more than three electrons, they break up and the fragments can be separated easily. However, as it is only efficient to excite these charge states at relatively high energy levels (2 to 3 MeV), the process requires large-scale accelerator facilities.

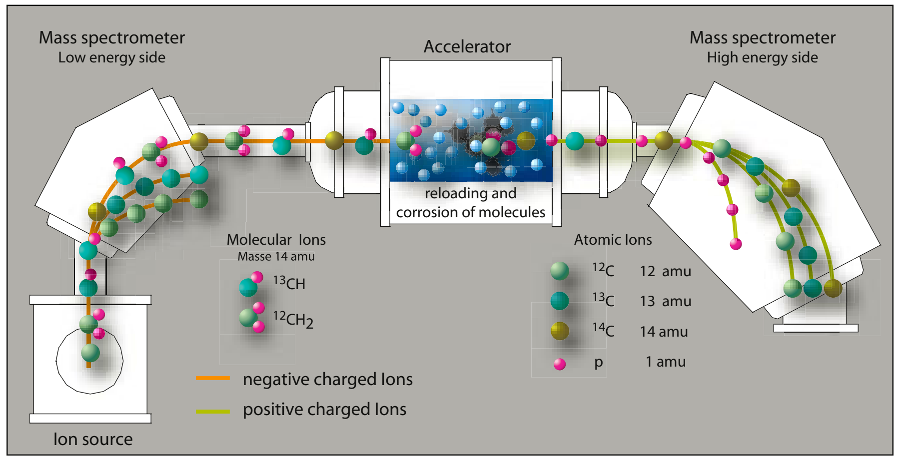
Breaking molecular bonds

It is also possible to break stable binding states of molecular ions with one or two electrons less than the neutral molecule. For this purpose, a mechanism of multi-ion-gas collisions is used, causing exponential decay in the intensity of the molecules. A high-precision dating system has been built based on this principle. The system was developed together with an industrial partner (NEC Wisconsin, USA), who now sells systems based on this design on the open market.

The Ion Beam Physics Laboratory has gone one step further. It has built an accelerator in which the gas stripper is located on a high-voltage platform, which is electrically isolated by a vacuum, making possible a design of a very compact unit. Following successful system tests, initial analyses have already been carried out. The system is currently being developed into a complete dating facility which will open up completely new possibilities for radiocarbon dating.



The new accelerator (central image) in the AMS facility enables radiocarbon dating within smallest space.



Accelerator mass spectrometer: Interfering molecular ions are destroyed in a gas stripper canal. The canal, which is part of the accelerator, charges the ions to high energy levels. Mass spectrometers are used to separate different types of particle for subsequent analysis.

Absolute dedication

Gudrun Goitein

The success of the research carried out at PSI into proton therapy for deep-seated tumours is due to a large extent to the tireless efforts of Gudrun Goitein. Work is now underway to adapt the technique for use in hospitals.

Gudrun Goitein

New technique based on team work

A milestone was reached in the Proton Therapy Division at PSI on January 1st, 2002. This was the date on which the new technique for treating deep-seated tumours became a standard benefit offered by health insurers. Gudrun Goitein had set the ball rolling. "This was a real personal achievement", the 53-year-old says proudly. "Approval of this nature means that we can now continue our research and develop models that are suitable for use in hospitals. The prototype we currently use in our daily experiments is far too complicated."

The use of proton beams to treat tumours has long been practised at PSI. The OPTIS (Ophthalmic Proton Therapy Installation Switzerland) program has been treating eye tumours successfully since 1984. In comparison with conventional X-rays and gamma rays, protons are particularly suitable for use in radiotherapy because they enable the dose to be matched precisely to the shape of the tumour and are less likely to damage healthy tissue. On the basis of this knowledge, a new facility was developed at PSI for treating deep-seated tumours such as those found in the meninges or other areas of the body which are sensitive or would benefit from more precise dosing in radiotherapy.

Gudrun Goitein was involved in this project right from the start. A radio-oncologist, she studied in Cologne, Lübeck and Zurich before joining the Institute in 1989. She had previously undertaken research at PSI as a visitor. She describes the wealth of knowledge she has acquired over the years as her "greatest gain".

Gudrun Goitein is keen to point out the interdisciplinary approach adopted at PSI, without which she feels the new technique would not have been possible. "The technology on which radiotherapy is based really has its basis in physics», she explains. «We, the doctors, simply provide ideas of how we think a technique could eventually be practised on patients. Actually converting these ideas into a project and developing the technique, well, that's down to the physicists." Those of us who are not experts and find this difficult to understand only have to take a look at the proton gantry which directs the bundled proton beams to patients in order to target their tumours – it weighs more than 100 tons. This magnificent invention is the work of PSI physicist Eros Pedroni, without whom, says Gudrun Goitein, the new technique simply would not have been possible.

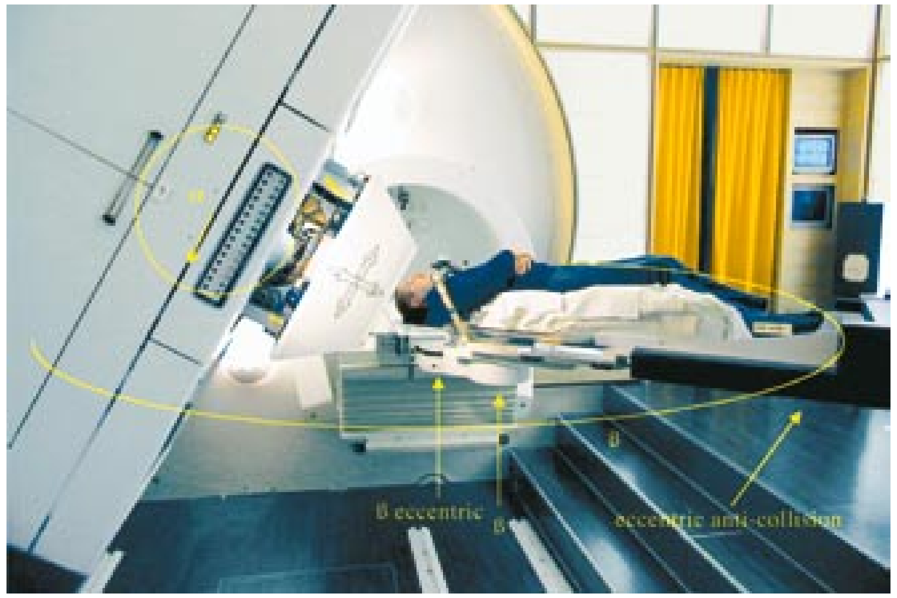
The major part of Gudrun's work involves collecting data by testing the facility on even more patients and driving the project forward for application in hospitals. However, her field of activity covers much more than this. «I'm also responsible for budgeting and administration as well as establishing external contacts. It's rare for me to leave the office on time», she says with a smile. Her primary concern is managing her team, who "all give their best".

Somehow, Gudrun Goiten, who exudes an air that is self-assured yet warm, seems to be a born leader. How can this be? She explains by telling us a story. In her early twenties, before starting her medical studies, she spent several years managing a pharmacy in Cologne. At the time, she was very young for such a responsible post. "But having suddenly been put in charge, I learned from the experience. It's something that has never left me."

Irène Dietschi

Improving quality and reliability still further

Spot scanning technique: This technique, developed at PSI, can be used to precisely adapt the beam dose to the shape of the tumour in all three dimensions.



The new patient table with couch, the three rotation axes (α, β, β eccentric) and the new anti-collision protection.

A new patient table has led to significant improvements of the proton therapy on the gantry.

The proton therapy facility at PSI for deep-seated tumours (gantry) has been in operation since 1997. So far 129 patients have been treated, and the results are very encouraging. It is the only facility in the world on which a dynamic application is used. This application is known as "spot scanning". An increasing number of experts are realizing that this technique is the one most able to compete with the latest developments in conventional radiotherapy.

On the basis of the interest and positive response attested to the therapy facility both inside and outside PSI, we are currently expanding and improving it under the umbrella of the PROSCAN project (see also pages 57 and 61). Gantry 1 was set up between 1992 and 1994 in order to demonstrate the feasibility of the spot scanning technique and will in the future serve as the "workhorse" for the proton therapy program at PSI. However, use of the system showed that technical modifications were needed. It is for this reason that the patient table on gantry 1 was modified during the shutdowns in 2001/2002 (see image).

Irradiation for all parts of the body

The improvements made to the system mechanics mean that it is now possible to irridate the supine patient automatically from several beam directions without changes of support type for left and right treatments. The new system has increased the horizontal rotational range of the patient table, yet the path of the beam remains unobstructed by metallic components and it is still possible to take X-ray images for the purposes of positioning. Irradiation can be applied to any part of the body (the tumour remains constantly centred in the isocentre of the gantry). Experiments carried out on the new system during the 2002 beam period achieved very positive results.

We are also building a new range modulator and making improvements to hardware and software which will further optimize beam control. This will increase the reliability of the components on gantry 1 to levels as high as the new PROSCAN components. These technical advances will also make it possible to carry out new types of treatment and improve the quality of irradiation therapies still further. The main beneficiaries of our efforts will be the patients we treat.

Degenerate proteins as in Alzheimer's

Researchers in the Life Sciences Department at PSI have developed a model system which can be used to investigate molecules in order to gain a better understanding of serious nerve disorders.

Amyloidoses include some of the most feared and most expensive to treat types of illness in the Western World. They are caused by deposits of abnormal proteins, which occur due to incorrect folding. More than 20 human forms of amyloidosis (including Alzheimer's, Parkinson's and Creutzfeldt-Jacob's) caused by the build-up of what are known as amyloid fibres have been discovered so far.

Although major progress has been made in this field of research in recent years, there is still a lack of detailed insight into the molecular mechanisms which cause otherwise healthy proteins to develop degenerate and toxic amyloid fibres (nerve fibres). This knowledge is essential if we are to learn more about the progress of this specific type of disease.

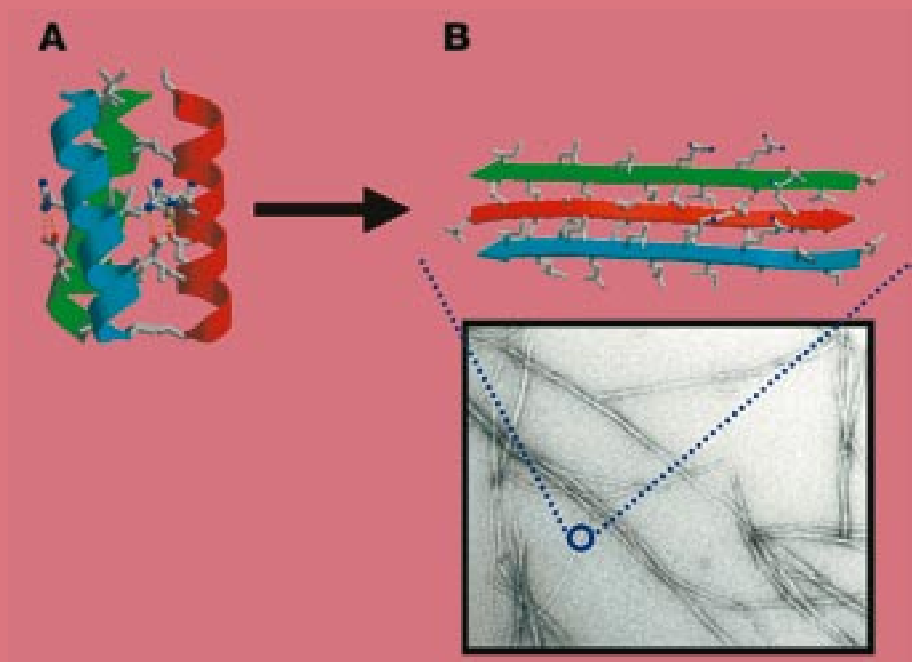
Effects like in pathogenic states

A research team at PSI developed a simplified peptide model system in order to investigate these mechanisms. The system is able to create a mini-protein (Figure A) which can be transformed into amyloid fibres (Figure B). A mutation study was carried out to simulate the effects leading to the development of disease. In particular, it was possible to specifically investigate the time taken for the sample to transform from a healthy state to the degenerate amyloid fibre structure by making minor changes to the peptide sequence.

Structural and biophysical investigations have shown that the build-up of amyloid fibres can be attributed to specific and sequence-dependent intermolecular interactions between polypeptide chains. This discovery is helping us to understand more about mutation-induced amyloidoses.

Amyloidoses describes a group of pathogenic and biochemical heterogeneous diseases in which deposits of abnormal proteins accumulate outside cells. They are often fatal. Types of amyloidosis include Alzheimer's, Parkinson's and Creutzfeldt-Jacob's disease.

Peptide: A small protein molecule providing a simple means of interpreting data. In the PSI peptide model, the molecule comprises a sequence of 17 consecutive amino acids.



Healthy (A): X-ray structure of the peptide model system developed at PSI in its "healthy" form (Figure A). Three helices (red, green, turquoise) have folded to create what is known as an alpha-helical coiled-coil structure. At 4°C, the mini-protein will remain unchanged in this soluble state for a number of days. Dimensions: 2.3x2.7 nanometres (millionth of a millimetre).

Degenerate (B): Electron microscopic image of the peptide system (degenerate amyloid fibre state) and investigative molecular model. At 37°C, the soluble mini-protein will take a matter of hours to change into a beta sheet-based insoluble fibre structure. These amyloid fibres are as complex as those occurring in Alzheimer's. Dimensions of the fibres: approx. 10 nanometres (nm) thick, over 1 micrometre in length.

Using copper nuclides to kill cancers

Ligand: An atom or molecule which is absorbed by the central atom in a higher order chemical compound.

Systemic: Affecting the entire organism.

Becquerel (Bq): Unit of (radio) activity; 1 Becquerel equates to a statistical decay rate of 1 atomic nucleus per second (M: Mega = millionfold, G: Giga = billionfold).

High-resolution positron emission tomography (PET) enables us to accelerate the optimization of the use of Cu-labelled antibodies to diagnose and treat tumours.

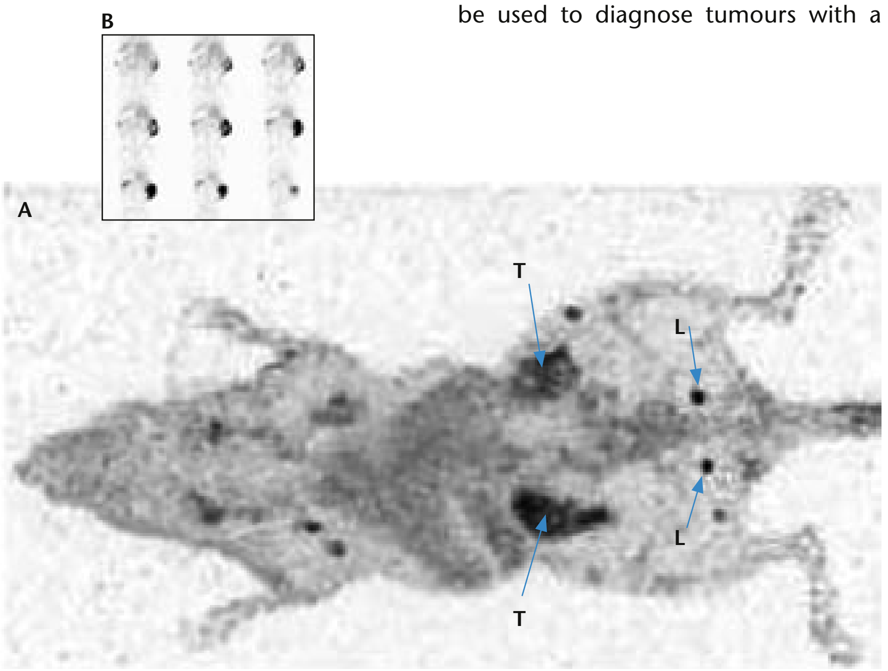
The copper nuclides ^{67}Cu and ^{64}Cu are produced on the PSI ring cyclotron and used in the Center for Radiopharmaceutical Science. These nuclides can be bound with tumour-specific antibodies in order to image (^{67}Cu, ^{64}Cu) and destroy (^{67}Cu) tumours. As part of this process, tumour-specific antibodies are coupled with suitable copper ligands and labelled with the copper nuclides. These antibody conjugates can be used for systemic or local radioimmune diagnosis and treatment.

^{67}Cu is a source of β-rays with a low range of up to 1 mm, which means that it is ideal for destroying small metastases. ^{67}Cu also emits γ-rays, which can be used to diagnose tumours with a γ-camera. The Center for Radiopharmaceutical Science has completed a diagnostic study of the ^{67}Cu-labelled C595 antibody for treating bladder cancer with 12 patients (70 MBq dose) in partnership with the Nottingham University Hospital in the UK and a therapeutic study with an increased dose of up to 1 GBq of ^{67}Cu-C595 is currently underway.

Distribution of radioactivity

Since the PET scanner for imaging small animals became available at PSI, it has been possible to use the ^{64}Cu positron emitter for high-resolution tumour imaging. Unlike imaging with a γ-camera, the PET method has significantly better resolution and supports quantitative data evaluation. The PET image of a mouse provides important information about the exact distribution of radioactivity in the tumours and other organs. The PET method is able to detect radioactivity concentrated in lymph nodes (Figure A). Such small structures cannot be captured with the γ-camera. The level of concentration of the antibodies is, as required, at its highest in the two tumours.

Figure B shows cross-sections of a kidney tumour. Radioactivity is concentrated at the outer edge of the tumour and this uneven distribution may interfere with the efficacy of the treatment. We are now able to use ^{64}Cu PET imaging to track the optimization process of our antibody conjugates. It is now possible to draw conclusions about the exact distribution of the compound in the tumour and in normal tissues.



PET tumour images following the application of ^{64}Cu-labelled antibodies

Figure A: Part of a mouse with two human kidney tumours (T). The concentration of radioactivity is at its highest in the tumours. L: lymph nodes which store the radioactive decomposition products of the antibody.

Figure B: Coronal sections of a kidney tumour measuring 0.9 cm showing the uneven distribution of radioactivity in the tumour, which may interfere with the efficacy of the treatment.

A means of transport for therapeutic radiation

Radionuclide: A type of atom nucleus (nuclide) which emits radiation and thereby changes type.

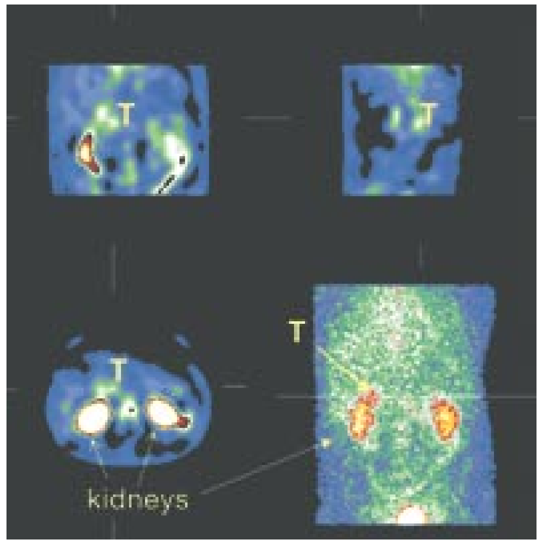
Neurotensin receptor: A protein molecule found on the surface of cells with a structure which can bind neurotensin.

The results of an initial study of patients with pancreatic tumours treated with neurotensin labelled with technetium are encouraging.

For approximately four years, a research group at PSI has been working on the development of neurotensin for diagnosing and treating pancreatic tumours. Following the encouraging results of preclinical trials on cell cultures and animals, initial studies have now been carried out on patients. Although these studies confirm our theory about the potential of neurotensin, we have still not been able to draw a definitive conclusion about the value of the method applied. The number of patients is far too small.

The chances of curing many tumours have significantly increased over recent years, in particular those for which metastases were not developed. However, the prognosis for pancreatic tumours remains poor. Because overexpression of neurotensin receptors is present in approximately 70 % of pancreatic tumours, the chance of a cure should rise if we could find a way of using neurotensin to transport radionuclides in these tumours. Our first task was to prove this hypothesis.

