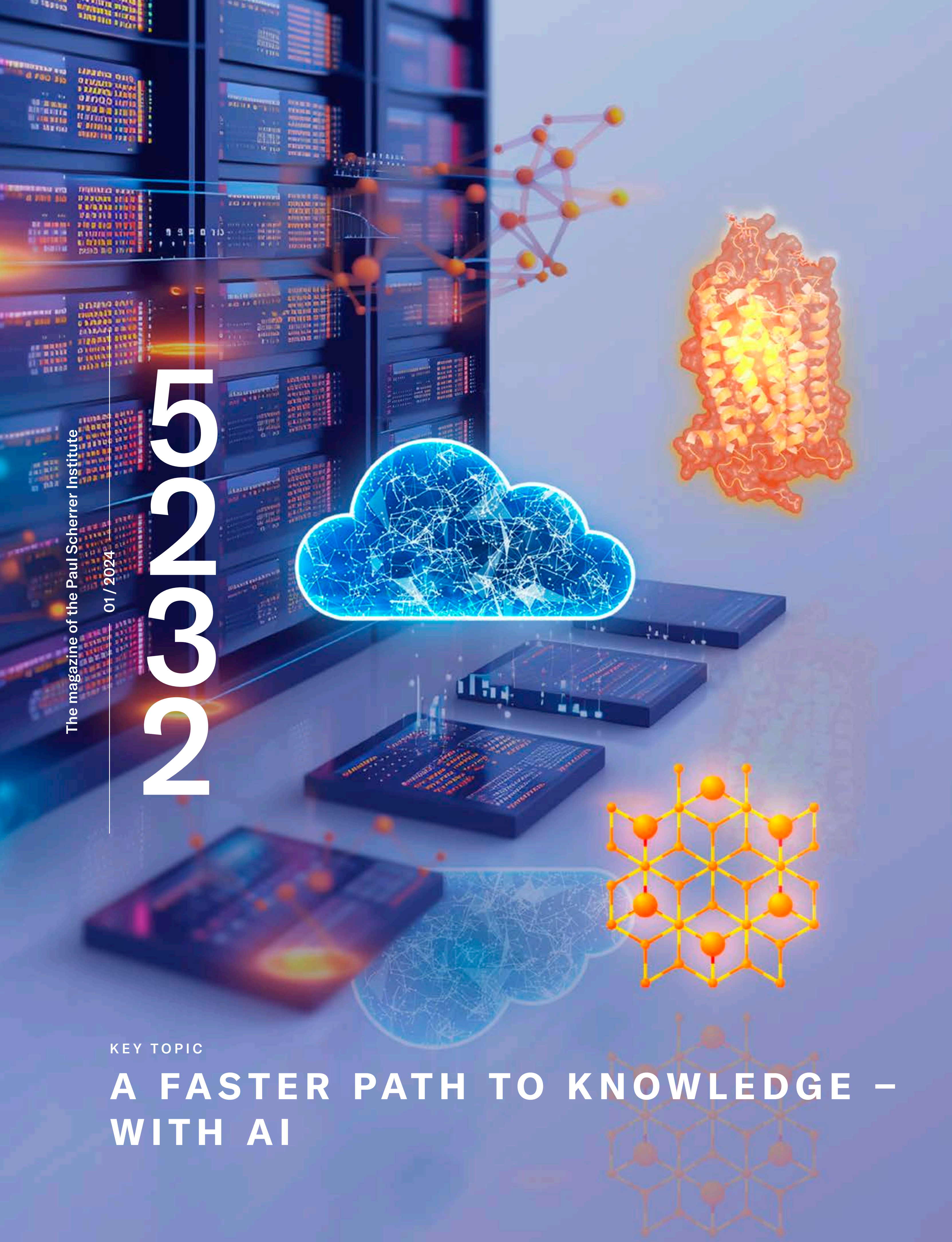

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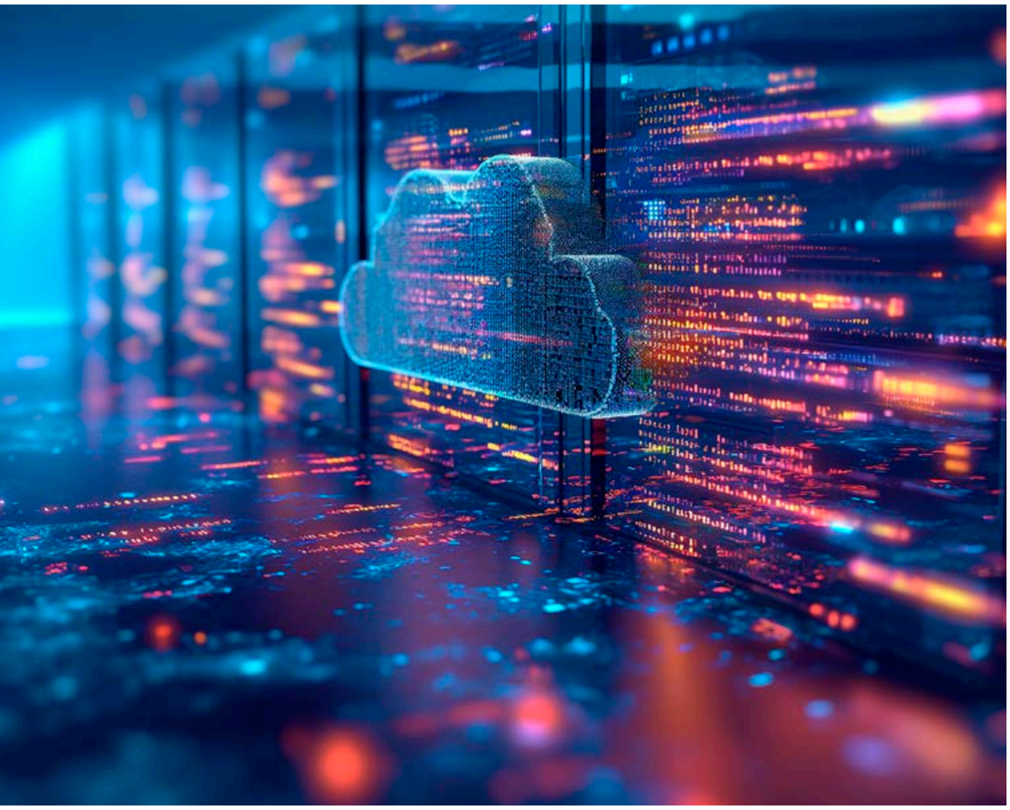
The magazine of the Paul Scherrer Institute

01 / 2024

KEY TOPIC

A FASTER PATH TO KNOWLEDGE – WITH AI

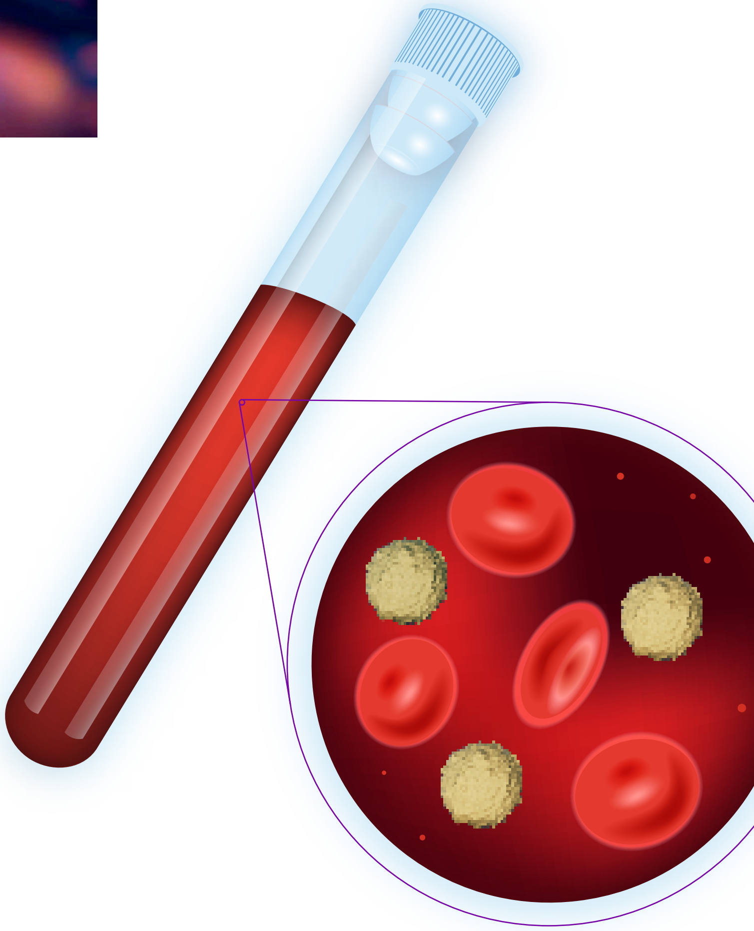


BACKGROUND

A potential shortcut

Researchers at PSI are opening up new paths to knowledge. In doing so they are, for example, discovering novel materials, improving the safety of nuclear power plants and optimising the analysis of aerosols in atmospheric research.

Page 10



BACKGROUND

Fundamentally different

Proteins are the workhorses of life. Hardly anything happens in biological cells without them. Their composition, from different amino acids, is crucial to their functionality. Strung together like a string of pearls, these essentially determine a protein's properties. Researchers at PSI are using artificial intelligence to decipher this code.

Page 18

INFOGRAPHIC

Targeting tumours

Artificial intelligence can, among other things, recognise patterns quickly and accurately. The big advantage: with appropriate training, it can also identify patterns previously unknown to it. PSI researchers are using this to improve tumour diagnosis and also monitor the success of therapie.