Neurotensin (NT) is a peptide (small protein molecule) comprising 13 amino acids. Amino acids 8 to 13 are important for receptor binding. Because peptides generally are very quickly degraded once they have been injected into the bloodstream, we made some modifications, which increased stability without affecting receptor binding. A ligand was also integrated which is suitable to bind metal ions, thereby permitting labelling with ^{99m}Tc tricarbonyl (technetium compound).



Pancreatic tumour (T): Patient SPET images (SPET = Single Photon Emission Tomography). The compound consisting of a neurotensin analog and ^{99m}Tc tricarbonyl is broken down via the kidneys, therefore showing a high accumulation in this organ.

Labelling method successful

We used a range of 16 compounds (NT analogs) to investigate pharmacological properties in cell cultures and in mice. The properties of one of these compounds were good enough to be reported to the Swiss Federal Office of Public Health (BAG) and clinical trials were started at the Centre Hospitalier Universitaire Vaudois (CHUV) in Switzerland. Once patient activity images (scintigrams) had been created, surgery was carried out after which the tumours were investigated. The investigations showed that whilst there was no (or very little) evidence of receptors in tumours not visible on the scintigram, tumours with high amounts of receptors did appear in the SPET image.

In addition to providing us with proof that our theory was fundamentally correct, this also confirmed that the ^{99m}Tc tricarbonyl labelling method developed and patented at PSI could work in medical practice. Further patient studies are required in order to assess the medical value of the method. In parallel, we are working on labelling with rhenium-188, a radionuclide which emits β-radiation and should make possible the radionuclide therapy of pancreatic tumours.

Scaling great heights

Olivier Auban

In terms of Olivier Auban's work in the PANDA test facility, "physical" has two meanings: in order to test new measuring instruments, he has to climb hundreds of stairs.

When Olivier Auban (30) arrives home after a day's work in the PANDA facility, his knees really know about it. The structure inside the white test building is 25 metres high and has numerous steps and bridges via which test engineers gain access to the individual components. Olivier Auban specializes in measuring instruments. When he is installing a new device, he spends most of his day climbing stairs, chalking up hundreds of metres in the process. Approximately half of his time is dedicated to office-based analyses. "At least I can sit down in here!" the Frenchman laughs.

The world famous PANDA test facility at the Paul Scherrer Institute opened almost ten years ago and where the «passive» cooling of light water reactors is tested. In nuclear power stations, the "afterheat", which is generated by nuclear disintegration following the shutting down of the reactor, is usually dissipated via an "active" cooling system outside of the reactor, for example a cooling tower. PANDA simulates processes in which afterheat is dissipated without active systems. In other words, dissipation takes place via energy that is stored/released internally and can therefore be described as "passive". This approach is both safer and more cost-effective.

It's essential that everything fits together as it should

Olivier Auban, who has been working at PSI since March 2001, says that he very much enjoys working in his internationally assembled five-man team. It is the young physicist's first "real" job. However, he has had to adapt his methodology. «During my studies I became used to working on small-scale experiments – I was able to repeat a test 25 or 30 times. At the PANDA facility, however, things take place on an infinitely bigger scale. An experiment is worked on in minute detail for months. There's no margin for error – it's essential that everything fits together as it should." There is also a high level of individual responsibility within the team – if one engineer makes a mistake, it affects the whole team. "Having said that, the flip side of the coin is that success is shared and we are able to motivate one another, which is great."

Olivier Auban comes from Toulouse in France, where he studied physics. His doctoral thesis took him to Nancy and his first job was in Paris. However, he found that the hectic pace of life in the big city wasn't to his liking. "When I happened across the advertisement for the job here at PSI I applied straightaway." Although Villigen is ten hours' drive from his home town, Olivier feels very much at home here – not least because of the close proximity of the Swiss Alps. He often spends weekends there skiing or climbing – mountains this time, rather than stairs!

Irène Dietschi

Tracing fatigue degradation

Austenite: A specific solid solution structure, part of the iron/carbon system (named after the English researcher Sir William Chandler Roberts-Austen).

Martensite: A microstructure of iron and carbon that is typically produced when steel hardens (named after the German engineer Adolf Martens).

Non-destructive methods have been developed to detect the very early stages of fatigue degradation. Fatigue damage of nuclear materials can affect operational life of nuclear power plant components.

The Component Safety Group at PSI has been investigating changes in the microstructural and magnetic characteristics which can occur under certain power plant transients at piping and nozzles. The long-term goal of the investigations is to develop a lifetime monitoring technique for pipelines.

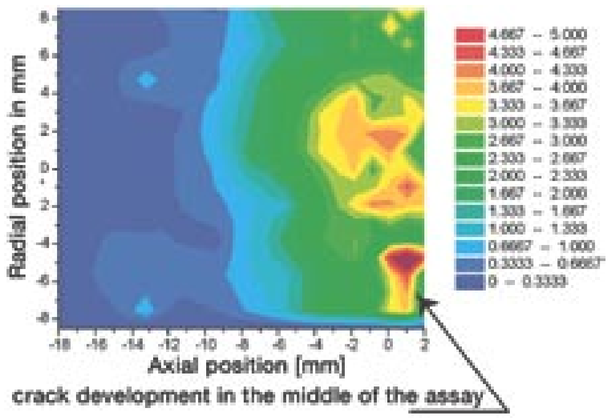
The method developed by PSI is the first non-destructive approach to assessing the material state of components in industrial applications. The non-destructive material inspection focuses on identifying macroscopic material flaws, in particular cracks. Prior to cracks appearing, changes occur in the microstructure of the steel, and under certain circumstances, these changes can lead to the early detection of material damage. That is why this method of diagnosing materials is specializing in investigating the relationships between microstructural, mechanical and physical characteristics.

A high-precision sensor measures strains at the fatigue sample. The formation of martensite, an indicator of fatigue, is checked as part of this process.

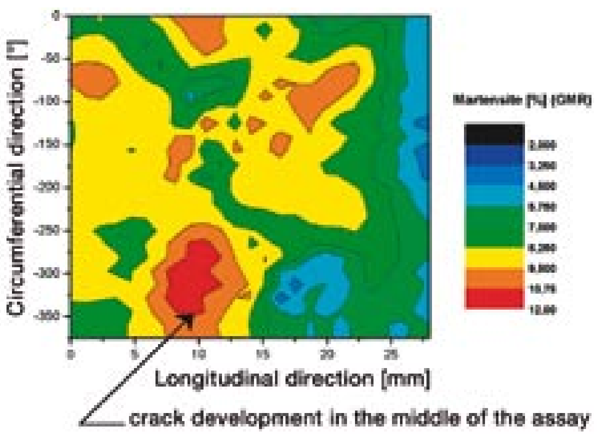
Martensite as an indicator of fatigue

It has been shown that for the material and test conditions investigated, the incidence of deformation-induced martensite can be interpreted as a sign of fatigue. When placed under load, the structure of the austenite in these steels partially changes into martensite. The incidence of transformed martensite can be used to measure the extent of the fatigue damage.

Neutron scattering techniques were used in the SINQ at PSI to develop a method for precisely determining martensite content. Investigations using X-ray scattering techniques (synchrotron light) were carried out to ascertain the incidence of martensite on the surface of the material samples. The investigations showed that under certain restrictions, it is possible to apply non-destructive magnetic test methods to detect fatigue in its earliest stages.



X-ray scattering (synchrotron light): Incidence of martensite on the longitudinal section of a fatigue sample with evidence of cracking. The areas marked in red indicate high concentrations of martensite (the area around the crack contains the highest levels of martensite).



High-tech magnetic measuring technique: A type of magnetic card on the surface of a fatigue sample with evidence of cracking. The image shows eddy current impedance measurements (GMR sensor) on the surface of a fatigue sample. Here too, the highest concentrations of martensite were also evident around the technical crack.

Trapping fission products as aerosols

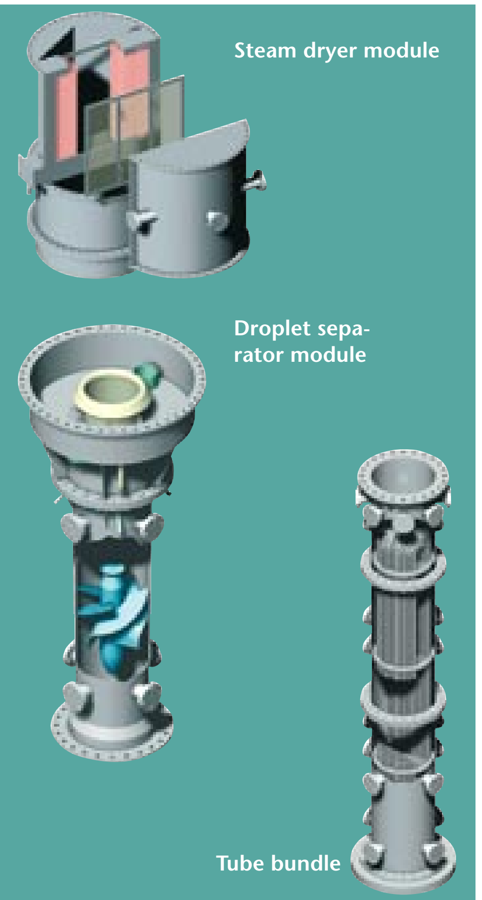
An international research project has been launched at PSI to find out more about accident management in pressurized water reactors and therefore increase safety.

In spite of significant improvements in the design, material selection, manufacture and operation of steam generators in pressurized water reactors (PWR), accidents are still happening all over the world, for example as the result of a leak or even a break in one of the more than 3000 heating tubes in the steam generator (SGTR: **S**team **G**enerator **T**ube **R**upture). Now more than ever, SGTR processes are becoming the subject of increasing scrutiny as part of safety analyses.

PWR risk studies cite the occurrence of an STGR in conjunction with another type of fault as a fatal combination. Possible scenarios include one or more SGTR occurring at the same time as a design-basis accident resulting in a coolant leak or even a serious accident, which could lead to the melting of the reactor core. Although the probability of a serious accident occurring at the same time as an SGTR is minute, given the lack of recorded data, even a conservative estimate would consider the possible consequences to be devastating. It is entirely conceivable that in the event of such an incident, radioactive fission products could escape directly into the nuclear power station itself. In Switzerland, the plants at Beznau and Gösgen are fitted with PWR.

International interest in the project

To help reduce uncertainties relating to SGTR, an experimental project, ARTIST (**A**e**R**osol **T**rapping **I**n a **S**team Genera**T**or) has been initiated at PSI. The experimental investigations aim to provide measurement data and to simulate the physical conditions for trapping fission products in the form of aerosol particles and droplets in the various components of a steam generator (filter effect) under similar conditions as those in a nuclear power station.

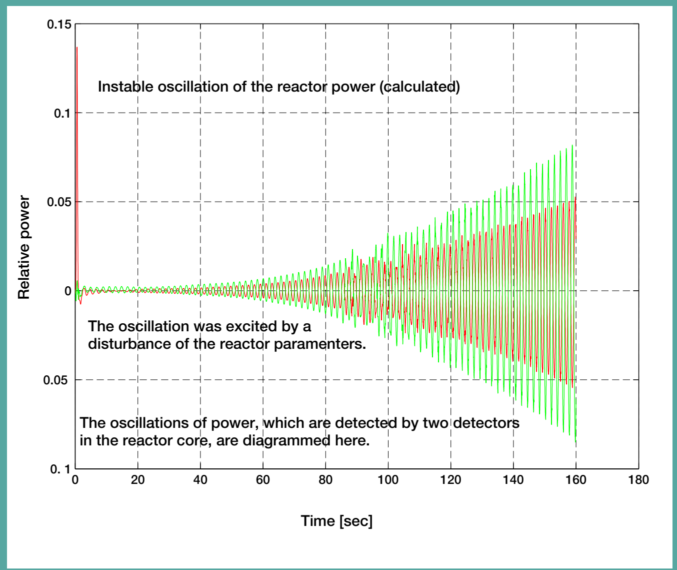


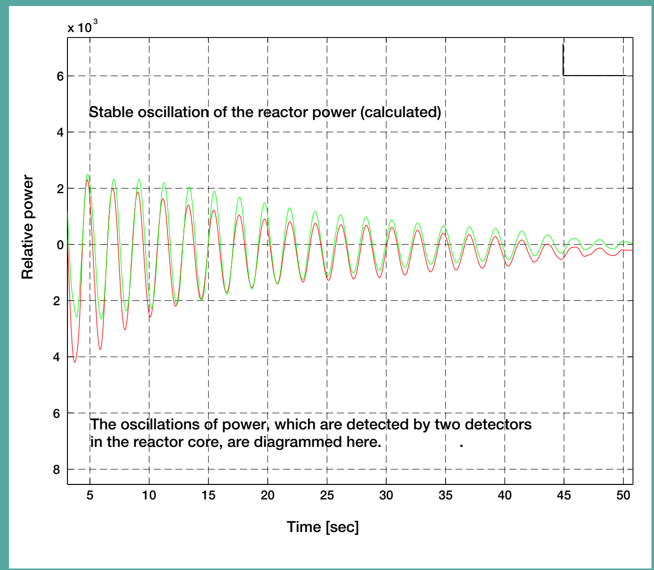
Reality and model: A real steam generator (on the left) in a pressurized water reactor is simulated in ARTIST with a tube bundle (270 heating tubes) along with one prototype droplet separator and one steam dryer module (on the right).

ARTIST has aroused a great deal of interest in research institutes, nuclear power operators and regulatory authorities all over the world. Over the past two years, PSI has been able to set up a consortium in partnership with 11 organizations from Europe, Japan and the USA. The consortium aims to produce realistic models of potential accidents and to use the results of their investigations to develop physical models and validate accident codes for safety analyses. Eventually, the insights gained will be used to develop, test and improve emergency procedures and guidelines for accident management in the event of SGTR. ARTIST starts in January 2003 and will run until the end of 2007.

Unwanted power oscillations

Simulation of power oscillations: On the left diagram the BWR is operating in an unstable point, on the right one in a stable point. The power oscillations are excited by a perturbation of the reactor power and detected by the in-core neutron flux detectors (simulated in the system code).





Models and experiments are being used to investigate the stability characteristics of boiling water reactors.

Boiling water reactors (BWRs) are nonlinear dynamic systems primarily because of internal feedback processes. In Switzerland, the nuclear power stations at Mühleberg and Leibstadt are fitted with boiling water reactors. The many ways in which the equations used to describe the physics of these types of system can be solved include both stable and unstable oscillatory solutions which can be proven in experiments. In order to operate boiling water reactors safely and cost-effectively, we must have an exact as possible understanding of the stability limits.

BWRs are reactors with light water cooling, whereby the coolant is allowed to boil in the reactor. Because the water also acts as a neutron moderator (it slows down the high-energy neutrons which occur during nuclear fission in thermal reactors to thermal energies), the generation of steam has a significant effect on the multiplication characteristics of the reactor core and therefore on the dynamic behaviour of the reactor power. As a consequence, the dominant feedback parameter, which determines the stability characteristics of the dynamic BWR system, depends on the steam content.

Experiment and calculation

Unstable power oscillations need to be avoided both from safety and plant operation point of view. Avoidance of them requires as detailed knowledge as possible of an area in the operational characteristic of the BWR in which these oscillations are likely to occur. The instability range is then calculated by means of experiment and computation by analysing the stability characteristics of a number of operating points on what is assumed to be the edge of the area and set as a conservative exclusion area in the operational characteristic.

Due to the level of complexity, experiments and calculations with system codes which can be used to simulate the dynamic behaviour of these facilities are only carried out for a small number of operating points. In order to obtain more detailed data relating to the mathematic characteristics of the stability limits and to gain a better understanding of the physical processes which determine the stability characteristics, simplified SWR models are being developed to simulate the physical processes in the reactor with an appropriate degree of detail. A model of this type has been developed as part of a doctoral thesis at PSI.

The latest coded chemical knowledge

Thanks to an extensive collection of chemical numerical values, it is now possible to predict the low solubilities of radioactive waste materials with constantly improving precision because the quality of the data provided by PSI researchers is getting better all the time.

Radiation in radioactive waste from power generation, medicine, industry and research can pose a risk to the human environment if it is not processed correctly. Therefore present concepts foresee to dispose these waste in deep geological formations where they remain isolated from the human environment for very long periods. The radioactive elements in the waste decay during the long isolation. Numerous natural and technical barriers and processes help to retain the buried waste materials deep underground.

One of these retention processes relies on the dissolution of chemical elements at lowest possible levels of concentration in the interstitial waters of waste matrices and surrounding host rock. Minimizing the amount of waste dissolved also reduces the levels of radioactivity which are able to penetrate the human environment through groundwaters.

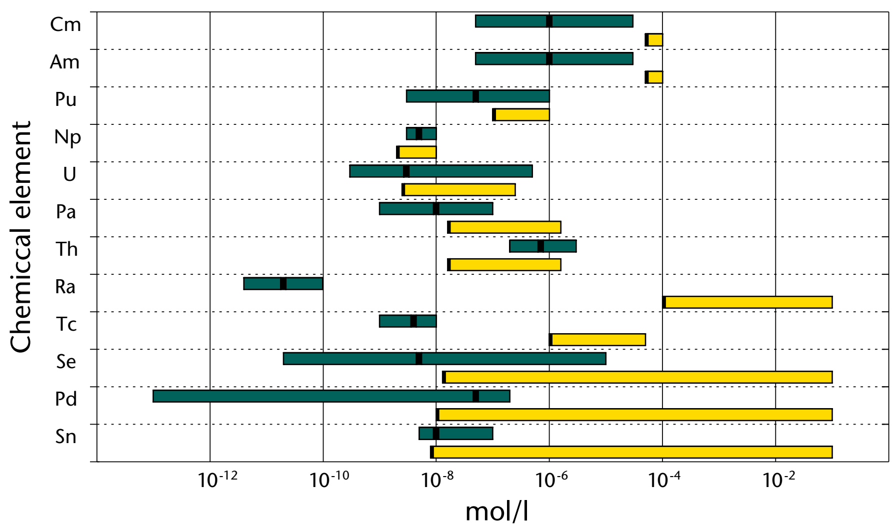
Generally accepted principles

A research group at PSI is building what are known as thermodynamic databases for the chemical elements involved in these processes. The databases are collections of basic numerical values which summarize quantitatively – encode, so to speak – the latest chemical data. This coding provides a reliable means of modelling the low solubility of stored elements even for chemical systems which cannot be accessed experimentally, e.g. for a waste repository. Such predictions are possible because the basic thermodynamic principles are generally valid.