Page 16

CONTENTS

Christian Rüegg, PSI Director

An invaluable tool

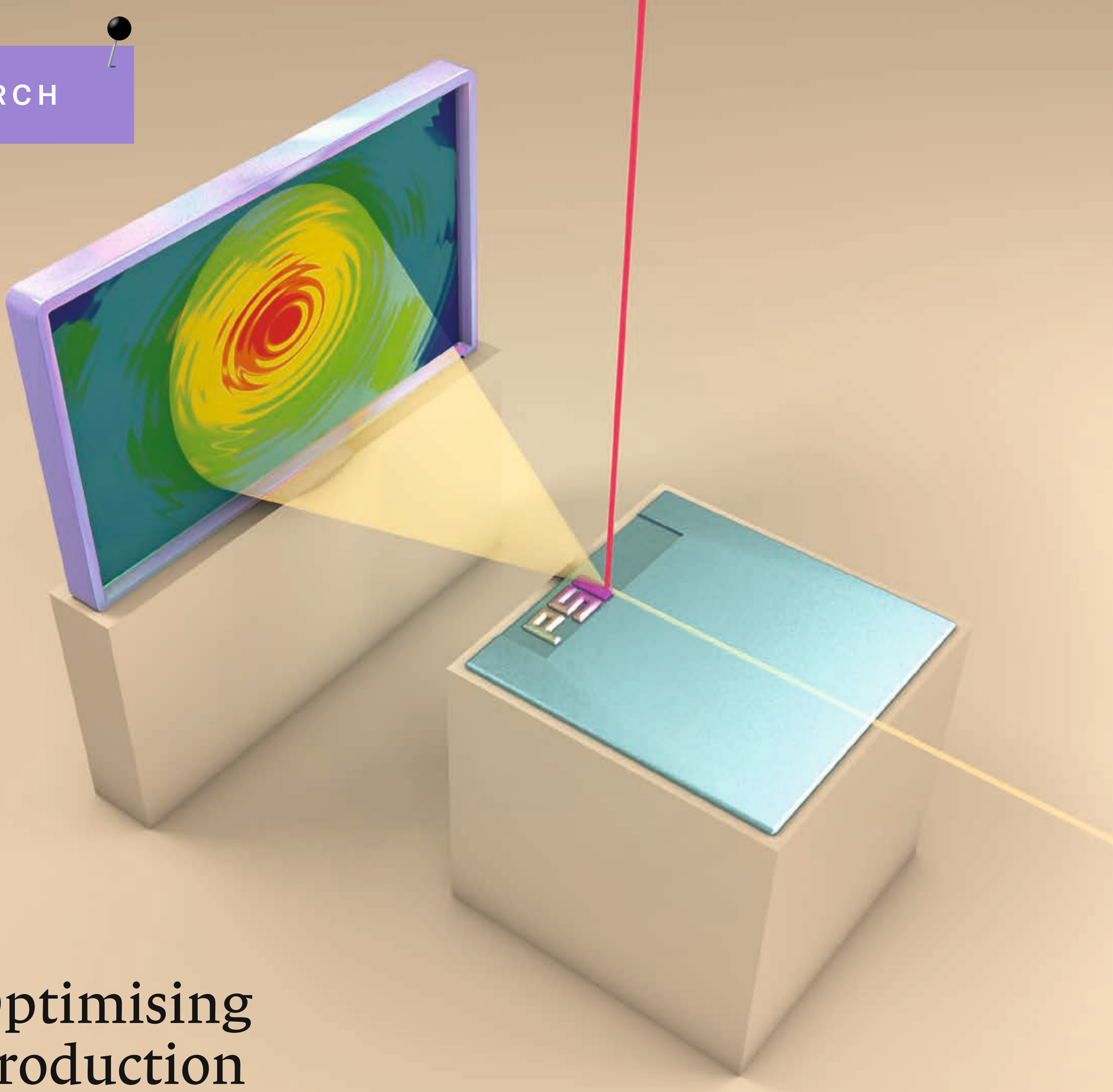
Artificial intelligence (AI) is making a lot of noise and changing modern research: it is improving the way we do science and accelerating the pace of new discoveries. In just a short time, it has become an indispensable tool in research, and will surely play its part in deciphering previously unsolved mysteries.

Two key strengths of AI are its ability to process huge amounts of data on the one hand, and on the other to recognise patterns rapidly and with precision. This perfectly matches the requirements of many researchers at PSI, since we generate enormous amounts of data with our large research facilities. To handle that, we not only need AI models, but also the appropriate infrastructure, such as data lines and computers. AI already provides valuable assistance, enabling advances in fields that play a central role at PSI – for example, in medical and pharmaceutical research, and in energy and environmental sciences. We show you some outstanding examples in this issue. One thing is clear: artificial intelligence is an invaluable tool. But clever minds will always be needed to use it appropriately. Obviously, that includes using this new technology responsibly, ensuring that it serves the well-being of society.

Besides all its useful aspects, AI can also bring more fun to life. To demonstrate this, we have designed part of this issue with appropriate AI applications, though naturally under the constant professional guidance of our staff. The backdrop you see behind me is a good example: this server room was generated using AI and does not exist in reality – neither on the premises of PSI nor anywhere else. It is a pure invention using AI. I invite you to immerse yourself in the exciting world of research with AI at PSI.

Beautifully colourful

A rainbow is the best example of how bright daylight is made up of many different colours. But you can also observe this when light falls on the underside of a CD or DVD. Then, very much like a rainbow, different light reflections appear in rainbow colours. This phenomenon is based on the diffraction of light, since daylight is composed of different wavelengths. We perceive these individually as colours: for example blue, green, yellow, or red. The underside of a DVD, contrary to what its reflective surface suggests, is not smooth but has tiny grooves and elevations for storing information. If white light falls on the CD, it is diffracted by the grooves and elevations. The diffraction occurs differently for the various colours, which in turn leads to the splitting of light into its different colour components. Our eyes are then able to perceive these individually, allowing us to enjoy the beautiful rainbow colours.



Optimising production

Just like visible light, X-ray light can be diffracted, such as when it penetrates material samples. Behind the sample – similarly to what happens when light falls on the underside of a DVD – a special diffraction pattern develops which depends on the composition of the respective sample material. For non-scientists, these diffraction patterns appear diffuse. But by applying complex techniques, researchers at PSI can precisely determine the specific character of the sample. They can then use this information, for example, to find out how 3D printing can be optimised. In that process, a laser (represented here as a red beam) falls on a powder and solidifies it layer by layer. The X-ray light generated with the help of the Swiss Light Source SLS shines through the sample and is diffracted according to its composition. By analysing the diffraction pattern, researchers can then detect changes in the local structure and establish a correlation with the printing parameters.

1 BACKGROUND
A potential shortcut
Page 10

KEY TOPIC

A faster path to knowledge – with AI

Artificial intelligence is revolutionising research. Not only does it produce results more rapidly and with less experimental effort, it also opens up completely new pathways of understanding to explore the fundamentals of nature and matter. PSI researchers are exploiting the advantages AI offers them – whether in materials, atmospheric, nuclear or medical research.

Magazine with AI

We designed the backgrounds for the cover, the editorial, and the entire main topic of this issue using the AI application Midjourney. That was helpful, and exciting. But as always, the expertise of our staff in design and photography was required for the finishing touches, to ensure that the backgrounds and the photographs of researchers looked just right.

A potential shortcut

Today, machine learning and artificial intelligence are part of the toolkit for most researchers at PSI. In many cases these methods are fundamentally transforming the way we do science.

Text: Bernd Müller

Could the future of the world and all the atoms in the universe be calculated? An intelligent entity with knowledge of all the forces would be able to do it, according to French mathematician Pierre-Simon Laplace (1749–1827). "To it, nothing would be uncertain: it could make sense of both the future and the past." But now we know that Laplace was wrong: the universe can never be completely calculated and predicted. This has been resoundingly proven by the theory of relativity and quantum physics, among other things.

Really? Maybe Laplace's demon, as it's called, knows some kind of shortcut that allows it to infer an effect from a cause without needing to perform all the physical calculations in between. This shortcut actually exists and is referred to as machine learning and deep learning with neural networks. Both are forms of artificial intelligence.

Today machine learning is an integral part of physics, chemistry, biology and many other scientific disciplines. Most of the time this involves recognising connections without investing the computational effort that would be necessary to solve all of the physical equations in the Laplacian sense. At PSI, machine learning, neural networks and AI-based methods are applied in many projects. Four examples show how these methods are changing – one could say revolutionising – research at PSI.

Materials research: No more trial and error

What happens in a lithium-ion battery? When the battery is charged, lithium ions migrate into the cathode; when the battery is discharged, the ions migrate out of the cathode again. In the process, the number of electrons in the cathode material is constantly changing; that much is known. "But up to now, computer calculations have had difficulty accurately capturing exactly what is happening, especially what forces are at work," says Nicola Marzari, head of PSI's Laboratory for Materials Simulations and professor at EPFL in Lausanne. But this is crucial, for building better batteries for example for electric vehicles. To calculate these processes, physicists like Marzari use the Schrödinger equation, the most basic – yet also, unfortunately, very complex – equation in quantum physics. Calculating the dynamics of just a few lithium ions during charging and discharging would require the computational power of all the computers in the world. Fortunately, chemist Walter Kohn managed to simplify the numerical application of the Schrödinger equation in 1965.

Yet even in this form, it exceeds today's computational capacities. Here it would be useful if there were a shortcut that bypasses the complex calculation and infers the result directly from the starting conditions – without having to consider the behaviour of each individual lithium ion. This sounds like a job for machine learning – and that's exactly what researchers have been using successfully for several years. "Our model is a black box: it delivers the dynamics of the lithium ions directly without the complexity of thorough quantum calculations," Marzari says.

But first the model must be trained. To do that, Marzari uses Walter Kohn's theory to calculate many different atomic configurations, varying temperature, displacements and the diffusion of all the atoms of a material. In this way he generates physical "snapshots" that he feeds into the model. Once trained, the model is able to generate new snapshots without the need for complicated formulas and massive computing power. The PSI team is using this method to develop solid electrolytes for batteries that will not catch fire as easily as current ones with flammable liquid electrolytes. For large-scale energy storage, it would also be interesting to see if lithium could be replaced with other materials that are more common in the earth's crust, such as sodium, magnesium and potassium.

Better materials for batteries are just one example showing how quantum simulation and machine learning are revolutionising materials research. At PSI's Laboratory for Materials Simulations, which is part of the Scientific Computing, Theory and Data Research Division founded in 2021, scientists develop and refine computational methods for predicting and characterising the properties of materials. The laboratory collaborates closely on this with

Nicola Marzari, head of PSI's Laboratory for Materials Simulations and professor at EPFL in Lausanne, is searching for new compounds with unique electronic and magnetic properties, like jacutingaite – represented here as a structural formula.

Terttaliisa Lind, an engineer in the Laboratory for Reactor Physics and Thermal Hydraulics at PSI, and her colleague, energy engineer Christophe D'Alessandro, are developing simulations for safely controlling accidents in nuclear power plants.

EPFL and MARVEL, which likewise is headed by Marzari. MARVEL stands for Materials Revolution: Computational Design and Discovery of Novel Materials. It is one of the national research priorities funded by the Swiss National Science Foundation over the period 2014 to 2026. "We want to understand how materials behave and what properties they have, to find new and better materials," the scientist explains. "We can do this without experimental input. We actually work solely on the basis of fundamental quantum simulation. But then we go to our colleagues at PSI who carry out the experiments, and we work together on the synthesis and testing of these materials."

One example in which the trial-and-error principle still worked is graphene, a carbon layer just atoms thick, with a large number of carbon atoms arranged in a honeycomb pattern. It is this two-dimensional platelet form that gives graphene its special properties. For decades, researchers cleaned graphite, which they used as a test material in the laboratory, by sticking an adhesive strip on it and peeling it off. In 2004, when two physicists first examined the residue on the tape, they discovered the extremely thin carbon layers of graphene. Graphene has fascinating properties, which earned its discoverers the Nobel Prize in 2010.