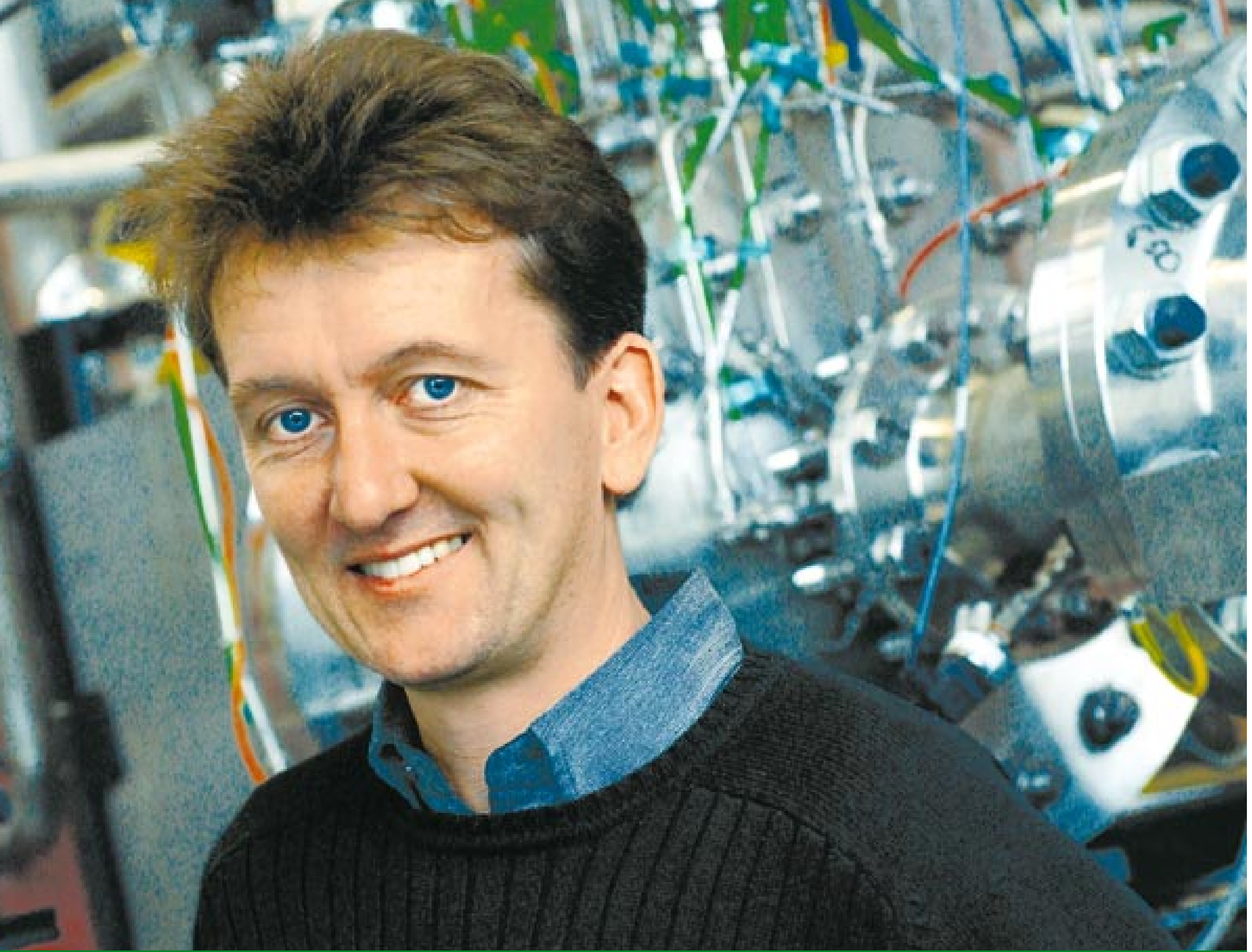
The figure illustrates the progress made by PSI researchers in this field. It shows the solubilities and uncertainty ranges of safety-relevant chemical elements in a high-level waste repository. The calculations are based on the interstitial water of bentonite (a clay-rich backfill material). Future research into the field of thermodynamic databases intends to reduce levels of uncertainty still further.

The conventional unit for expressing concentration, mol/l, is equal to 6.023×10^{23} particles, dissolved in 1 litre of water. By way of comparison, sea water contains approx 0.5 mol/l common salt, our gastric juices up to 0.1 mol/l hydrochloric acid and tap water 0.000'000'003 (3×10^{-9}) mol/l dissolved uranium.

Curium (Cm)
Americium (Am)
Plutonium (Pu)
Neptunium (Np)
Uranium (U)
Protactinium (Pa)
Thorium (Th)
Radium (Ra)
Technetium (Tc)
Selenium (Se)
Palladium (Pd)
Tin (Sn)



Progress made by PSI scientists in waste disposal research: The bars illustrate the uncertainty ranges of elements solubilities in a repository. Previous findings appear in yellow (the "Gewähr" project carried out in 1985 by NAGRA, the Swiss National Cooperative for the Disposal of Radioactive Waste). The latest information (Project Opalinus Clay, 2002) is shown in green. Future research intends to reduce levels of uncertainty (size of bar) still further.



Undaunted by the limelight

Felix Büchi

He travels to work by train and bicycle and is highly critical of those who travel by car. However, this doesn't prevent PSI's fuel cell system expert from lending his support to the technology of the future for our roads. He's keen to point out that he's an idealist.

Not only research reports but also prototypes

Felix Büchi's battered aluminium briefcase doesn't contain the tools and measuring instruments you might expect for a man working on the car of the future. Instead, it protects his laptop on his travels. The fuel cell specialist does a great deal of travelling – more, in fact, than he would like. For example, he spent 50 days away from home last year. His trips included a lecture tour of South Korea, regular visits to development partners at home and abroad and a conference in the USA.

The frequency of his travels is very much due to the increasing publicity Büchi's field of research is enjoying. Last year, for example, a VW Bora fitted with fuel cells by PSI met with avid public interest. In the endurance test carried out during the winter, the hydrogen-powered car conquered the Simplon Pass and subsequently made a much celebrated appearance at the motor show in Geneva. However, fame has its downsides: expectations of researchers are sky high and the pressure to succeed is constantly increasing.

"Fuel cells will not solve the energy problems of the future." Felix Büchi thinks carefully before justifying his statement: "Although the cells themselves are not the solution, they can help to build a system based on renewable energies." When we will see fuel cell cars rolling off standard production lines in the future remains in the lap of the gods.

Felix Büchi spends very little time in the laboratory. The electrochemist, who joined PSI in 1991 as part of a small team developing new membranes for fuel cells having completed research posts in Australia and Texas, now finds himself doing the job of a research manager. He organizes, coordinates and establishes contact with new partners. However, Büchi's enthusiasm for his work has remained unchanged. "I'm fascinated by the numerous different fields of research which this technology combines – from chemistry to materials research and mechanics and even control electronics. Success depends on our ability to integrate all these disciplines."

There's something else motivating Felix Büchi. If all goes according to plan, Büchi intends to produce not only research reports but also prototypes. The PowerPac project is working towards a portable fuel-cell-based current generator. The possible areas of application, which include alpine huts, light electric vehicles and even street entertainment, are limitless.

The fuel cell applications worked on in the Electrochemical Laboratory are not only based on basic research but also tackle specific practical problems. "Sometimes, if we are short of time, we have to find solutions at any price, even if this means taking an approach that we won't subsequently be able to reapply." A flaw, it seems, that Felix Büchi is perfectly happy to live with.

Kaspar Meuli

Fuel cell stability

Durability test for membranes

Durable: The fuel cell membrane can achieve an equivalent service life of 200,000 km at an average speed of 50 km/h, based on a laboratory longevity test.

Fully operational for 4,000 hours: the result is a major achievement in the development of cost-effective polymer membranes.

A proton-conducting polymer membrane with surface coatings of electrocatalytic active particles is the essential electrochemical component of a polymer electrolyte fuel cell. This type of cell is of particular interest for the direct electrochemical energy conversion of hydrogen into electricity in a variety of applications, e.g. for hydrogen-powered electric vehicles like the VW Bora HY.POWER which has been developed as part of a project at PSI (see page 81).

If the technology is to be a commercial success, the costs must be reduced significantly. For a number of years, PSI has been working on a method to simplify and thus make more cost-effective the process stages and in particular the chemistry of membrane production. This requires compromises in terms of the stability of the membrane. Recent laboratory tests demonstrated that membranes at the required operating temperatures for vehicles (80°C) can remain stable in the fuel cell for more than 4,000 hours – a major achievement.

Lithium-ion batteries

High current increases power

More than ten years of research in the field of batteries at PSI contribute to the material selection: Graphite is best suited for high currents.

For their intended application in vehicles (as starter batteries and 42 V board batteries) and for hybrid and fuel cell vehicles, large lithium-ion batteries must have a high current rate capability. This means that all battery components must be optimized. PSI is carrying out a collaboration with TIMCAL, canton of Ticino, Switzerland, to improve graphite electrodes. A PSI research team has designed a specific method to measure the suitability of graphite electrodes at high currents.

The current rate capability test comprises a series of selected current intensities at which test cells are charged and discharged. The result: Thin graphite electrodes (50 to 80 μm) are capable of discharge rates above 10 C, i.e. the entire charge can be withdrawn within 6 minutes. The result corresponds to a tenfold increase in rate capability compared to the state of the art. Charge losses in this type of graphite electrodes are low, confirming the well-known excellent stability. The best C-rates achieved on discharging were 12, still providing 80 % of the maximum charge.

C-rate: Value expressing the rate of charging (or discharging) of a battery. At a C-rate of 1, a cell will discharge its nominal capacity in one hour. At a C-rate of 10, it will take 6 minutes.

The graphite's journey from powder (front) via electrode manufacture to the cells for the electrochemical investigations (rear).

Diagnostics for fuel cells

Getting to the origin of and improving weak points

A number of measuring techniques have been applied to identify the crucial electrochemical variables of the energy converter.

The polymer electrolyte fuel cell is a key technology for efficient and sustainable power generation and is particularly suitable for applications in transportation. In order to make the technology ready for market launch, it is essential to be able to determine the factors restricting performance in a selected operating state so that we can find an efficient and targeted means of improving the fuel cell's weak points.

The equipment and technical expertise available at PSI provide the basis for a combination of a variety of measurement methods which are unique the world over and can be applied to unlock the secrets of the fundamental processes of the fuel cell. For example, neutron radiography on the spallation neutron source (SINQ) has shown how liquids and gases are distributed locally in bipolar plates. Conclusions about how these distribution elements work can be drawn by means of comparison with power generated locally. We can also specifically stimulate the fuel cell from a stationary state in order to analyse its reaction. This enables us to identify the performance-limiting processes in the system. In addition to impedance spectroscopy, a high-precision current pulse measuring system developed by electronics specialists at PSI is also used.

Fuel cell research at PSI (photo H. R. Bramaz).

High-temperature solar technology

A novel reflectometer

Integrating sphere: A hollow sphere having a highly reflecting inside surface used as a device to collect, with very high efficiency, light scattered or emitted from a sample contained in it or located outside and near one of the ports. Small ports allow the entrance of light and access to a detector.

A special device is measuring the reflectivity of materials and is helping us to develop solar reactors.

PSI is investigating a number of different chemical reactions and developing solar reactors for converting concentrated sunlight into storable and transportable fuels. In order to design and model these reactors and carry out non-contact high-temperature measurements, it is essential to find out how the reactive materials and construction materials reflect to light at high temperatures. Reflectivity, one of the physical properties describing this interaction, can be also a useful parameter for remote monitoring of chemical reactions.

PSI has developed a new method for measuring reflectivity. In a device developed specifically for this purpose, collimated white light is directed onto a sample placed in an integrating sphere, the reflected light is collected by an optical fibre, sent to a spectrograph and recorded with an ICCD camera. The signal from the sample is then compared with that of a reference material. The process enables the simultaneous measurement of reflectivity within a wide, continuous wavelength range (currently 510 to 860 nm). At present, measurements can be carried out at temperatures of up to 930°C (1200 K) in a variety of atmospheres.

The PSI reflectometer: By directing white light onto the sample (in the metal container) from the top left we can draw conclusions about its reflectivity.

Combustion research

Three times less nitrogen oxide than before

ppmv (parts per million volume): One volume part in a million, a measure of concentration

Catalytically stabilized combustion (CST) is providing a means of drastically reducing NO_x emissions in stationary gas turbines. At PSI, numerical models are being developed and tested under experimental conditions for dimensioning in gas turbine combustion chambers.

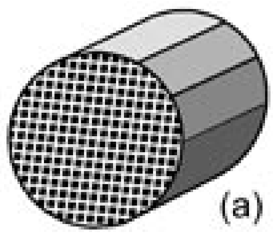
CST technology has made it possible to cut nitrogen oxide emissions (NO_x) in gas turbines to values at least three times lower (<3 ppmv) than were possible using previous methods. Current efforts are focussing on its application in larger gas turbines (> 20 MW) and understanding the underlying reaction kinetics.

In recent years, the trend for environmentally friendly energy production (without NO_x and CO_2 emissions) has increased. In some areas, legislation is targeting NO_x emissions in stationary gas turbines of less than 3 ppmv. Unlike other technologies for the aftertreatment of NO_x, CST is able to meet these requirements and minimize the costs incurred.

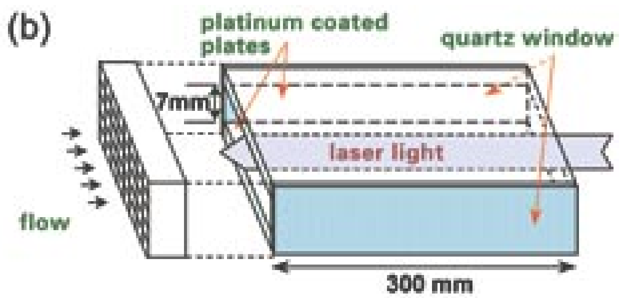
Exclusive software for simulations

Figure (a) shows a commercial catalytic converter comprising a multitude of catalytically coated channels. However, it cannot be used to investigate combustion processes in an individual channel. For this reason PSI has developed an optically accessible catalytic reactor for high-pressure measurements which is the only one of its kind in the world (Figure b). Laser diagnostics can be used for spatially resolved measurements of chemical components and temperature and the data collected can be compared with calculations. For this purpose, a software program, of which there are only two comparable ones in the world, has been developed at PSI. The aim of the comparison is to validate various reaction mechanisms under relevant gas turbine operating conditions.

In the figure below, the measured and calculated distribution of the OH radical inside the channel is compared for a methane/air feed on platinum coated plates at a pressure of 3 bar. The good correlation between data and simulation shows that the numerical model can be used to calculate the ignition point of the gas phase combustion for CST. The validated model can now be used to design a honeycomb catalytic converter (as in Figure a) in order to avoid ignition of the gas phase within the catalytic converter.

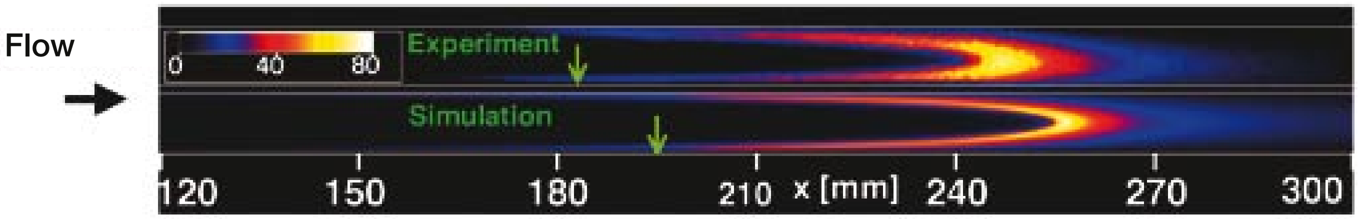


Commercial: Honeycomb catalytic converter for gas turbines.



The only one of its kind in the world: The optically accessible catalytic reactor developed at PSI.

Experiment and simulation: The correlation between the measured (top) and calculated (bottom) distribution (in ppmv) of the OH radical in the catalytic converter is good. The arrows indicate the ignition point of combustion in the gas phase.



CO_2 in the biosphere

More carbon dioxide and what it means

Research of the CO_2 problem with stable isotopes at PSI is constantly leading to new insights in processes of the ecosystem.

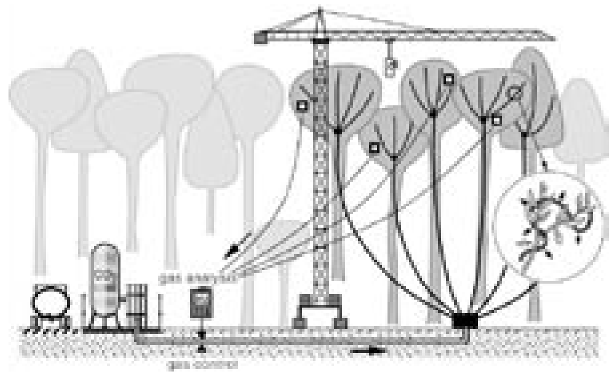
Together with the greenhouse effect, the increase in CO_2 of the atmosphere is having a sustained effect on metabolic processes in the biosphere. The fact that an increase in CO_2 concentration stimulates growth in plants may have encouraged the belief that the vegetation compensates for the increase in the amount of CO_2 in the air. This apparently logical conclusion leaves a whole range of questions unanswered. Researchers at PSI and Basel University are working together within the framework of the Swiss Canopy Crane Project (lead: Prof. Ch. Körner, Basel Univ.) to identify where and in what format the additional bound CO_2 is stored.

The best way to answer these questions is by analysing stable isotopes. Adding artificial CO_2 exposes the tree canopies to increased CO_2 levels of 550 ppmv (parts per million volume). Artificial carbon dioxide contains significantly less ^{13}C than carbon dioxide in the air. The stable, heavier and naturally occurring carbon isotope is therefore ideal for use as a tracer. The heavier oxygen isotope ^{18}O is ideal for investigating the hydrological regime.

Initial results show that an increase in CO_2

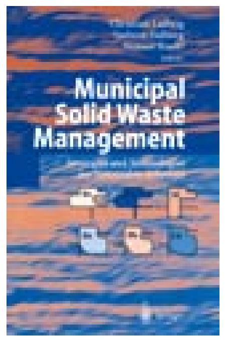
- transports the carbohydrate generated by trees much more quickly and in greater volumes than previously suspected to the soil, where most of it is released through the roots and micro organisms, thereby indicating that soils are much less effective carbon sinks than previously postulated;
- changes the quantitative shares of various wood components, which is presumably reflected in wood quality;
- reduces the opening of the foliage pores (stomata), thereby restricting transpiration. This increases the soil moisture content and, as a consequence, alters the micro organism population in the soil and with it the decay processes.

Artificial carbon dioxide (CO_2) being distributed with irrigation hoses (approx. 2 tonnes per day). Infrared gas analysers monitor CO_2 levels and a computer-controlled valve system assures a setpoint of 550 ppmv. A pod attached to a crane provides researchers with unrestricted access to the forest canopy (small image).



Waste management

Coping with refuse



Experience gained at PSI over many years about strategies and technologies for sustainable solutions have now been published in book format.

Municipal waste levels are at an all-time high. In Switzerland, we currently produce a total of 2.6 million tonnes every year. However, waste deposits heaps are not just increasing in size, they are becoming more toxic. For example, filter ashes from domestic waste incinerators contain a variety of heavy metals. Our local and global environment is very much affected by the ways in which we treat waste. New technologies could be applied to recover raw materials from waste and make use of the energy stored in waste for generating heat and power. Toxic residues would disappear.

The available technical/ecological options, social acceptance and the economic situation determine the conditions for implementing new technologies. Supported by the Swiss National Science Foundation in collaboration with industry, authorities and international experts, researchers at PSI have spent more than a decade taking up the challenges of waste management. The discoveries made have now been published by Springer-Verlag in a book entitled “Municipal Solid Waste Management – Strategies and Technologies for Sustainable Solutions”.

The User Lab

About People & Machines

Development of the PSI User Lab

Portraits & Projects connected with the Research Facilities

The vacuum laboratory ▶

Attracting attention from all over the world

Spallation: Spallation describes the process in which neutrons are created due to a collision between protons and elements rich in neutrons (uranium, lead).

Leptons & Quarks: The most fundamental building blocks of matter, according to present knowledge.

Nano science, nano technology deals with objects measured in nanometres (nm). One nanometre is equal to one millionth of a millimetre (10^{-9} m).

As a user laboratory, PSI allows researchers from universities and industry to use its facilities for their experiments. The facilities available were further extended in the year under review and will continue to increase in significance in the future.

Strategic decisions imply that elementary physics at PSI will be reduced slightly and muon research (SμS) will remain about the same, use of the neutron source (SINQ) and above all the Swiss Light Source (SLS) is set to increase considerably (see graphic page 88). Each research facility provides numerous experimental equipments, which can be used simultaneously. Some of these cannot be found anywhere else in the world. This has led not only to an increase in the quantitative significance of PSI as a user laboratory, but also to the enhancement of the quality of research carried out in PSI facilities to amongst the best in the world. Factors contributing to this success are the thorough work of the PSI Research Commission, Department Advisory Committees and regular expert assessments, which are also known as audits.

SμS: Muon spin resonance.

SLS beamlines under construction

When the SLS was commissioned in 2001, PSI obtained both a gigantic X-ray tube and a huge microscope. Synchrotron light is sharply focussed electromagnetic radiation which is emitted by electrons flying close to the velocity of light. It is used to investigate new types of materials and biomolecules as well as microstructures and nanostructures. The insight gained into microscopic characteristics leads to real progress, for example in semi-conductor technology, high temperature superconductivity, magnetic data storage and the rational design of drugs or materials used in energy and environmental research. Demand for synchrotron light is high, which is why a number of new beamlines are currently under construction (page 48).