With MARVEL, graphene might have been found earlier. PSI and EPFL researchers have used their computers to investigate the properties of inorganic crystalline materials such as silicon, gallium arsenide and perovskites. From 80,000 known inorganic compounds, they used quantum mechanical algorithms, simulations and machine learning to identify more than 2,000 materials that can be peeled off in two-dimensional layers. It should be possible to produce these from a three-dimensional starting material, just as easily as graphene is made from graphite.

A first success story from this work was jacutingaite. This mineral, discovered in Brazil in 2008, consists of platinum, mercury and selenium. It has nearly the same structure as graphene but is much heavier. Marzari's team used its simulation methods to predict the unique electrical and magnetic properties of jacutingaite. It is the first and so far the only known material that realises the physics of a quantum spin Hall insulator, conceived in 2005 by two theoretical physicists at the University of Pennsylvania, Charles Kane and Gene Mele. Inspired by this discovery, experimenters at the University of Geneva managed to produce jacutingaite artificially and examine it using synchrotron radiation. The result: the predictions were experimentally confirmed, precisely.

> "We create simulations with real physics, which is calculated at every moment."
>
> Terttaliisa Lind, engineer in the Laboratory for Reactor Physics and Thermal-Hydraulics (LRT)

Nuclear power plants: safely mastering accidents

There's something you do not want to experience in any nuclear power plant: the electric power goes out and the coolant pump stops. The nuclear reactor reaches a critical temperature. Now, quickly introduce cooling water to lower the temperature. But not too much, because that had fatal consequences in the 2011 Fukushima disaster in Japan. The scenarios used to train staff regularly to safely master possible accidents in nuclear power plants tend to run more or less the same way. But the simulations neither run fast enough nor represent the physical and chemical processes in the reactor with sufficient accuracy. Besides that, they only cover the kinds of minor accidents that occur frequently.

It's a different matter in the images viewed on a computer screen by Terttaliisa Lind, an engineer in the Laboratory for Reactor Physics and Thermal Hydraulics at PSI. "That's not a video," she says. "It's a simulation with real physics that is being calculated in every moment." If a test participant intervenes in the process, for example by opening a valve, the simulation adapts immediately. But how is that possible? The thermodynamic and chemical processes in a nuclear reactor are so complex that even the most powerful computer can't calculate them in real time. The computer would need ten minutes to calculate what happens in reality in one minute. This means that accidents – and serious ones in particular – cannot be simulated realistically. On the other hand, some processes that occur during an incident are very slow and can take hours. The test participants would spend most of their time twiddling their thumbs.

What the power plant operators need is simulations that run in real time but can also be accelerated without sacrificing accuracy. This is precisely what Lind is working on in a project for Euratom, an organisation for the coordination and monitoring of civilian use of nuclear energy and nuclear research in Europe. Her team is one of 14 partners from ten European countries. The project started in November 2022 and runs for four years. The goal of the project is to develop a simulator for unusual and severe accidents that will represent the processes realistically according to the laws of physics. "There is currently nothing like this," says Christophe D'Alessandro, an energy engineer and expert for ASTEC at PSI.

ASTEC is a system code, developed in France, for the simulation of serious accidents in nuclear power plants. It calculates thermohydraulic parameters such as pressure and temperatures in the reactor vessel, coolant circulation and containment, but it is very slow. In the Euratom project, D'Alessandro is developing the simulator and using a trick to do it: the model skips the multitude of physical formulas for which the computer needs so much time, and draws conclusions directly from the beginning to the end of a time step, for example when a test participant opens a valve. How does it work? Through machine learning. The model is fed with many ASTEC simulations, and at some point it is able to link causes and effects and predict the result just as correctly for new situations as if it had calculated all the formulas.

Cancer research: tracking down tumours

If detected early, cancer is often curable. An important step in this direction was achieved by G. V. Shivashankar, head of the Laboratory for Nanoscale Biology at PSI and Professor of Mechano-Genomics at ETH Zurich. His team was able to confirm that changes in the organisation of the cell nucleus of some blood cells provide reliable evidence of a tumour in the body. Using machine learning, the researchers can identify healthy and sick people with an accuracy of around 85 percent. They were also able to correctly distinguish between different types of tumours. They were able to correctly distinguish between melanoma, glioma, and ear, nose and throat tumours. "This is the first time, worldwide, that anyone has achieved this with an AI-based biomarker for chromatin imaging," says Shivashankar happily (see also Infographic, page 16).

The tumours give themselves away through the blood cells' chromatin – essentially a compact package of DNA resembling a ball of yarn. Using fluorescence microscopy, the researchers recorded properties such as the external texture, packing density and contrast of chromatin in the lymphocytes or monocytes – a total of around 200 features – using semi-supervised learning methods. They fed microscope images of samples from healthy and sick trial participants into a machine learning model. Once it was trained, the model could identify differences between healthy and diseased cells that would not be visible to human observers. In patients who had undergone treatment at the PSI Center for Proton Therapy CPT, the researchers also showed that the structure of the chromatin came closer to the normal pattern over the course of the treatment. This holds promise for potential approaches to the evaluation of therapeutic results.

Atmospheric chemistry: thousand-fold boost in calculation speed

You don't see them, but they're everywhere: aerosols, tiny particles in the air from dust, salt, pollen, exhaust fumes, tyre wear and many other sources. While rural residents inhale only a few hundred particles with each cubic centimetre of air, it can be tens of thousands in built-up areas – with corresponding health risks. To understand the formation and effects of aerosols, researchers in atmospheric chemistry measure the amounts and types of aerosols around the world using light-scattering experiments aboard satellites and aircraft, as well as ground-based measuring stations.

There's a problem: depending on the properties of the aerosols, the measurement data change. But how can you draw conclusions about the properties of the aerosols from the measurement data? Robin Modini and the Aerosol Physics and Optics team in PSI's Laboratory for Atmospheric Chemistry have gained groundbreaking insights in recent years – by training artificial neural networks in the computer, which are often used for pattern recognition. The researchers first use physical equations to simulate light-scattering patterns generated by the aerosols, and then train the neural network with these virtual patterns. The output of the neural network is the properties of the aerosols for specific measurement data. And then something like a magic trick comes into play: the polarity of the neural network can be reversed and then used to determine light-scattering patterns for specific aerosol properties.

Control measurements in the laboratory show how amazingly well this works. Samples of the air are fed into a polar nephelometer, which measures laser light scattered by the aerosols. These measurements fit the theory and the predictions of the neural network very well. With that, the researchers have a powerful instrument in hand that enables them to better understand scattering measurements from satellites and aircraft. But that's not all: because the physical equations are redundant after the neural network has been trained, the method is extremely fast. "With machine learning, we can calculate the properties of aerosols a thousand times faster than before," Robin Modini says. The researchers want to combine these algorithmic developments with their long-term aerosol monitoring, which has been carried out continuously on the Jungfraujoch since 1995. ◆

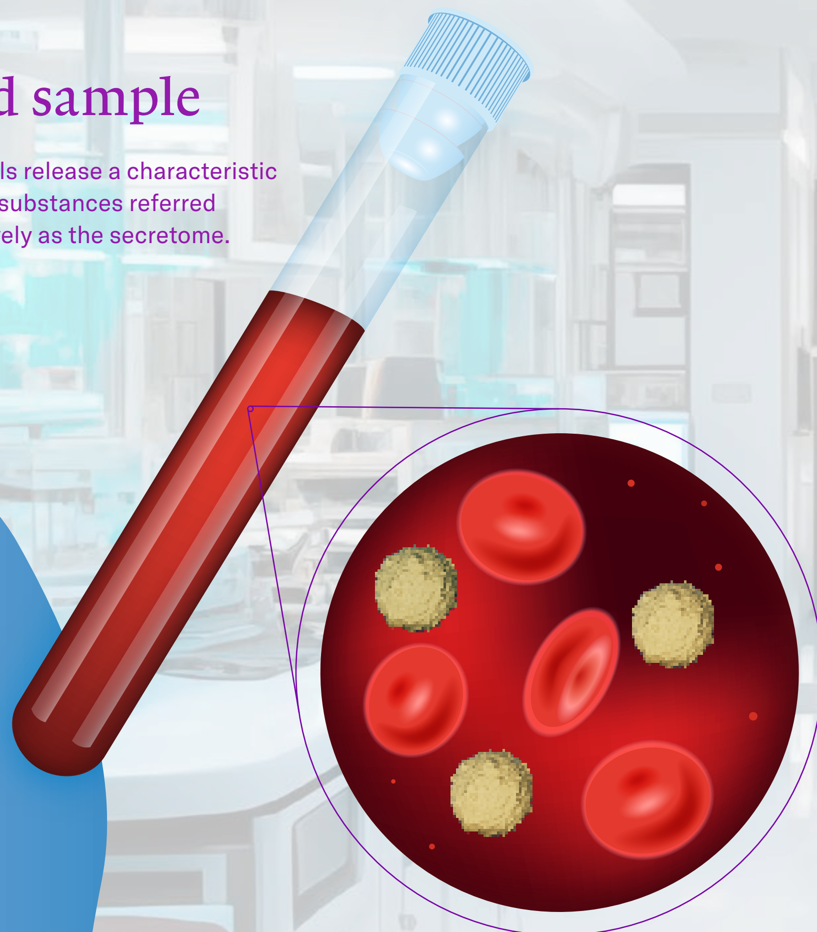
Robin Modini, from PSI's Laboratory for Atmospheric Chemistry, wants to improve the measurement of aerosols with the help of artificial intelligence. His methods are also expected to be used at the research station on the Jungfraujoch at a height of more than 3,000 metres.

Targeting tumours

Researchers at PSI are working to improve the diagnosis and treatment of tumours. Artificial intelligence can help, for example, by quickly and accurately detecting changes in blood cells revealed by imaging techniques.

Blood sample

Tumour cells release a characteristic mixture of substances referred to collectively as the secretome.



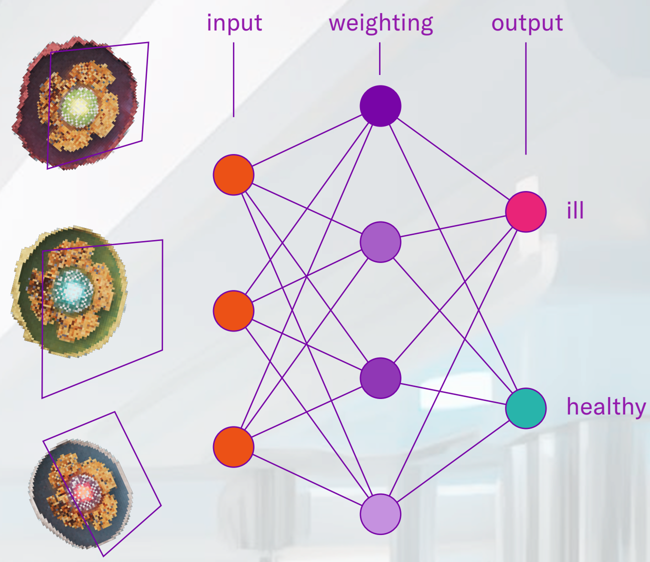
Blood cells

The secretome of tumours differs from one type of tumour to another. Certain cells in the blood (shown here in a yellowish tone), so-called mononuclear cells, react specifically to this in a way that changes their appearance.