A proton accelerator has been in operation at PSI for more than 20 years. Thanks to continuous development, it is the one with the highest average beam power in the world. Research groups use the proton beam for experiments in fields of elementary particles, condensed matter and materials research, furthermore it is also used for projects in the medical field such as tumour therapy. The remaining, high-intensity proton beam is directed onto the Spallation Neutron Source, SINQ. There, the protons are directed onto a lead target at high velocity. The protons colliding with the lead nuclei cause them to become highly excited and internal energy is released primarily by "evaporating" neutrons; these are known as spallation neutrons. In contrast to nuclear fission, spallation does not result in a chain reaction.

SLS: Swiss Light Source.

A successful working year for the SINQ

The SINQ, with its nine instruments, enjoyed a very successful working year in 2002. The tenth instrument, POLDI, was commissioned in November (page 62). Interest has increased significantly – in fact, numbers have reached record levels – since the facility was granted financial support (approx. 2.8 million Swiss francs for the SINQ and SμS) under the EU's fifth framework programme. A total of 315 experiments were carried out at the nine instruments on approximately 4,600 user days. 280 users were recorded, almost 60 % of whom came from Switzerland. International users came from 21 different countries, primarily Germany, Denmark and Britain. A survey carried out in autumn 2002 recorded high levels of user satisfaction, with instrument quality and technical support being the most impressive features on offer.

Experiments in Particle Physics

High intenisity secondary beams of pions and muons produced by the primary proton beam are used to perform various particle physics experiments. These particle beams are among the best in the world, attracting research groups not only from all over Europe, but also from the US and Japan. Pions are the lightest members of the class of mesons, composed of quark/antiquark pairs. Muons belong to the class of leptons, and are like electrons, but about 200 times heavier. Both pions and muons are unstable particles and decay. The high precision experiments at PSI using dedicated detectors concentrate on very rare reaction and decay modes, which might signal new effects not seen so far and could lead to a revision of the basic theory of elementary particle physics. A strong beam of cold polarized neutrons derived from SINQ is used to study subtle effects in the decay of free neutrons.

SINQ: Spallation Neutron Source.

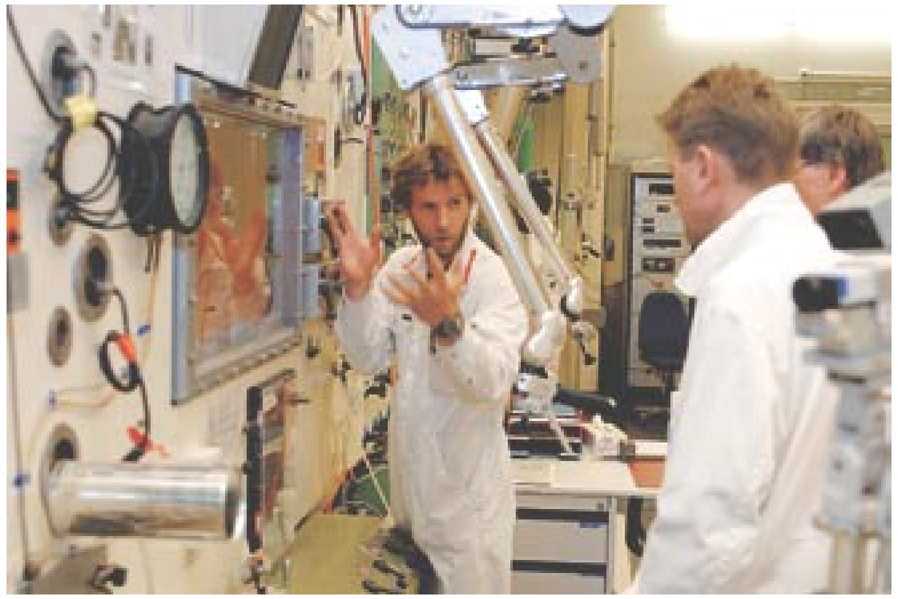
Six instruments with muons

Muons are short-lived elementary particles belonging to the family of leptons, similar to but much heavier than electrons. Implanted into a material, these tiny magnetic gyroscopes probe the internal, local magnetic fields with high precision. By virtue of their electrical charge, they are very sensitive probes of structural defects in crystals and impurities in materials. PSI can provide six different instruments for research with muons generated with the ring accelerator – among them the low energy muon beam, which was developed in-house and is the only instrument of its kind in the world. It can be used to implant muons at very small and controllable depths (from a few to a few hundred nanometres) below the surface of a specimen, thus making a wealth of new applications available.

Renovated Hotlab

PSI Hotlab is used for applied materials research into highly radioactive specimens and research into waste disposal. The specimens originate primarily from reactor cores in Swiss nuclear power stations and from research reactors, the SINQ and the ring accelerator at PSI. The Hotlab was renovated and refurbished before being put back into full operation in May 2002 (page 50).

Hotlab.



Turning up the brights

Leonid Rivkin

Lenny Rivkin calls himself a machine builder. Preferably big machines. So being part of the team that designed PSI's state-of-the-art synchrotron light source gave him a chance to do what he likes best.

Like cathedral building

Leonid Rivkin grew up in Odessa, a port city of 1 million people on the Black Sea. In the summer, he says, the climate is so wonderful that friends and relatives would start writing in April to warn of impending visits. In addition to the influence of his father, who is an engineer, Rivkin credits two very unusual teachers with stimulating his interest in mathematics and physics. By high school, he was taking part in international science competitions.

In 1975 Rivkin's family moved to Boston, and he entered Harvard University as an undergraduate student. Attracted early on by accelerator physics, he went to the California Institute of Technology for graduate school, but admits that he spent most of his time at Stanford University working on the Stanford Linear Collider. He was also part of the Large Electron-Positron collider project at CERN, in Geneva, before arriving at PSI 13 years ago.

Rivkin was delighted to get in on the SLS from scratch. Synchrotron light is an amazing phenomenon, he says: a process of bending and kicking electrons, making them "so angry that they start emitting light". When it was first discovered, such light was considered a nuisance. But today scientists use synchrotron radiation – a million times more brilliant than the sun – to unlock the structure of life, probe the character of materials, and decide the authenticity of works of art.

Along with others, Rivkin's job was to design the major components of the SLS, including the electron injector and the storage ring. From the beginning, the team was unanimous in wanting to design and build a state-of-the-art light source that would surpass existing machines in brightness and stability, meet the needs of Swiss users, and do it all in time and within budget.

That's no small challenge. But building an accelerator is no ordinary undertaking. Rivkin likens it to medieval cathedral building in that it takes many years and relies on a close-knit community of "artisans" with a very strong oral tradition. Indeed, throughout the design stage the team had extensive exchanges with colleagues worldwide, which allowed them to capitalize on existing expertise and know-how.

The approach paid off. The SLS was first turned on in late December 2000 and worked right away. "It was a fantastic Christmas present", says Rivkin, who lives in Baden with his Swiss wife, whom he met at CERN, and their 13-year-old daughter. With the SLS now setting the standard for light sources worldwide, Rivkin is enjoying teaching at the ETH Zurich and planning with his colleagues future possibilities for shedding even more light on the nature of matter.

Giselle Weiss

A refined approach to stretching electron beams

Cavity: Hollow body made out of metal that can be filled with electromagnetic energy to accelerate particles.

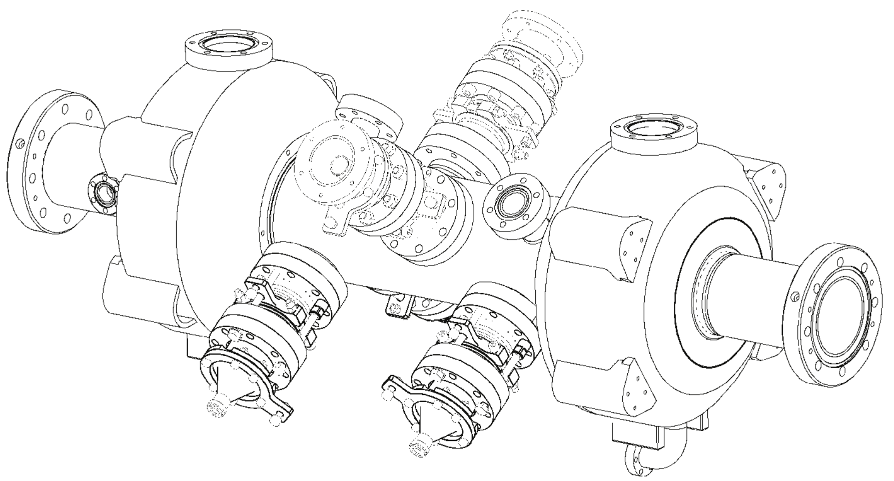
Resonance: Strong response of a system when excited at its natural frequency.

CERN: European Laboratory for Particle Physics in Geneva.

The superconducting cavity which has been successfully installed in the SLS storage ring is a world first. The module improves the stability of the synchrotron light and more than doubles the lifetime of the electron beam.

The more intense and focussed synchrotron light must be, the smaller the electron beam required to generate the light. However, this can cause the tightly packed flying particles to collide, thus blowing up the beam. This effect can be alleviated by increasing the length of the individual bunches. It reduces the charge density and increases the lifetime of the beam.

For this purpose the recently installed cavity in the SLS storage ring was designed. The cavity comprises two superconducting niobium-copper cells which are connected to a central tube. Six couplers, which are designed to suppress unwanted high-frequency resonances, are located on the tube. The components are housed in a vacuum chamber and liquid helium is used to cool them down to 4.5 Kelvin (-268.5 °C) in order to achieve superconductivity.



The cavity: Two superconducting cells connected by a central tube with couplers to damp parasitic resonances.

The superconducting cavity assembly as installed in the SLS storage ring.

Electron gymnastics

As an electron bunch flies through the two cells, it excites electro-magnetic field oscillations at the cavity resonant frequency of 1.5 gigahertz. The bunches are stretched by this field becoming less dense which leads to fewer collisions between electrons and a longer beam lifetime.

The design is the result of a project involving participants from all over the world on the basis of which the module was manufactured. It was a joint venture between the four labs: CEA-Saclay laboratories in Paris, CERN in Geneva, Sincrotrone Trieste (ST) and PSI, which worked on the theoretical aspects of the interaction between the beam and the cavity. The support provided by the team from the Swiss Federal Institute of Technology in Lausanne, which specified and commissioned the complex cooling system, was also vital.

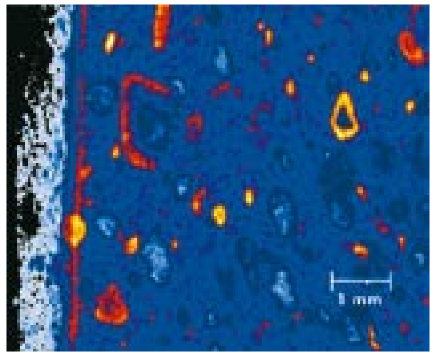
The cavity was commissioned at the beginning of October 2002. It performs in accordance with expectations: the length of the individual bunches has been increased by a factor of 3 and the lifetime of the electron beam by a factor of 2.2. Stable operation has been achieved up to the nominal current intensity of 400 milliamperes.

Using trillionth-second flashlights

Following the successful construction of four beamlines in the first phase, work has now begun on the second phase with the installation of three more experimental stations.

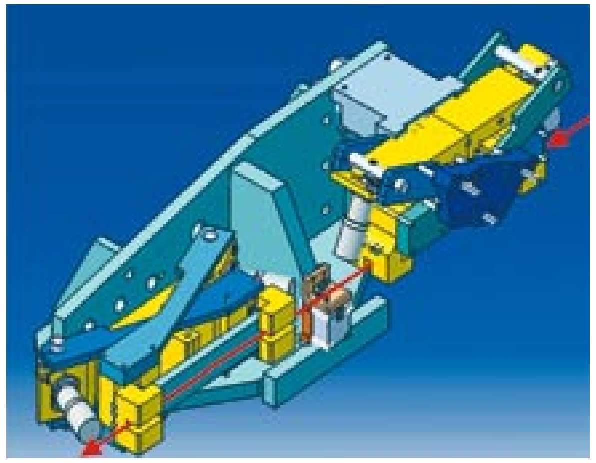
On the basis of the needs of users and the general trend in research, two X-ray absorption lines with microfocus capabilities (MikroXAS, LUCIA) and one line for protein crystallography (PX II) are currently under construction. The two X-ray absorption lines complement one another (MikroXAS: 4 to 18 keV, LUCIA: 0.8 to 6 keV). The focal point of the research is environmental sciences, in particular the investigation of heterogeneous and diluted systems. The properties of the beam make it possible for example to determine the spatial distribution of trace elements or the local chemical environment of an absorbent atom. The MikroXAS line is being built by PSI and the LUCIA line is a joint venture between the SLS team and the French partner institutes SOLEIL and LURE.

On the basis of the excellent research results achieved on the first protein crystallography line, the pharmaceutical companies Novartis and Roche and the Max Planck Society decided to finance jointly a second PX line (see page 84).



Under synchrotron light: After biochemical efflorescence, the distribution of cobalt (packed in cement) illustrates the stability of heavy metal scrap. High concentrations of cobalt atoms appear in yellow and red.

The time structure of the synchrotron light produced in the storage rings has an increasing usage in pump/probe and time resolved experiments. The typical length of the SLS single bunches is of the order of 30 to 50 picoseconds. The electron slicing scheme developed at the ALS will be further improved and implemented in one long straight section. The combination of a ultra-fast laser and a wiggler will alow us to produce light pulses as short as 100 femtoseconds. Measurements of ultra-fast laser-induced processes will be possible.



Focusing optics for micrometre-specific focal points, developed for the new LUCIA X-ray absorption line by the French partners SOLEIL and LURE (model drawing).

Palette of projects

The following proposals were submitted to the meetings of the SLS Scientific Advisory Committee (SAC) in 2002:

- Infrared beamline for spectroscopy and microscopy;
- Beamline for dynamic studies of chemical processes in the vacuum ultraviolet range;
- Construction of a super bend based beamline for high throughput tomography and real-time radiology;
- Undulator line for studying correlated electron systems using resonant X-ray scattering.

Detailed information about the technical scope of and schedule for the various projects is currently being drawn up. The additional beamlines will mark another major milestone on the way to achieving our aim of making complete and effective use of the experimental potential of the SLS.

Beamlines comprise a variety of components (magnets, mirrors, monochromators) which are used to prepare the synchrotron light as required before it is fed into the experimental apparatus.

Protein crystallography: Proteins are crystallized and synchrotron light applied to them. The resulting diffraction pattern can be used to identify the structure of the protein molecules. The method is used primarily in the development of new medicines.

Picosecond: One trillionth of a second or one millionth of a millionth of a second (10^{-12} s).

Femtosecond: One thousandth of a picosecond (10^{-15} s).

Wigglers and undulators: Special magnets used to direct electrons in the storage ring onto very narrow slalom courses so that they will emit sharply focused and highly intensive synchrotron light.

Super bend: A bending magnet with a high magnetic field (3.1 Tesla).

Renovated in its 40th year of operation

Following three years of planning and building, the refurbished Hotlab was inaugurated and approved for a return to active operation in May 2002.

The Hotlab is a complex nuclear facility for researching and developing materials which are used in intensive nuclear radiation fields and are highly radioactive. Major areas of research include investigations into progressive light-water reactor fuel elements for high burn-up and power ratings and investigations into damage processes of environmentally assisted aging of components from Swiss nuclear power stations. Other important responsibilities include the selection of materials for the PSI liquid metal spallation target at the SINQ and for fusion reactors in addition to research into radionuclide emissions from waste storage sites.

Safety-related studies had shown that the Hotlab was no longer able to meet current fire protection regulations. This discovery was the catalyst for the complete renovation of the building. The lab underwent refurbishment not only in order to provide adequate fire and radiation protection but also in terms of earthquake safety and building system control.

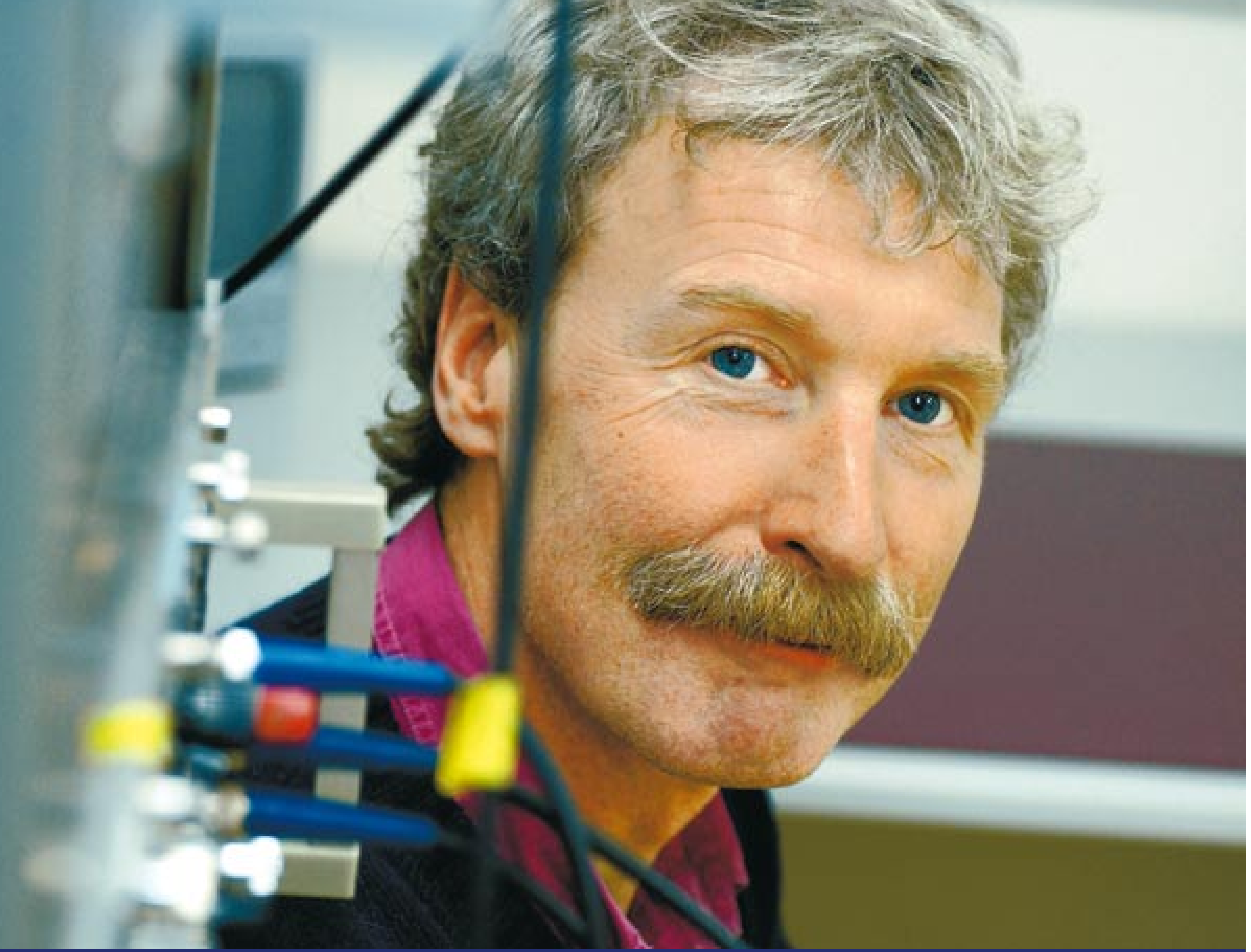
The difficult task of finding cost-effective solutions for complex building problems, maximizing safety and at the same time minimizing interruptions to operations shaped the renovation project. The renovation concept selected comprised the addition of a media installation corridor above and along the radiochemistry section. This allowed the use of a new vertical system for supplying media to the individual labs on two floors. Large complex analytical installations and heavy radiation shields in the labs, which could not be moved during renovation, had to be sealed tightly in order to protect those working on the project against exposure to radiation.

A concrete shield was installed around the windowed facade of the radiochemistry section in order to increase earthquake safety. Instead of simply having the outside of the building painted, which would not have been very imaginative, a talented graffiti artist was employed to provide a more refreshing look.

Unusually colourful: Graffito at the non-renovated front of the Hotlab.

Hotlab: Research with highly radioactive substances.