Training the algorithm

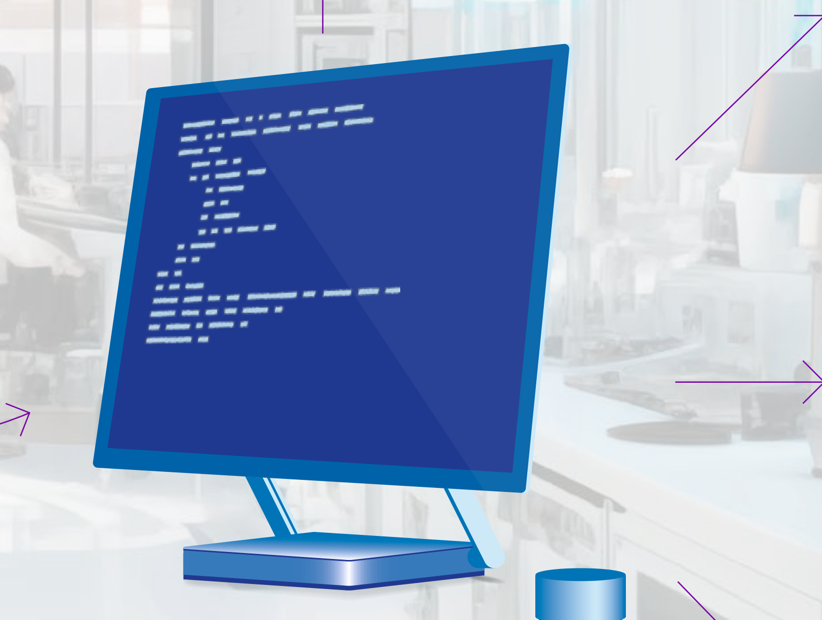
The computer receives images of cells as input. During the training phase, it learns to weight the various abnormalities according to their relevance. Using this weighting, it can estimate whether a cell might indicate a tumour or not. Ultimately, AI should also accurately recognise anomalous cells for which it has not previously been given an exact image as a template.

Further information:
https://psi.ch/en/node/60742

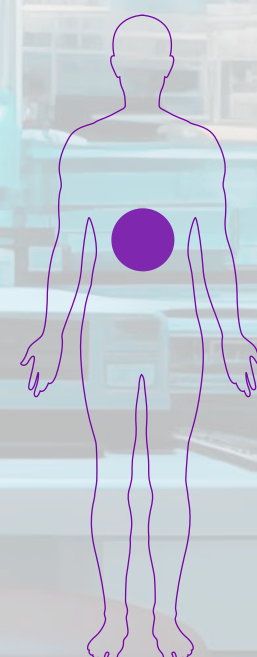


Better diagnosis

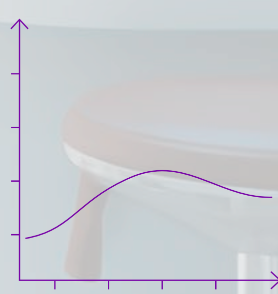
The ultimate goal of all these efforts is to create faster, simpler and better diagnostic options.



Identification of possible tumour diseases



Identification of different tumours



Monitoring the success of therapy

Screening

AI can identify conspicuous changes in blood cells. The algorithms learn independently to register and distinguish between these abnormalities.

Fundamentally different

Large research facilities at PSI such as the X-ray free-electron laser SwissFEL and the Swiss Light Source SLS – especially after the upgrade SLS 2.0 – deliver unimaginably vast amounts of data. Artificial intelligence is helping to evaluate data efficiently and exploit the facilities' full potential for research.

Text: Bernd Müller

Proteins are the workhorses of life. As tiny molecular machines, they are found in every cell and have a role in nearly all biological processes – from metabolism to cellular communication. Their diversity is enormous, because in the human body alone there are hundreds of thousands of different proteins, each with its own function. Proteins are important targets for drugs, and understanding their structure and function is an important task in biological research. One challenge in drug development is to find, if possible, an active agent that interacts with just one type of protein, to the exclusion of all the rest.

To achieve such a feat, one must first understand the language of proteins. The basis of this protein language is a kind of alphabet. It essentially consists of 20 building blocks analogous to letters. In proteins, however, it's not about letters, but rather amino acids. Each protein is built up from a certain sequence of these amino acids; the sequence in turn largely determines its properties. Researchers would now like to know which protein sequence leads to which property. This is where so-called large language models such as GPT4 come into play. The AI chatbot ChatGPT, which has been causing a stir since 2022, is based on GPT4. Both were developed by the company OpenAI. ChatGPT uses an extensive dataset of texts created by humans to learn the patterns and structures of language. When the user enters a question or task, the model produces a response based on its understanding of the contexts and patterns that it learned during training. In this way it can write poems, novels and even programming code.

Flurin Hidber, a doctoral candidate supervised by Xavier Deupi, an expert in bioinformatics and protein structure at PSI, uses AI in protein research. Hidber uses a sophisticated model similar to ChatGPT that is trained to predict amino acids in protein sequences, instead of generating human-like language. This unique ability does not merely mimic the predictive capabilities of language models in AI, but rather provides valuable insights into the structure and function of proteins. Pharmaceutical researchers could use these to tailor medications and significantly shorten the process of trial and error in the laboratory, which in the end yields only a small proportion of drug candidates with promising properties.