At the Hotlab ▶



Expert in constant change

Jost Eikenberg

His professional passion is disintegrating isotopes. These radioactive atoms have assisted Jost Eikenberg on the way to exciting discoveries, which have included identifying meteorites, date-stamping dripstone caves and tracking radionuclides in solid rock.

On the look-out with his spectrometer

«The earth's surface is covered in radioactive materials», Jost Eikenberg tells us when describing his work. Jost, who works in geological research, goes into raptures as he explains how radioactive atoms have broken down barriers for curious scientists. He uses spectrometers and other measuring equipment pursuing research in many different directions. Projects completed so far include the discovery of minute traces of plutonium residue in soil samples from the atomic weapon tests formerly carried out above ground in the South Pacific and the various radium isotopes yielded up by the incoming and outgoing ground waters of the Rhine.

The Karlsruhe nuclide chart lies open on the desk. It records how radioactive isotopes change weight and name as they disintegrate: from uranium, the heaviest of all the naturally occurring elements, to thorium and radium before changing to inert gas radon and finally, after several thousand years, to stable lead. The chart is the radio analyst's atlas. It describes the properties and interrelationships of changeable atoms in detail.

Jost Eikenberg was appointed head of PSI's radioanalytical laboratory, which is part of the Logistics and Marketing Department (LOG), ten years ago. A native of Lower Saxony, Eikenberg describes 80% of the work he does as essential duties. Amongst these he counts regular check analyses which are a routine part of the major research institute's activities: air filters, wipe tests, waste water samples and radioactive medicines must all be checked for radioactivity in accordance with applicable guidelines.

The rest of Jost Eikenberg's working time is invested in research. "It spices things up for me", says the disintegration expert, who, having completed a degree in petrography, won the silver medal at the ETH Zurich for his doctorate in geochemistry. On joining PSI in 1988, he initially undertook research into safe methods of permanent waste disposal before switching to radio analysis four years later. He describes it as "a researcher's heaven".

Eikenberg and his team make discoveries again and again. This part of his work provides a much needed contrast with daily routine. Whether characterizing cosmic bodies (a new lunar meteorite was discovered recently), experimenting with short-lived bromide isotopes way underground or calibrating a geological uranium-radium clock, Eikenberg sets about every task with equal enthusiasm. His personal drive and scientific success were no doubt instrumental in the success of the post-doctoral work carried out by the newly qualified ETH freelance lecturer in addition to his post at PSI.

Now a resident of the Waldshut region who commutes across the border, Eikenberg leads just as hectic a life away from his profession. He can often be found tripping the light fantastic dancing the cha-cha-cha and jive with his vivacious wife, he plays the double-bass and the flute and has three children. "A perfect antidote to PSI", the 46-year-old says with a smile before returning to the loves of his professional life - his constantly changing atoms.

Beat Gerber

Kicker for the proton beam

Beam switching at lightning speed

Ultra cold neutrons: Extremely cold and thus slow neutral particles of the atomic nucleus which can be stored and are particularly suitable for experiments relating to the basic questions of physics.

Power electronics engineers have developed a precision power supply which can be used to deflect the proton beam quite drastically.

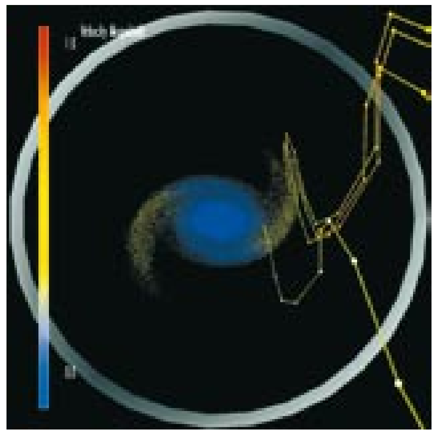
As part of the UCN (Ultra Cold Neutrons) project, the proton beam has to be deflected very quickly and very precisely between two beam paths. A device known as a kicker, built by specialists at PSI, was used to switch the current of more than 150 amps (A) in the bending magnet in less than one thousandth of a second.

The power electronics of the kicker power supply.

The precision achieved actually far exceeded the required levels. After approximately 3 ms, the error rate is lower than one per thousand. Like all new PSI power supplies, the UCN kicker has also been designed on signal-processor-based control. Design of the beam control as well as concept and manufacturing of the kicker magnet were further top achievements of PSI in this projects.

3D simulations of proton beams

Comparing model and measurement



3D journey: MAD9p can be used to track selected particles as they pass through the accelerator (snapshot from animation/ A. Adelmann, PSI; C. Siegrist NERSC/LBL).

PSI reached a milestone in the handling of highly intensive particle beams with the first production run of the new MAD9p simulation program.

The program is based on MAD9 (Methodic Accelerator Design Version 9), a software package originally developed at CERN. Working in conjunction with a number of partners from all over the world, PSI was able to considerably expand the functionality of the program. It can now be used for the three-dimensional simulation of particle bundles under space charge with particles which can realistically run into several million.

Space charge describes the electrostatic repulsion (Coulomb force) which dominates charged particles (e.g. protons) in the beam bunch. This internal interaction has a significant effect on beam dynamics and must not be ignored. The p in MAD9p stands for the adaptation of the code to the particular features of parallel computers, thanks to which a typical simulation run can be completed in a matter of hours rather than taking several days or even weeks. The direct comparisons between beam measurements and simulations of highly intensive proton beams which can now be carried out at PSI are a major step on the way to a better understanding of how space charge affects particle beams.

Proton accelerator

Repaired in no time – operational for a long time

Cyclotron: Device for accelerating charged elementary particles.

Cavity: Hollow body made out of metal that can be filled with electromagnetic energy to accelerate particles.

Proton current: A measurement of proton intensity expressed as current. 2 mA (milliamperes) are approximately equal to 1.3 10^{16} protons per second.

Service-friendly: The beam control section in the centre of the ring accelerator.

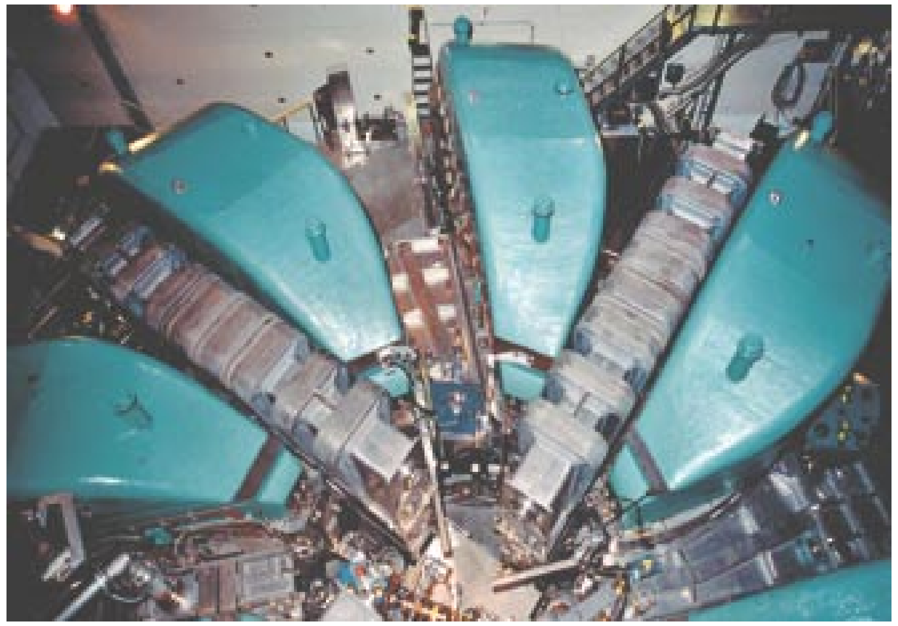
In the centre of the ring accelerator, the beam control section has been restructured and made ready for the installation of more advanced cavities.

Increased facility availability, shorter repair times and a reduced beam dose for service personnel were the aims behind the renovation of the 30-year-old beam control section in the centre of the ring accelerator. It will now be possible to remove or reinstall critical beam control components in less than 15 minutes – without having to linger in zones where the beam is at its strongest and without having to ventilate the entire ring cyclotron.

Modifications required for the subsequent installation of more advanced cavities have also been made, in order to increase the beam current as planned. In order to be able to generate more intensive neutron beams, the proton current on the production target must be increased. The existing facility enables a limited increase in the region of 2 mA. In the medium term, an increase in current can only be achieved with new, more advanced cavities.

The protons are accelerated in the injector cyclotron to 72 MeV, transported to the ring cyclotron and reach the centre via cavity 5 and intermediate sector 3. From there they are injected into the innermost orbit of the ring cyclotron, which accelerates them to 590 MeV. The lack of space and inhomogeneous scatter and disturbance fields made many compromises necessary in the design of the beam section in the centre, which, as a consequence, also reduced service-friendliness and availability.

The upgrading work included the construction of a new support structure and the securing of the beam control as well as the retrofitting of the input and output areas of the beam section with stop valves in order to create a separate vacuum section. The ring injection magnets, which are mounted on a single aluminium plate, facilitate installation and removal operations affecting the noses of the new cavities, thus reducing the time which personnel have to spend in zones where the exposure is at its strongest.



Ring cyclotron with green sector magnets, grey acceleration cavity and renovated beam control section (in the centre at the bottom).

Experiment for extreme conditions

MEGAPIE: Megawatt **Pi**lot **E**xperiment.

LISOR: Liquid metal-**So**lid metal **R**eactions.

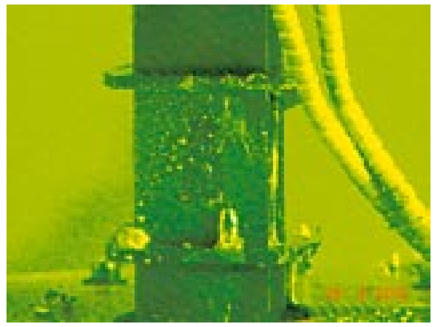
Target: Material on which protons are bent in the SINQ in order to release neutrons.

Pascal: Unit of pressure, derived from the SI units newton and metre (1 Pa = 1 N/m²).

PSI experts are using LISOR to investigate components which can pose particular problems in the development of a liquid metal spallation target.

In the MEGAPIE project, PSI is developing a liquid metal spallation target which it is hoped will lead to an increase in neutron flux when compared with the current solid matter spallation target. The target material is a lead bismuth alloy (Pb-Bi) which liquefies at 125.5 °C. A particularly critical aspect of MEGAPIE is the beam window, through which the intensive proton beam penetrates the lead bismuth in order to generate neutrons. It is subject to a complex thermal and mechanical load, the effects of which have not yet been fully researched.

As part of the LISOR experiment, the various factors by which the window material – a proton beam selected specifically for this application – is affected during MEGAPIE operation are simulated. First of all, an investigation is carried out into the simultaneous effects of lead bismuth, radiation and mechanical load on the material. The experiment rig, which is based on an LBE loop, was installed in the accelerator facility at the beginning of 2002. Following a test phase, the beam was approved for operation by the authorities.



Beam spot (dark spot in the centre of the image) caused by the proton bombardment of a special type of steel which is to be used as the beam window material.

Corrosion and embrittlement

A research team was then able, for the first time, to carry out an experiment under irradiation. A steel specimen stressed with 200 MPa (approximately 40 % of the yield point of the material at test temperature) was brought into contact with liquid lead bismuth heated to approx. 300 °C and irradiated with protons (72 MeV) from an accelerator. The reaction of the steel with the liquid metal – corrosion and embrittlement – under irradiation provided some surprising results, into which further investigations are to be undertaken.

During the relatively short irradiation time of the first experiment, no operational errors were detected on the systems in the complex experiment rig, e.g. control and safety devices. The test section was subsequently removed from the LISOR loop successfully before being dismantled and broken down in the hot cell equally easily. No problems were encountered deconstructing the specimen. Researchers hope to obtain significant material data from this first experiment. Irradiation tests with extended beam times are planned for 2003.

Where lead bismuth circulates: The LISOR experiment rig.

Optimizing proton flight paths

250 MeV cyclotron for PROSCAN (with cover removed).

Extensive simulations and calculations have to be completed in advance in order to ensure the reliable operation of the new irradiation facility.

As part of the PROSCAN project, a second treatment unit is to be added to the PSI facility for proton-based tumour irradiation along with a dedicated proton accelerator – a 250 MeV cyclotron complete with superconducting coils (see also page 61). Physicists and engineers of PSI have been working together with the manufacturer ACCEL Instruments GmbH to optimize the quality of the proton beam. An extensive simulation was carried out at PSI in order to calculate the electrical fields required for the acceleration process. This was the first time it had been possible to complete such a detailed and complete system simulation.

The electrical fields were then combined with the magnetic field calculated from the superconducting coils in order to calculate the flight paths of the accelerated protons. The most critical issue is the extraction range, i.e. the point at which the particles should exit the cyclotron. In order for the machine to be used in medical applications, operation must be extremely stable and reliable as well as assuring fast access should maintenance be required. During maintenance, the exposure of personnel to the active components must be minimized. Radioactivity can be reduced by working with high proton extraction efficiency. The experts worked incredibly hard to optimize this area of operation.

Preparations for PROSCAN

A special-type media show

As part of the preparations for the new irradiation facility and the cyclotron, the NA Hall on the West site many supply lines and pipes for cooling water, electricity and gases have to be moved, removed and rebuilt.

Move and new construction of the supply media in the NA Hall are complex and delicate tasks. In addition the LOG sections Process Cooling and Electric Services had to fulfill high requirements such as uninterrupted operation and demands for several provisional constructions. LOG stuff was actively supported by GFA division Technical Support and Co-ordination, which planned and prepared the challenging work.

In order to ensure that the proton gantry continues to operate correctly, electrical devices, electronics, vacuum controllers and many more items and equipment were moved from the east gallery to the west gallery during the accelerator shutdown in 2002. Several hundred cables and connectors were replaced and a provisional power supply installed, enabling us to push on with dismantling the gallery, the distribution board and the old transformer.

Changes afoot in the NA Hall: The existing electrical cabinets being removed.

Transfer of Knowledge

Dissemination of Know-how &
Commercialization of Technology

From Hanover to China

Floating superconductor ▶

Contacts in economic and political arenas

PSI held three Industry Days in 2002 to showcase new processes and discoveries. Once again, the Institute also took part in the joint presentation made by the Swiss Federal Institute of Technology domain at the Hanover Fair.

At PSI, we consider the commercialization of knowledge to be an important task. It is a way of generating new impetus in economies, which can secure existing jobs or create new ones. The most direct way of transmitting knowledge is by educating professionals and academics, who will then put their skills to use in the private sector. Joint projects with industry in the field of applied research, joint ventures to develop new products ready for market launch, spin-offs from basic research and patents are particularly important. The success of these activities depends on a close network of contacts which must be established and maintained.

Driving ahead: PSI presented its research (including the fuel cell drive) at the Hanover Fair 2002.

Workshops and seminars for industry

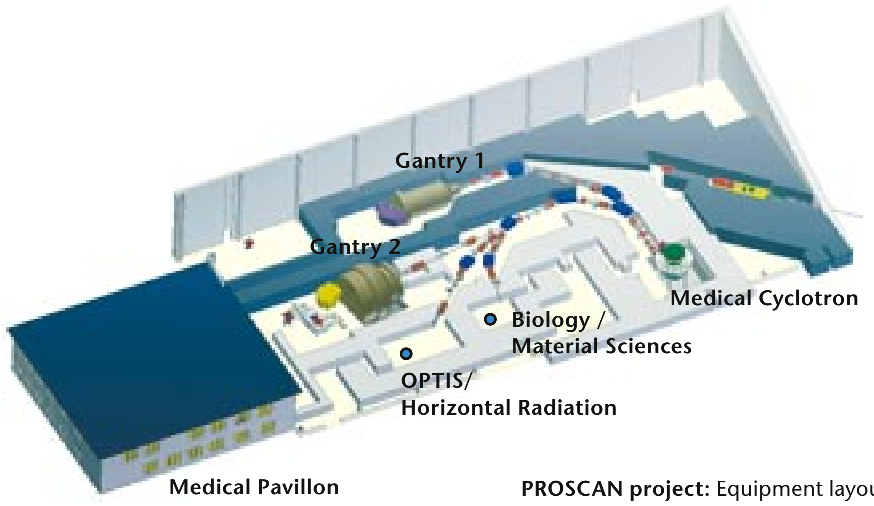
Workshops and seminars targeted to attract industrial users and to some extent scientists from other institutes were held on topics relating to the use of synchrotron light, the application of neutrons in stress field analyses and the potential of surface technology.

Contributions from external sources were combined with the presentation of new options at PSI in order to establish dialogue with potential users. An additional aim was to provide easy access to PSI experts and indicate how collaborations can work without bureaucracy getting in the way. The direct contact and the possibility – in addition to attending lectures – of visiting the research facilities helped to forge a considerable number of new business relationships.

At the Hanover Fair, PSI tried to give visitors a closer view of how the SLS functions as a research instrument as well as introducing them to fuel cell projects, arousing a great deal of valuable interest in the process. By presenting encouraging research data, the booth at Hanover each time provided opportunities to groom and develop contacts in the economic and political arenas.

Talking to users: René Amstutz, Head of Core Technology at Novartis, attending an Industry Seminar about the potential applications of synchrotron light.

Highly effective yet harmless



PROSCAN project: Equipment layout.

Protons: Positively charged elementary particles which can be precisely controlled.

Spot scanning technique: This technique, developed at PSI, can be used to precisely adapt the beam dose to the shape of the tumour in all three dimensions.

Proton therapy has been used at PSI for a number of years to successfully treat cancer tumours.

By the end of 2002, more than 3,700 patients will have undergone irradiation treatment for eye tumours. The tumour control rate is more than 98%, i.e. in more than 98 of every 100 patients, no new tumour growth has been detected over a period of five years following treatment. This success spurred us on to develop a new technique, known as the spot scanning process, which can also be used to treat deep-seated cancer tumours in the rest of the body.

The rotating gantry used for this technique was commissioned in 1997. By the end of 2002, 129 patients will have been treated for skin tumours at the base of the skull and in the pelvis and prostate. The results are very encouraging. We are confident that our method of treating tumours will achieve significantly better results than today's conventional methods for treating cancer with photon beams. Proton therapy can be used to apply radiation to cancerous tumours in the high doses required without subjecting the healthy tissue which surrounds them to excessive radiation.

Wide international interest

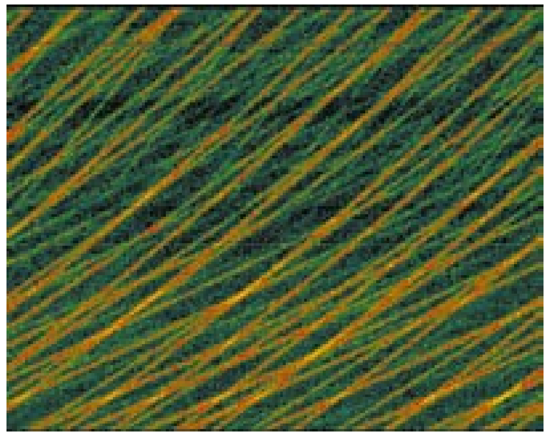
PSI research in this field has aroused a great deal of international interest, since the gantry is the first in Europe and the first irradiation facility in the world to use the spot scanning technique. We decided to develop proton therapy with our technique farther for use in hospitals and therefore launched the PROSCAN project. Together with partners in industry, we have built a new extremely compact proton accelerator and expanded the facility (see also page 57).

Our industry partners are currently using the discoveries made at PSI in the field of proton therapy to build a large proton therapy clinic in Munich, Germany. It is the first commercial facility of its type in Europe and has been designed to treat between two and four thousand patients per year. Other projects are currently being planned for Europe and further afield. This transfer of knowledge means that PSI is now receiving royalties that will provide financial support for the PROSCAN project and clinical research in the field of proton therapy.

The gantry in the proton therapy facility at PSI makes possible an irradiation technique which is the first of its type in the world.

Strain analysis with POLDI

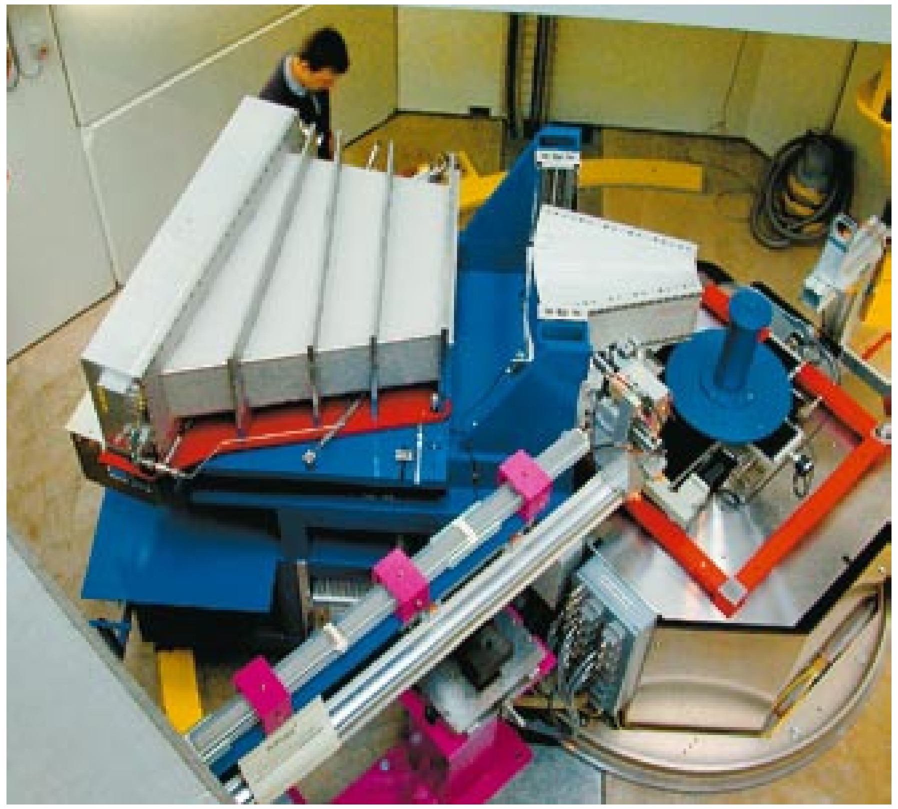
Neutrons on a collision course to information



Scattering diagram of a steel specimen: From the position of the lines the spacing of the atoms in specific directions in the crystal can be calculated and from that the internal stresses are determined.

In order to determine the effective load of a structural component, the internal state of stresses must be determined in addition to the external stresses to which the component is subjected. A special procedure based on the diffraction of a neutron beam is used for this purpose.

The reliability of structural components can only be ensured when the effective local mechanical loads are known to which they are subjected. These loads comprise external and internal stresses. Internal stresses are constantly present in the material and arise both during manufacturing, e.g. in welding processes, and under operational conditions.



The POLDI lab: On the right is the sample table to which the neutron guide is directing from the lower left. On the top left is the neutron detector, which registers the arrival of the scattered neutrons.

From scattering diagrams to stresses

Unlike external stresses, internal stresses cannot usually be estimated correctly from the beginning. This is why it is essential to be able to determine internal stresses in components non-destructively, precisely and with good special resolution. A particularly well suited method of doing this is to use neutron scattering. The neutrons scattered in the material are characteristically deflected by atoms or molecules forming a scattering diagram which can be used to draw conclusions about local deformations. These deformations in turn are used to determine internal stresses.

Instruments originally designed for other applications are used at many neutron sources to determine internal stresses. At PSI, we have adopted a different approach and developed POLDI, an innovative instrument designed specifically for measuring internal stress fields.

The design is based on the time-of-flight method, which uses neutrons of a wide wavelength range. For each detected neutron the corresponding wavelength is determined on the basis of its time-of-flight. In order to measure an entire stress field, sequencies of measurements must carried out on the specimen. These can be conducted exceptionally fast at POLDI – in times comparable to those which can otherwise only be achieved on high-flux neutron sources.

Antibiotic detection

On the trail of penicillin in steak

A research group at PSI has developed a biosensor which can be used to trace even the minutest concentrations of antibiotics.

Antibiotics are frequently used in veterinary medicine to treat infections. However, it is vital that no antibiotic residues remain in foodstuffs such as meat and milk. Highly sensitive procedures are required in order to assure the quality of these animal products and detect any misapplication of antibiotics.

Even the minutest concentrations of antibiotics in milk will prevent its fermentation into cheese and yoghurt. This can have a devastating financial effect. Detection procedures that are quick, sensitive and easy to apply are the order of the day. It is for this reason that a research project was set up at PSI with the aim of developing an automated biosensor for tracing penicillin antibiotics.

Reliable and 100 times better

Essentially, a biosensor comprises two components: a binding biomolecule which will find the proverbial needle (in our case antibiotic molecules) in the haystack (or specimen) and a detector trace up this specific bond. Specific preliminary investigations showed that penicillin decomposes within hours, rendering concentration level measurements unreliable. The research group therefore developed an antibody directed against a stable decomposed form of penicillin.

Before analysis, the antibiotic in the specimens undergo complete enzymatic conversion into this stable form and are then traced by immunoanalytical means. This ensures the reliability of test results. Surprisingly, this new process, which was patented by PSI, has improved the detection limit by up to 100 times. This means that the specimens to be tested can be diluted considerably, thus excluding almost any possible source that might distort the results obtained.

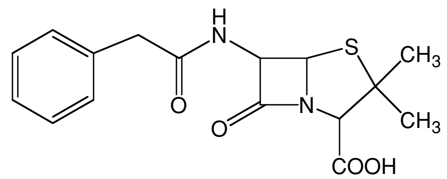
The biotechnology company Bioreba, based at Reinach in Switzerland, which develops test procedures for biochemical analyses and sells its products all over the world, recognized the benefits of the new immunoanalytical process. A contract was drawn up to regulate the transfer of expertise and key components. Only a few minor modifications were needed before the kit was ready for evaluation on a broader basis. This example shows how even parts of the findings of a complex, application-based research project can be put to use.

Antibiotic: a chemical substance comprising metabolic products of microorganisms, capable of inhibiting the growth of or completely destroying other microorganisms (e.g. bacteria).

Penicillin: cheap antibiotic; discovered by Alexander Fleming in 1928.

Enzyme: a protein produced in living cells which controls the metabolism of the organism.

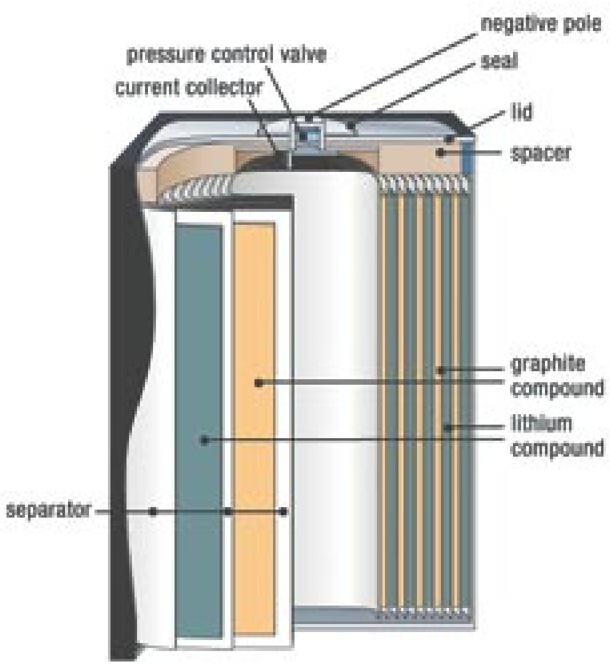
The chemical formula of penicillin.



Patented: The benzylpenicillin detection kit.

Lithium-ion batteries

Ceramics between electrodes



Lithium-ion battery: The separator separates the anode from the cathode (illustration: Varta).

Working in partnership with industry, PSI has developed a new type of increased safety separator for batteries.

The use of lithium-ion batteries in portable electrical equipment is increasing. Their safety and performance is determined also by the separator used. It separates the electrodes, thus preventing dangerous internal short circuits. It also absorbs the electrolyte, a current-conducting solution which ensures the proper working of the battery. Polymer separators are currently used, but they bear the risk of melting at temperatures above 150°C and initiating a fire under extreme circumstances. For this reason new solutions are being sought.

PSI worked together with the German company Degussa, Creavis Technology & Innovation, to develop new types of ceramic separators. These are non-melting and therefore safer than conventional products. Batteries with these separators also have a very low internal resistance, which increases their performance. The lifetime of the batteries is increased because, unlike polymer separators, ceramic separators do not age. A patent application has been submitted by Degussa to protect the ceramic separators. We hope to see them being used in lithium-ion batteries in the not too-distant future.

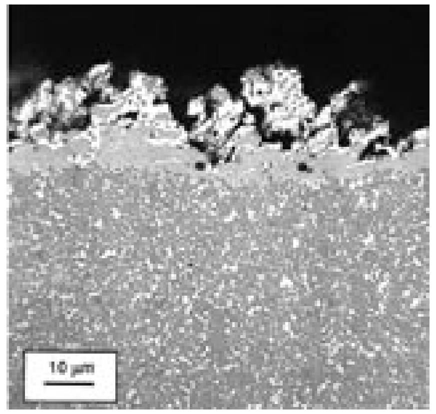
Wire Electro Discharge Machining (EDM)

Corrosion problems with spark discharge

A team of researchers from universities, industry and PSI is investigating corrosion impairing a machining technique ahead of its time.

Wire EDM is a process with enormous potential for machining workpieces to dimensions of micrometres or nanometres. An electrical voltage is used to generate numerous sparks that slowly cut the required shapes from pieces of metal. In order to further refine machining accuracy and surface quality, the machine parameters must be controlled thoroughly. Wire EDM in water can cause workpieces to corrode and discolour (see photo), thus negating any of the benefits provided by the process. Although wire EDM in oil would reduce or even eliminate problems due to corrosion, EDM in water offers a greater number of advantages. It is quicker, easier to control and does not pose a fire hazard.

It is for these reasons that, as part of the Top Nano 21 programme, a project was launched in May 2002 to investigate corrosion caused by wire EDM in water. It was a joint venture between the Swiss company AGIE SA, a manufacturer of EDM machines, the Swiss Federal Institute of Technology in Zurich, the University of Berne and PSI. Because corrosion often appears on hard metals such as tungsten carbide with cobalt, first investigations were carried out on this material.



Corrosion: Evidence of zinc and copper oxide on the surface of the specimen. It is due to the zinc-coated brass wire used in the wire EDM process (scale: 10 thousandth of a millimetre).

At the psi forum ▶

Challenge for power electronics engineers

The SLS is the first accelerator in the world to use complete digital control for all magnet power supplies. The solution was considered difficult to implement for many years. It is understandable, therefore, that our digital control concept has aroused a great deal of interest in research and industry.

A look back through history: From the start, the concept of the largest power supply for the Swiss Light Source (SLS) heralded a completely new approach. The desire to implement state-of-the-art control arose as part of the concept. In December 1998, standard test boards were used to convince project managers that a control concept based on a signal processor could function with the required precision and dynamics.

In January 1999, work started on the specification for the processor and analogue/digital converter hardware. The two boards were engineered and manufactured by external companies. Only minor modifications were required before the cards could be used in the SLS.

Digital open-loop and closed-loop control: The SLS magnets.

In parallel with the hardware development, work started at PSI on developing the software: for the digital signal processor (DSP) and also for a large, programmable gate array (FPGA).

Powering precision and speed: The analogue/digital converter card.

For 900 units and further applications

Today, some 550 digitally controlled devices are in operation in the SLS, some even with multiprocessor systems. The UCN kicker (see page 54) uses the same hardware, the new PROSCAN magnet power supplies will also be equipped with it and old devices on the proton accelerator are being replaced by new digitally controlled ones. Eventually, more than 900 units will be in operation at PSI with the processor and analogue/digital converter cards developed for the SLS.

The flexibility of the hardware has enabled its use in other applications. A slow but constantly rotating DC motor drive has been developed for the rotating target in the proton beam along with – the pick of the bunch for power electronics engineers – a high-speed high-performance AC drive.

High-speed sensors with maximum resolution

The SLS beamlines provide extremely high-quality synchrotron light which conventional detectors are often not capable of recording accurately. This problem has been solved by a new generation of solid state detectors in which a new type of technology developed at PSI has been applied.

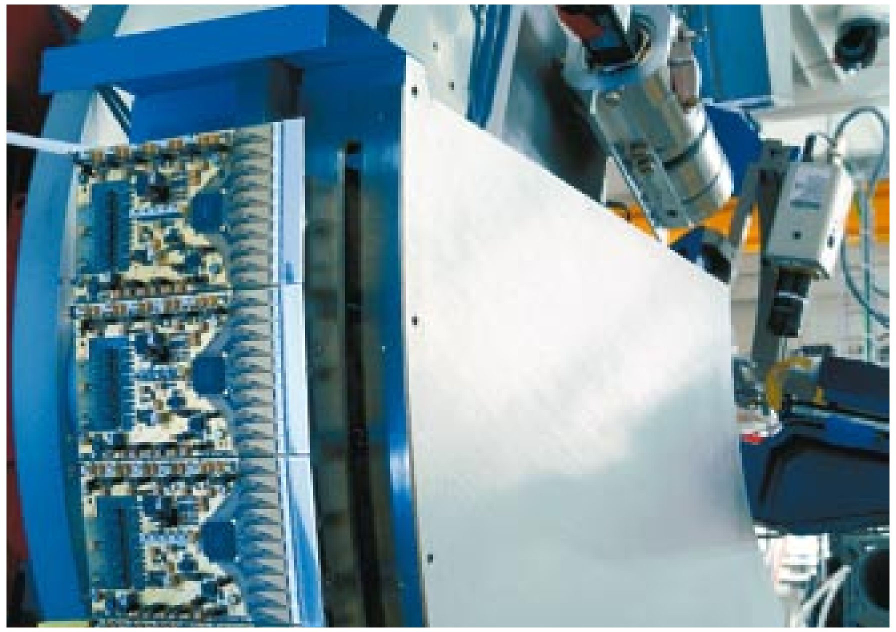
PSI is amongst the world leaders in the field of semi-conductor detectors. A team is currently developing the central pixel detector for one of the largest particle physics detectors, the CMS detector at the LHC accelerator to be installed at CERN (see page 22). The same technology is also used at the SLS. The aim of the PILATUS (Pixel Apparatus for the SLS) project is to build a pixel detector measuring approx. 40 x 40 cm^2 on the protein cristallography beamline. Already in operation is the MYTHEN detector. The devices convert synchrotron light directly into electrical signals for subsequent evaluation.

Research is benefiting from the advances in the area of miniaturization in microelectronics. The pixels on a silicon sensor, on which tiny indium pellets (diameter: 20 micrometres) sit, are bonded with the pixels on a readout chip (bump bonding). One pixel (area: approx. 0.05 mm^2) has more than 300 transistors, which are used to process the sensor signals. Digital counters, which can count up to 30,000 X-rays per exposure in a single pixel, have been integrated into the current generation of pixel detectors.

Reducing measurement times

In addition to improved high-sensitivity resolution and increased dynamic range, one feature dominates: the readout time of the detectors is about 1000 times faster than a commercial detector. On the one hand, this advantage enables overall experiment measurement time to be reduced, i.e. the available beam can be used more efficiently and, on the other hand, the short readout time allows new experiments impossible to do before.

The high-speed PILATUS detector can be used to rotate a protein crystal at continuous angular velocity during the measurement at the beamline. The readout time of only 7 milliseconds after an exposure is so short that the crystal can continue to rotate without interruption. This significantly increases the angular resolution of the data. The way that the technology has been developed in partnership with experts from a number of departments (SYN – Synchrotron Radiation, TEM – Particles and Matter, LOG – Logistics and Marketing) is an example of PSI's multidisciplinary approach to its work.



Microstrip detector at a beamline of the SLS (left in front). In the sample positioned in the background at the right side synchrotron radiation is deflected and then impinging on the detectors.

Pixel: Picture element; the smallest element in the grid-based digitized representation of an image on a screen or output via a printer.

Detector: Measurement device.

Readout time: Time taken to transfer digital image to storage.

State-of-the-art power supply for China

Air pollution in industrial regions is one of China's most urgent environmental problems. (image from CETP film).

PSI researchers together with international partners investigated how China can make its power supply more sustainable. The team produced a CD/DVD containing the comprehensive results of their studies in interactive and graphic format.

The work was carried out as part of the China Energy Technology Program (CETP), sponsored by the ABB in partnership with the Alliance for Global Sustainability (AGS). In addition to researchers from PSI, the project team also included U.S. (MIT) as well as numerous Chinese, Japanese (Tokyo University) and Swiss (Federal Institutes of Technology in Zurich and in Lausanne) partners. In addition representatives of major Chinese stakeholders participated in the program. The focal point of the research project was to investigate how the electricity supply system in China can be made more environmentally friendly and more sustainable.

Most detailed analyses were carried out for the Shandong province on the east coast of the country.

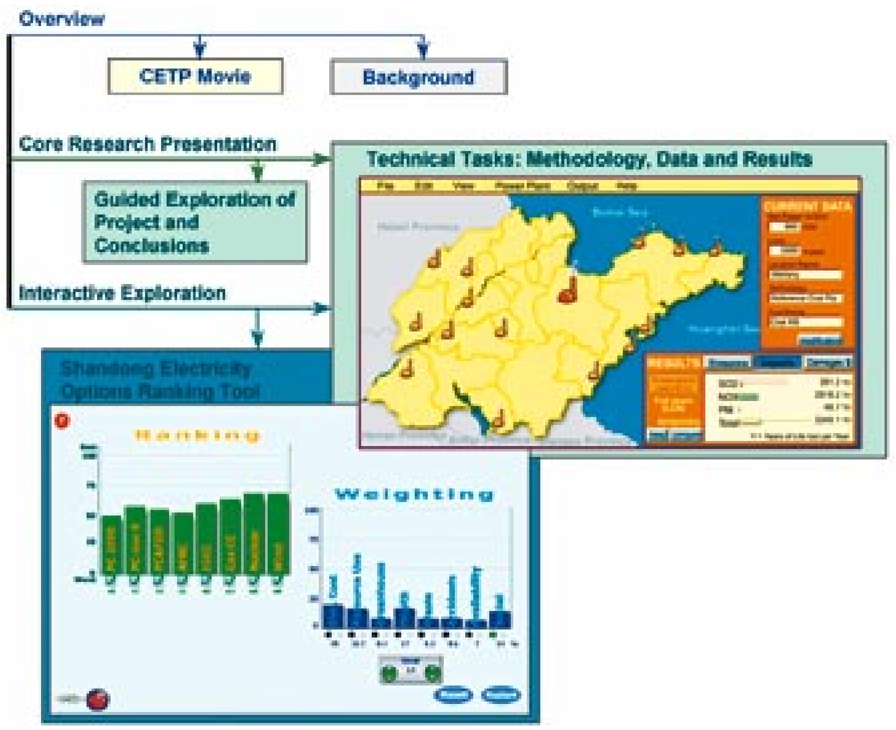
During the last project year (2002), the PSI team, with the support of its research partners, developed an integrated software tool. It was designed to provide decision-makers at top and middle management level as well as other users (engineers, environmental experts, academics) with flexible means of accessing the CETP results. Information is presented in hierarchical format on a CD/DVD, which allows users to select the level of detail most appropriate for their background and interests.

Estimates in a matter of seconds

Some research task representations also have special features including extended analytical capabilities. For example, a tool was developed to allow an interactive simulation of impacts of air pollution and associated monetary losses for a variety of power plant sites. For each site, the user can select among several generation technologies, establish basic plant characteristics and choose emission abatement methods for major air pollutants. Based on a parametric model, pollution damage can be estimated within seconds, compared to the hours needed for the underlying full-scale simulation.

The multi-criteria-based decision-support module generates and presents ranking results in an interactive, graphic format. Aggregated CETP results for a range of criteria are combined with user inputs on criteria weights to produce a ranking of either individual technologies or one or more mixes of individual technologies. The user can identify the most suitable options according to different stakeholder perspectives based on their economic, ecological and social preferences.

Examples of decision support from the CETP CD/DVD: On the right hand we can see the simulation of the effects of pollutant emissions from power plants in the Chinese province of Shandong: How can various options for reducing pollutant emissions help to reduce death rate? The graphic at the bottom illustrates the ranking of power plant technologies based on multiple criteria decision analysis.



A neat package for clean electricity

Portable, quiet and even emission-free: the benefits of the PowerPac fuel cell system are numerous. The portable power generator was developed by Paul Scherrer Institute and the Swiss Federal Institute of Technology in Zurich and has been awarded one of the prestigious awards for innovations in Switzerland.

Caravans with environmentally friendly electrics, chainsaws which don't need smelly diesel generators, wheelchairs with efficient drives – PowerPac can make all this possible. This fuel cell system converts hydrogen into water and heat, thereby directly generating electrical current. It has been designed for the power range from 500 to 2000 watts – to power all types of portable device and small vehicles.

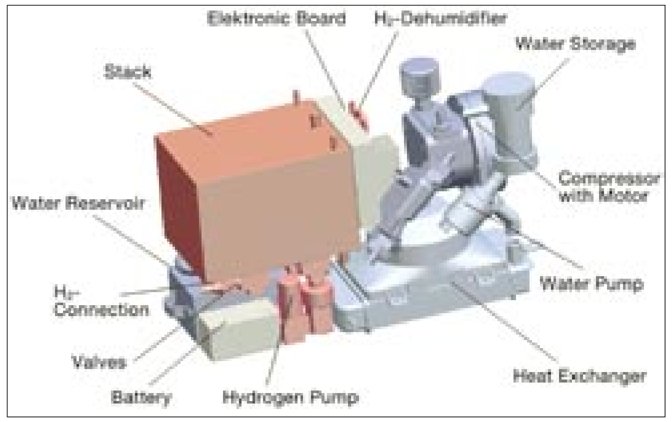
A special type of technology is used in PowerPac. Unlike fuel cells for motorised drives or combined heat and power in heating systems, the design of the system must be as simple, compact and light as possible. A team of researchers from PSI and the Swiss Federal Institute of Technology in Zurich have spent the past two years working on crucial concepts for PowerPac. The team has tested and patented innovations relating to the electrochemical process and to design, including a concept for an integrated humidification of process air. The project is being financed by the Swiss Federal Office of Energy, the Swiss Federal Institute of Technology in Zurich and PSI.

Compact and portable: The PowerPac power generator developed by PSI and the Swiss Federal Institute of Technology in Zurich is approx. 60 cm long, 35 cm high and weighs 20 kg (design illustration courtesy of Tribecraft AG).

Product with global market potential

The team from PSI and the Swiss Federal Institute of Technology in Zurich built the prototype for a 1,000 watt system together with a number of industrial partners. It is expected that the modular product range will enjoy high levels of market success due to the numerous advantages it offers: it has a high efficiency in the region of 40 %, low hydrogen consumption levels, it can be refuelled up quickly and emits low levels of noise. PowerPac is also extremely environmentally friendly, which is an increasingly important feature in the face of global warming.

The product is not expected to go onto the market for a number of years yet. However, the advanced key technology developed by the PowerPac researchers was recognized at the Swiss Technology Awards 2003 with the awarding of one of the most sought-after prizes for Swiss innovation. At the heart of this power package of tomorrow are fuel cells which are able to produce electricity from hydrogen with practically no pollutant by-products. Crucial to the protection of the environment is the way in which the hydrogen is produced. If the fuel is produced with fossil fuels, PowerPac will only be pollutant-free and climatically neutral on the local scale. The most environmentally-friendly way to produce hydrogen is from renewable resources such as solar energy or wood, as neither pollutants nor greenhouse gases occur in the energy process chain of the power generator.



Let's take a look inside: Structure of the fuel cell system (illustration courtesy of ZPE/ETHZ).

PSI Training and Education

Meeting Point of different students

Higher Education

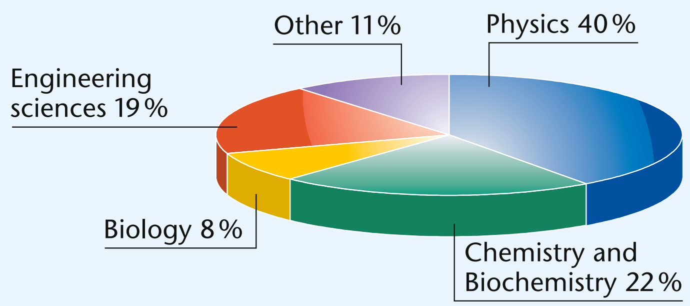
Apprentices

For High Schools

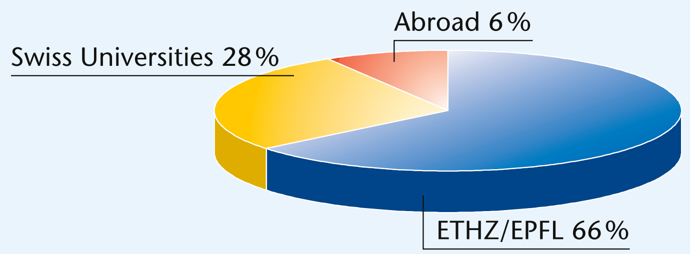
Radiation Protection & Reactor School

The technical laboratory ▶

Attractive steps on the career ladder



Basic training completed by doctorate students working at PSI. 27% of these are women.



Educational backgrounds of students studying for doctorates at PSI facilities.

Numerous students undergo training at PSI as part of undergraduate or graduate courses – in close collaboration with universities.

More than 240 students are currently using PSI facilities to prepare for their doctorates as part of internal or external research groups. In the year under review, 172 of them were financed by PSI. The majority of the doctorate students had completed first degrees in physics, chemistry and engineering sciences. They come primarily from the Swiss Federal Institute of Technology in Zurich, the Swiss Federal Institute of Technology in Lausanne and the Universities of Zurich, Berne and Basel.

In 2002, 34 students completed their doctorate studies at PSI. Eight of them were women. The subjects studied ranged from "Investigations into magnetic penetration depth in YBa_2Cu_{7-d} films with low-energy muons" to "Using electrochemical impedance spectroscopy to characterize selected phenomena in the polymer electrolyte fuel cell".

A popular place for practical training

37 diploma studies, the majority of which were written by students from the Swiss Federal Institute of Technology in Zurich, were also completed at PSI. The Institute is also a popular place for practical training. In 2002, 54 people took the opportunity to use our facilities for their experiments. Three quarters of these held foreign passports and 24% were women. Most practical students (and doctorate students) worked in the General Energy Department (ENE).

Inside the new research building ▶

High-tech youngsters hit the Grisons mountains

Training camp 2002: Building new byres at Reischen, Grisons.

With its complex research facilities, PSI relies on qualified professionals. It is for this reason that the Institute trains its own personnel and currently has 75 apprentices. Once a year, the young trainees leave their workstations to work in unfamiliar surroundings.

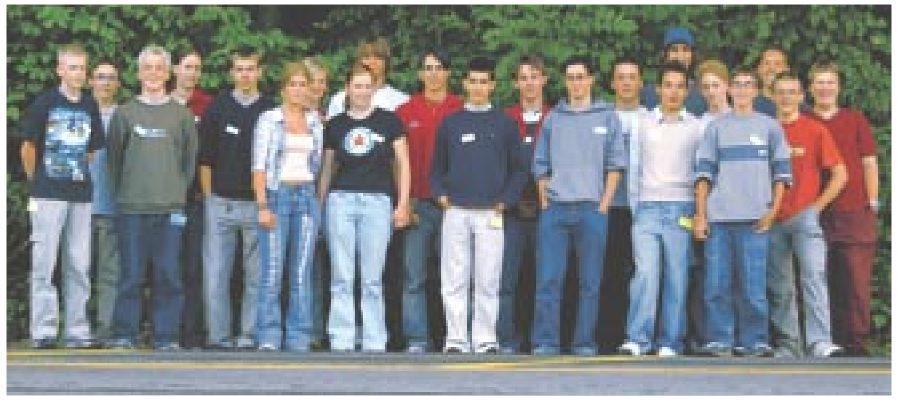
Away from the research institute and up into the Grisons mountains. This perfectly describes the training camp held by the PSI in September 2002. Helping to build new byres at Reischen and Vaz, providing access to the historically significant lead and silver mine on Alp Taspegn (2,200 m above sea level), lending a hand renovating an alpine dairy, putting up railings at a dangerous point on the old Viamala road, helping a farmer to build his house in Zillis – the wide range of work undertaken demonstrates just how involved our trainees became with the mountain population.

The annual training camp is always an important event in our vocational training programme. It forges friendships between trainees, encourages an understanding of other social classes and is a welcome break from daily routine. The trainees and the team that accompanied them more than willingly donated over 2000 unpaid working hours to the public, in the process gaining valuable experience for life that cannot be measured in terms of educational grades.

Cultural activities: Access to the former lead and silver mine on Alp Taspegn.

Arrivals and departures

All 19 of this year's PSI trainees passed their final examinations in the year under review. A graduation ceremony hosted by Director Ralph A. Eichler was held for them at the beginning of August. Out with the old, in with the new: this year, PSI welcomed 21 new trainees. Most of them will become professionals such as automation engineers, polymechanics, technicians in chemistry and physics laboratories, electronics engineers, logistics assistants and design engineers. However, the PSI also needs office personnel and chefs.



Just starting out: 21 young trainees began their apprenticeships at PSI in 2002.

Where dwarves and giants come together

Physics for the young: PSI Director Ralph Eichler demonstrates the attributes of matter beams.

Eighteen pre-graduation students – five girls and thirteen boys – from high schools in the Aargau und Solothurn cantons of Switzerland voluntarily gave up part of their autumn holiday in exchange for a rather extraordinary week. The subject, "From the very smallest to the very largest – elementary particle physics and astrophysics" aroused a great deal of interest amongst these very talented youngsters.

Many intelligent and gifted young people long for an opportunity to delve into the fascinating worlds of the microcosm and macrocosm. Buzzwords such as quarks and big bang have real resonance. Some young people even harbour a secret desire to one day be at the forefront of knowledge and discovery. Research into the innermost interrelationships of our cosmos is a cultural challenge whose benefits are by no means superficial and it befits our Institute to take it on. Particle physics and astrophysics are part of the core activities of PSI and are a significant factor in its world-class reputation.

The ninth autumn school, which took place from October 7 to 11, 2002, gave the next generation of experts an opportunity to see the world of research for themselves, a world where the smallest and largest dimensions collide and which poses probing questions about culture and philosophy. PSI scientists shared ideas with the 18 highly-motivated representatives of the next generation which may just influence their chosen careers. In this way, the autumn school makes a worthwhile contribution to shaping the future.

Exotic atoms: Participants at the 2002 autumn school identifying the properties of special particles.

Further education for teachers

No end in sight for the periodic table

Radio chemistry at PSI.

Over 40 chemistry teachers from high schools in the German-speaking part of Switzerland took the opportunity to spend two days at PSI learning about the latest research topics.

How are new chemical elements discovered? What can alpine glaciers tell us about the climates of the past? What is the current and future efficiency of fuel cells? As 41 teachers from high schools in German-speaking Switzerland were able to discover, chemical research is wide and varied. On November 11 and 12, 2002, they visited PSI and attended lectures, visited the SLS and the psi forum and saw the radiation protection school and various laboratories.

Interest in the latest developments in radiochemistry, electrochemistry, solar chemistry and environmental chemistry was high. Many questions addressed the issue of how the latest discoveries can be applied in high-school classrooms. The course was of mutual benefit: the researchers were able to see how their work might be applied on a daily basis and the teachers were able to increase their scientific awareness. This could lead to more pre-graduation high-school students electing to study natural sciences. An excellent result.

Zuoz summer schools

Weeks of physical attraction

PSI has been holding annual summer schools at Lyceum Alpinum in Zuoz for more than 30 years. In the year under review, two courses took centre stage, addressing the themes of magnetism and attacking the standard model.

The inauguration of the Swiss Light Source (SLS) has considerably increased the scope of potential experiments at PSI. For this reason the traditional summer school was reworked in order to take into account all three microscopic probes used for research into condensed matter (solids and liquids) at PSI. From 10 to 17 August 2002, the theme of magnetism took centre stage as we welcomed 100 participants, mostly enthusiastic young scientists, to the Engadine from 18 countries.

In the week that followed, particle physicists attended their summer school at Zuoz. 81 experts from all over the world took part in intense discussions addressing discrepancies in the Standard Model. PSI is also involved in studying the limits of this model describing the fundamental structure of matter and is attempting to identify possible deviations from it – muon disintegration processes for example, which, according to the Standard Model, are "not permitted".

Group photo from the Grisons: These students at the 2002 summer school, with one or two female students among them, were able to learn a great deal about magnetic phenomena, models and experiments.

Radiation protection

Transporting radioactive materials safely

Metrology: How much radiation is being emitted from the container?

The radiation protection school at PSI has taken the necessary steps in good time in order to ensure adherence to new national legislation in Switzerland. It now even provides a training course for the transportation of radioactive goods.

The Swiss ordinance on officers for the prevention of the risks inherent in the carriage of dangerous goods by road, rail and water (GGBV), which came into force in 2001, specifies requirements in respect of the duties and training of personnel responsible for minimizing the risks which may arise from the packaging, loading, transportation and unloading of dangerous goods. This ordinance ensures that the Swiss Federal Council meets its obligation in relation to the national transport treaty with the EU. By the end of 2002, every company transporting specific quantities of dangerous goods had to designate an officer for the prevention of the risks inherent in the carriage of dangerous goods who would be responsible for ensuring adherence to relevant legal requirements.

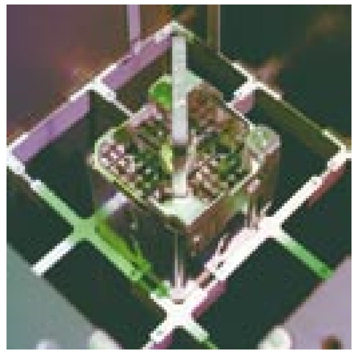
In order for goods to be transported in accordance with regulations, they must be classified according to risk. There are 9 classes of risk, and our school offers a five-day training course for Class 7, "Radioactive materials". It includes material relating to the basic concepts of radiation protection as applicable to the transportation of radioactive goods, radiation protection metrology, customs formalities, emergency protection and quality assurance. The certificate of vocational aptitude, or training certificate, is recognized by the regulatory authorities and is valid for 5 years. Candidates must pass a new examination before this period expires.

Nuclear power station technology

Know-how for operators on reactors

With its wide range of educational and training courses, the reactor school at PSI is a guaranteed source of basic theoretical training for technical specialists and advanced training for qualified operators in nuclear power stations.

The Advanced School for Technology is part of the PSI Nuclear Energy and Safety (NES) research department. It is financed by the Swiss association of electric power producers and distributors (UCS) and regulated by a supervisory committee comprising representatives from nuclear power stations and PSI. Other supervisory bodies include the Swiss Federal Safety Inspectorate and the Swiss Federal Office for Professional Education and Technology (OPET).



Proteus: Test reactor at PSI.

The school has a compact simulator designed to simulate interrelationships relating to reactor physics, control engineering and thermodynamics for the two types of nuclear power station operational in Switzerland (pressurized water reactor and boiling water reactor).

17 trainees started the T-32 full-time technical training course for prospective reactor operators in January 2002. Final examinations at the end of April 2003 will mark the end of the course.

By the end of 2002, the reactor school had successfully completed 11 technical training courses, 21 courses for reactor operators, 11 for reactor engineers and 3 for specialist engineers. A total of 473 people completed basic theoretical training in the field of nuclear power station technology. Advanced training for qualified operators during the same period included 14 shift-leader courses completed by 63 participants and 8 on-call engineer courses completed by 47 participants. 163 repeat courses and 51 refresher courses were attended by a total of 1576 participants.

Events 2002

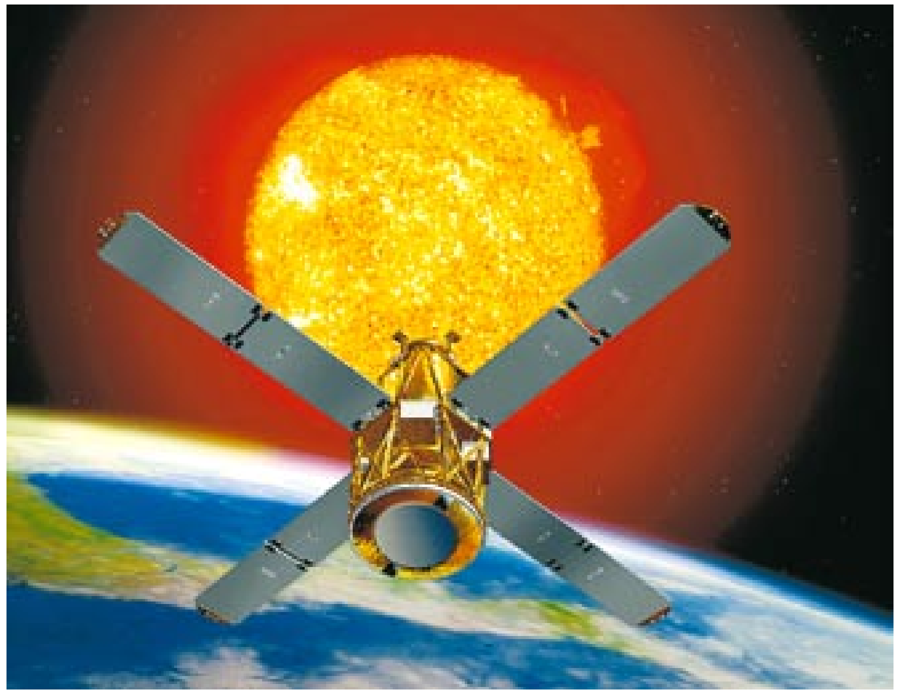
Selected Highlights

About a successfull satellite launch and
the PSI as magnet for the public

A glance into the Hotlab ▶

Success in space

HESSI has been circling the earth at an approximate height of 600 km since it was successfully launched on February 5, 2002. The satellite carries an X-ray telescope partly built by PSI to monitor high-energy solar activity.



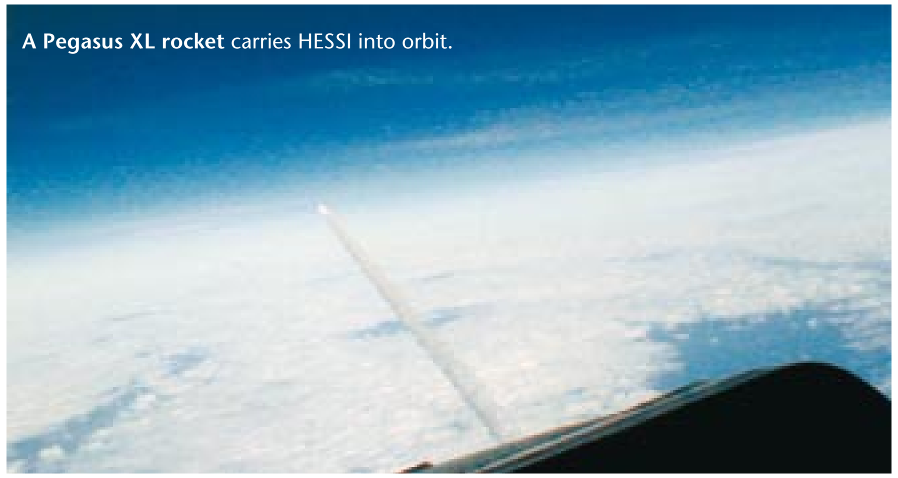
The HESSI satellite uses its instruments to measure solar bursts.

The HESSI satellite has been designed to measure hard X-ray and gamma ray solar emissions (3 keV to 17 MeV) over a period of three years. High-energy radiation is produced by electrons and protons with equivalent energies corresponding to temperatures of up to a thousand million degrees. Such particle energies do not occur in the quiet solar atmosphere, but are generated in what are known as flares, i.e. powerful bursts whose intensity and frequency reach the maximum of this 11-year cycle between 1999 and 2002 (see page 21).

Very intensive bursts lead to distorted solar winds that manifest themselves e.g. as polar lights. These events can threaten manned space stations and telecommunications satellites. The violent and sudden appearance of particles with extremely high energies poses fundamental astrophysical questions. One of the major objectives of the HESSI mission is to find answers to these questions. As it is impossible to generate conditions that cause flares (plasma density, temperature, etc.) on earth, the sun is used as a near-earth laboratory.

International co-operation

The High Energy Solar Spectroscopic Imager Satellite (HESSI) is an international project of the University of California at Berkeley, the Goddard Space Flight Center (USA), Spectrum Astro Inc. (USA) and Paul Scherrer Institute.



A Pegasus XL rocket carries HESSI into orbit.

PSI built the X-ray telescope and the systems for measuring the spacecraft orientation with regard to the centre of the sun, including the on-board computer.

Unlike visible light, hard X-rays and gamma rays cannot be focussed by lenses. As we know from medical X-ray images, dense matter attennuates the rays. The HESSI imager exploits this principle. The imager comprises 9 pairs of metal grids (collimators), through which the X-rays pass before each photon is analyzed in an X-ray detector.

The finest grid has a slit width of 20 micrometers (one third of a human hair). In order to guarantee accurate measurement the collimator pair, spaced by 1.500 mm must be aligned at a tolerance of less than 0.005 mm, which must be maintained during severe launch vibrations and in space. The HESSI team at PSI has solved the demanding task with great success.

PSI technology in the headlights

Sustained mobility: The VW Bora HY.POWER aroused the interest of the media and the public at the International Motor Show in Geneva.

Early in 2002 the VW Bora HY.POWER proved that a fuel cell drive – connected to a supercap storage device could work in practice. The prototype designed for sustainable mobility was exhibited at a number of public events.

Following the success of the operational test in which the Bora crossed the Simplon Pass in January, the vehicle made an appearance at the 2002 International Motor Show in Geneva. Numerous visitors were treated not only to a presentation of the zero-emission drive technology. They were also able to learn about the possible ways in which hydrogen can be generated on the basis of renewable raw materials. The vehicle's appearances were made possible by its sponsors, the VW importer in Switzerland, AMAG Schweiz AG, and Volkswagen AG in Germany.

Signal at the Earth Summit

Environmental pollution produced by vehicles was a central theme at the Earth Summit in Johannesburg. The VW Bora HY.POWER was on show at the high-profile event in South Africa at the end of August. The silver-grey vehicle was there to show the 60,000 participants how technology could be used to produce the environmentally friendly vehicles of the future.

The VW Bora HY.POWER is fitted with a fuel cell system comprising 6 stacks, each capable of outputting 8 kW of electricity. The supercap storage device has 282 individual cells and can output up to 60 kW for approximately 12 seconds. In order to drive the electric motor, the voltage is adapted using a AC/DC converter. The project is a collaboration between PSI, ETH Zurich, Volkswagen AG, FEV Motorentechnik GmbH and montena SA, with the financial support of the Swiss Federal Office of Energy and AMAG Schweiz AG.

High-profile visitors to the PSI stand: Next to Kaspar Villiger, Swiss Federal Councillor, and Micheline Calmy-Rey, then Geneva State Councillor, now Chairwoman of the Swiss Federal Department of Foreign Affairs.

A new Director at PSI

A well-respected Director bids us farewell

Meinrad K. Eberle was Director of PSI for ten years. Under his patronage, the Institute developed into a world-class research centre and user laboratory. He was succeeded by Ralph A. Eichler in mid-2002.

Colleagues held a party to bid farewell to the long-time Director of the Institute on June 19, 2002. The eight departments of PSI thanked Meinrad K. Eberle individually by springing four different types of surprise: amusing anecdotes from daily research activities, a highly intellectual classical concert held inside the Swiss Light Source (SLS), a refreshing trip down the river prior to the opening of the new barbeque and the baking of cakes and pastries using revolutionary production methods. The excellent weather, combined with the appeal and depth of ideas of each part of the celebration, made for an unforgettable day.

Professor Meinrad K. Eberle (on the right of the photo at the top; on the left of the photo at the bottom) was Director of PSI from 1992 until mid-2002.

New OFLG research laboratory

Building work on the East Site

A celebration was held on April 5, 2002, to mark the handing over of the building to PSI by representatives of the ETH board, the Construction Centre of Federal Research Institutes and the architects who had designed and built it.

During the 1990s, there was a significant lack of high-tech lab facilities at PSI. The ideal solution was to construct a new building on the East Site to house the East Research Laboratory and various other services. In conjunction with the renovation of the existing building complex, this would provide 750 m^2 of additional usable floor space.

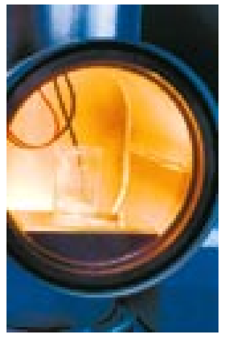
The basement of the seven-storey new building houses storerooms, electrical installation equipment for the building and laboratories that do not require daylight. Dry and wet laboratories covering varying amounts of floor space are located on the ground to third floors. In addition to the ventilation system, three conference rooms can be found on the top floor. Power is supplied vertically via vertical trunking in corridors and horizontally in laboratories via corridor ceilings. The new concept (supplying laboratories from above) has enabled us to expand our advanced power supply system at a relatively low cost.

Although furnishings have been kept simple, the architects have succeeded in creating a very pleasant working environment. The close co-operation with users during the detailed design phase is also to be commended.

The official opening party on the stairs of the state-of-the-art building.

Open Day

PSI draws the crowds



One Sunday in October, around 5,500 visitors flocked to PSI to see numerous experiments based on the theme "Surfaces – familiar and not so familiar limits". Researchers used the opportunity to encourage public interest in science.

Experts at PSI investigate surfaces in different ways. They develop better exhaust gas catalysts, detect tumour cells and test fuel rod cladding, identify the atomic miniature world of nanostructures, track short-lived muon particles and reveal what appears to be hidden.

The closer we get to surfaces, the more unfamiliar they seem to be. They obey physical laws we do not expect them to and complicated equipment is required in order to determine their chemical composition. Many secrets and unfamiliar perspectives of matter hide beneath them. Some surfaces are even able to change their properties like chameleons change colour. On October 20, 2002, PSI once again opened its doors to present its many and varied research projects to the general public.

Ice and vapour at the same time

Some truly amazing phenomena were on display. For example, visitors were able to see how water can boil and freeze at the same time, how a superconductor can float above a magnet and how electron beams can write more finely than human hair. The tour took in 24 stations from all the fields into which PSI carries out research. At each of the stations, experts were available to answer any and every question posed by visitors.

The number of people vying for space at some stations was overwhelming. The lines of waiting visitors were reminiscent of Expo.02, which was drawing to a close around the same time. Some 5,500 men, women and children made their way to Villigen on this sunny autumn day. The car parks were completely full and vehicles were parked bumper to bumper on the Aare Bridge. The OASE staff restaurant and the cafeterias did a roaring trade, selling over 900 complete meals and thousands of snacks. The number of visitors to the psi forum also reached a record level as 1,300 people passed through its doors.

A star in a circular cosmos

The pharmaceutical groups Novartis and Roche and Germany's Max Planck Society have invested jointly in a new synchrotron beamline at the PSI. The successful project had considerable media coverage.

The soon to be expected human clones, the falsified research results of the once celebrated nanophysicist Jan Hendrik Schön, a recent Swiss winner of the Nobel Prize (ETH Professor Kurt Wüthrich) – sensations, scandals and stars dominate media coverage, often excessively.

Star of the show: The SLS with the existing beamline for protein crystallography (photo H.R. Bramaz).

Stiff competition

In the face of stiff competition from politics, economics and cultural issues, science must also vie for its place in the press and for broadcast time on radio and television in order to gain any recognition whatsoever. In this race for news that will rouse interest, stories full of scandal and sensation will always have the upper hand. Background reports which discuss problems from various angles are left to struggle at the back of the field. Last November, PSI gave journalists an opportunity to gain access to more detailed information by inviting them to a media conference about a project of importance both to the Institute and to research in Switzerland.

The project came into being when the Max Planck Society (MPS), Roche and Novartis decided to build and use an additional beamline for protein crystallography at PSI. The MPS was to contribute half of the cost and each of the Basel-based pharmaceutical groups 25%. Total costs for building the beamline and running it for ten years are approximately 20 million Swiss francs.

Deciphering the atomic architecture

More than a dozen members of the media took up their invitations and congregated in the conference centre at the SLS. Experts gave specialist presentations about protein crystallography, a promising method, which is applied to decipher the atomic architecture of proteins. Almost all medicines act on proteins. Understanding these organic molecules is therefore the key to developing highly effective new medicines.

PSI's Swiss Light Source (SLS) is an invaluable instrument that really is fit for the future. Its potential benefits extend beyond the pharmaceutical industry, as material sciences, nano engineering and power engineering can also benefit.

Worth reporting

The media conference gave rise to numerous articles in both the regular press and in specialist publications. It was even the subject of radio reports. Despite the lack of scandal and sensation, the SLS succeeded in capturing the interest of the media, not least because of the visual impact and brilliance of the facility – a star among the circular giant microscopes. Surely that's worth reporting!

The audience: Media conference, November 7, 2002.

Daily marketing for our Institute

In addition to scientists, the general public are also frequent visitors to PSI. Research into areas of social relevance, large state-of-the-art research facilities and the attractive psi forum visitor centre all played their part in drawing over 16,000 visitors to PSI in 2002.

The Open Day was a huge success with the public and a clear sign of public interest in research. The high level of interest in science was also evident in the visitor service. Well over 300 groups visited PSI in 2002 and the psi forum's constant popularity was clear as it welcomed approximately 2,500 spontaneous visitors.

Visitors to the Institute came from all walks of life. From school groups of all ages to companies, industrial associations and groups from the health service to all manner of organisations. Enquiries from political and supervisory sources increased. An invitation was extended by the Aargau cantonal parliament to their colleagues in Schwyz to visit "their research centre". Presence Switzerland, which promotes our national image on behalf of the State, brought a number of overseas economics representatives to the Institute and presented it as an advertisement for the status of research in Switzerland.

Krebsliga und Krebsforschung Schweiz (Swiss Cancer Organisations) held an important major event for its patrons in November. On two occasions, 200 people took the opportunity to come to PSI and find out more about the potential of proton-based radiotherapy and how their donations are put to use in research projects.

Patrons of Krebsliga und Krebsforschung Schweiz **visit the proton therapy facility.**

Tailor-made tours

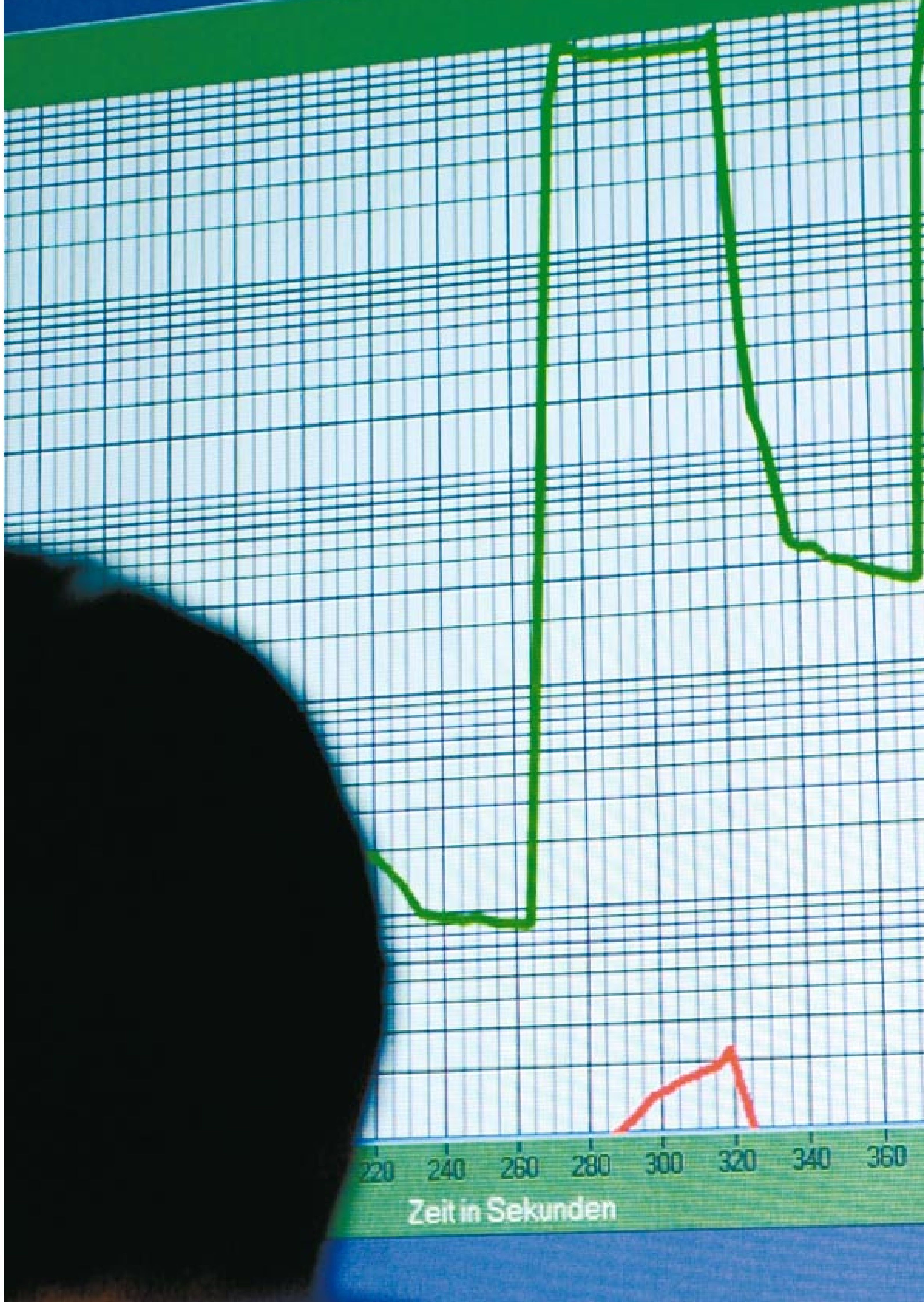
The high level of demand can also be attributed to the quality of the facilities available. In the areas of General Energy (ENE) and Large Research Facilities (GFA) we added two new visitor stations in order to help visitors familiarize themselves more effectively with the surroundings. PSI can provide tailor-made tours led by qualified specialists. Groups are afforded direct contact with researchers, who are more than happy to talk about the work they do on a daily basis. Visitors come within touching distance of the large facilities. Every visitor, whether sceptical or inquisitive, is taken seriously.

PSI has earned itself an ever more prominent place in the consciousness of the Swiss population and its profile within the country has increased. Setting up an effective and efficient visitor service has proved a successful marketing tool.

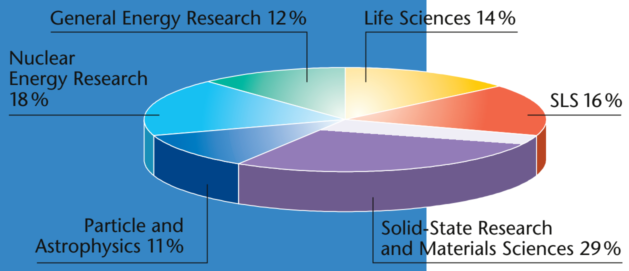
The fascinating world of research in the psi forum for young and old.

Statistics & Organization

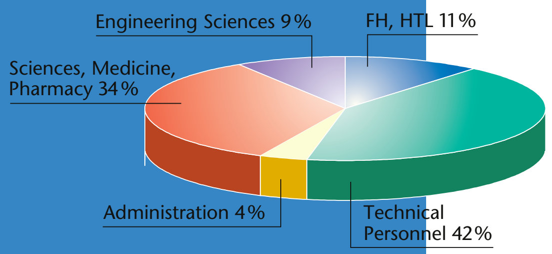
Results of a vacuum experiment ▶



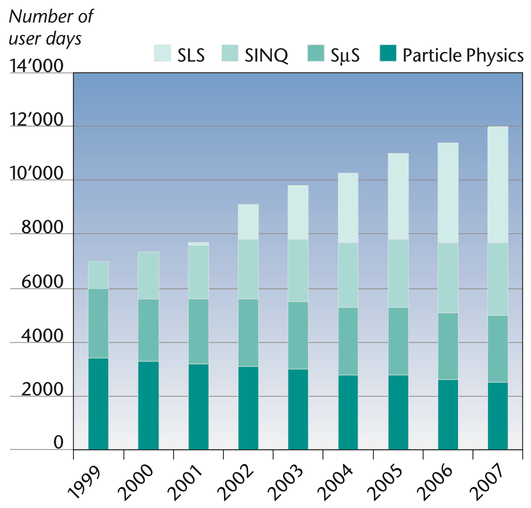
PSI in figures



In the distribution of total funding in 2002 (incl. external funding) amongst the main areas of activity (product groups) at PSI, research facilities – in particular accelerators and the SINQ – have been assigned to individual areas of focus; data for the SLS is recorded separately and accounted for 16% of the total funding of PSI (100% = 253.8 million Swiss francs).



The make-up of our personnel clearly indicates that PSI is taking on the function of a user lab: the large research facilities and the complex instrumental research equipment require a large number of technical personnel (100% = 1200).



A user laboratory with an international reputation: The graphic shows the total number of days on which researchers have used PSI facilities since 1999 and forecasts up to 2007. The increase in the number of user days is considerable due to the introduction of new facilities and instruments along with the optimization of existing ones.

In the year under review, PSI spent 253.8 million Swiss francs on research and development, building and operating research facilities as well as on services. Of this amount, the Swiss Confederation contributed 216.6 million Swiss francs. This is 11.7 million Swiss francs less than in 2001 and indicated the loss of the 10 million Swiss francs previously allocated to the SLS.

In the year 2002, 60% of our external funding was provided by the private sector and more than a quarter by the Swiss Confederation's research funding programme (Swiss National Science Foundation, Swiss Federal Office of Energy). 12% of our external funding came from EU programmes. Of PSI overall funding, 52.5 million Swiss francs (20%) were used for investments and 149.4 million Swiss francs (59%) were allocated to personnel costs.

Approximately 75% of the total expenditure in 2002 was spent on PSI user labs. The high number of applications received from users, most of whom came from outside PSI, meant a significant reduction in PSI in-house research. This particularly effected areas of research which only have an indirect connection with PSI user labs. However, optimum advice and support can only be provided for the external users of our research facilities if we can maintain the level of expertise and quality of PSI in-house research on the facilities.

At the end of 2002, a total of approx. 1,200 people were employed at PSI, most of whom (77%) live in the Aargau canton and the remainder in Zurich and surroundings (12%) and outside Switzerland (7%). 12% of employees are women and almost 40% hold a foreign passport. In the year under review, more than 240 doctorate students completed all or part of their theses at PSI. Of these, 172 received financial support from PSI (see page 72). The doctorate students also benefited from the research facilities provided by PSI and were advised and supported by PSI employees. In addition, 76 apprentices were also undergoing vocational training at PSI.

Organizational Structure for the Paul Scherrer Institute (August 1st, 2002)

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Department **Logistics and Marketing (LOG)** Department Head: H.-U. Boksberger	Finance and Administration Radiation Safety and Security Infrastructure and Electronical Engineering Mechanical Engineering Sciences Information Technology Buildings and Services	R. Gottardi Dr. R. Andres Dr. F. Jenni Dr. S. Zelenika Dr. St. Egli H.-U. Boksberger a.i.

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PSI Research Commission

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Prof. Dr. K. Ballmer	Life Sciences (BIO)
Dr. B. Delley	Condensed Matter Research with Neutrons and Muons (NUM)
Dr. J. Hadermann	Nuclear Energy and Safety (NES)
Dr. R. Henneck	Particles and Matter (TEM)
Dr. P. Hosemann	Nuclear Energy and Safety (NES)
Dr. G. G. Scherer	General Energy (ENE)
Dr. N. Schlumpf	Particles and Matter (TEM)
Dr. L. Simons	Particles and Matter (TEM)
Dr. U. Staub	Synchrotron Radiation (SYN)
Dr. W. Wagner	Condensed Matter Research with Neutrons and Muons (NUM)
Dr. P. Hasler, Secretary	Life Sciences (BIO)

Permanent Guest (President of the ETH Zurich Research Commission)

Prof. Dr. A. Green	Institute of Geophysics, ETH Zurich, CH

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