An ambitious goal

Deupi and Hidber are working towards an ambitious goal: being able to determine the precise amino acid sequence that leads to a desired protein property. One focus of their research is light-sensitive proteins, a speciality of Deupi's group and a research subject at SwissFEL. These proteins occur in many organisms, from microbes to humans, and have medical potential. Hidber's use of AI to predict the properties of light-sensitive proteins solely on the basis of the sequence of their building blocks represents a significant advance in this field.

Through the precise prediction of the light-absorption properties of proteins, Hidber's work could pave the way for the development of molecules with tailored properties – a step that could have a profound impact on optogenetics. This scientific technique employs light to control and monitor the activity of certain cells in living organisms, such as nerve cells in the brain. Researchers insert genes for light-sensitive proteins into these cells so they can precisely influence the cells' behaviour by irradiating them with light.

This technology could contribute to the understanding and treatment of neurological diseases, since it provides a tool that can be used to investigate and control the activity of specific brain cells with unprecedented precision. For the future, Deupi and Hidber have set themselves the goal of reversing this process. They want to design new proteins with properties tailored to meet specific requirements, for example proteins that react to light of a particular colour. This blueprint could then be checked experimentally, and hopefully confirmed by colleagues in the laboratory.

Xavier Deupi (left) and Flurin Hidber from the research group for Condensed Matter Theory want to better understand how the function of proteins is related to their structure. They are targeting light-sensitive proteins in particular.

The topic of protein dynamics is also at the heart of Cecilia Casadei's research. The physicist has developed a new algorithm that enables more efficient evaluation of measurements at X-ray free-electron laser facilities such as SwissFEL. The building blocks of life often perform ultrafast movements. Investigating these with precision is crucial to gain a better understanding of proteins. In the long run, this can provide valuable information about disease processes and enable the development of novel medical approaches.

Evaluating extremely short flashes of X-ray light

SwissFEL delivers extremely intense and short flashes of X-ray light in laser quality to measure these ultrafast movements of proteins. Examined in crystal form, the proteins' structure is revealed in so-called diffraction images, which arise from the regular arrangement of proteins in the crystal and are registered by a detector. But the data from a single crystal contains only two percent of the information for a complete image. Getting around this limitation usually involves dividing the data into rough time periods and averaging all data within a period. With this averaging, however, a lot of detailed information is lost. "You could say that the individual frames of the protein movie are a bit washed-out," Casadei says. "That's why we developed a method that gets more out of the measurement data."

The new method that Casadei and her team developed is called low-pass spectral analysis, LPSA for short. Through highly complex mathematical equations, the researchers remove unwanted noise

> “The process of how science is conducted is changing fundamentally.”
>
> Xavier Deupi, Laboratory for Condensed Matter Theory

from the data without losing the relevant details of protein dynamics. Thus instead of blurry diffraction images, sharp pictures can be generated in the shortest time periods that smoothly trace protein movement – like switching from an old tube television set to high-resolution digital video.

“The new algorithm helps the researchers here at PSI’s SwissFEL extract more information from their data,” Casadei says. Conversely, the algorithm can help to shorten the long measurement times. Since beam time is always in high demand and short supply at large research facilities in general, and at SwissFEL in particular, this represents an extremely welcome prospect for protein researchers who use these top facilities.

With the SLS 2.0 project, the researchers are facing another challenge. From 2025 on, after its upgrade, the Swiss Light Source SLS will deliver many times more measurement data than before. Then even extremely high-performance computers will struggle to process it. Machine learning will therefore play a central role. The researchers have developed algorithms for SLS 2.0 that use the brightness values the detectors register to determine the phase shifts of the incoming light at high speed and provide especially valuable information about the sample. “In this, PSI is a world leader,” emphasises Gebhard Schertler, head of the Biology and Chemistry Research Division at PSI.

Rapidly revealing changes in cells

One further strength of machine learning is that it can combine data from different measurement methods. So, for example, pictures of cell nuclei could be made with a light microscope, and X-ray methods in SLS 2.0 could provide additional high-resolution images. AI would combine these different types of data with biochemical clinical data from patients. It’s not possible to examine one and the same cell with different analytical methods, but with machine learning, sets of data from different methods can be compared. The algorithm recognises the properties of cells from different experiments. That is almost as if one and the same cell had been examined with all methods simultaneously.

Large research facilities still indispensable

Will large research facilities such as SwissFEL and SLS soon become superfluous because everything can be investigated with AI and machine learning? Xavier Deupi says no. “Large research facilities remain indispensable even in the age of AI. Large language models do offer high-performance tools for the analysis of known data, but they can never replace the capability of these facilities to generate new fundamental data.”

Nevertheless, AI has become an integral part of the research toolkit: from extracting insights from a large number of scientific publications to automatically generating program code or even writing articles on the basis of experimental data. “These tools are part of our daily routine,” Flurin Hidber confirms. Xavier Deupi stresses: “Despite these advances, the interpretation and critical discussion of the results will always rely on experienced researchers.” But he admits: “Today young researchers like Flurin work very differently from the way I did 20 years ago – the way science is done is changing fundamentally.” ◆

The mystery of cloud formation

In the Laboratory for Atmospheric Chemistry, Lubna Dada works on cloud formation. She discovered that certain gaseous hydrocarbon compounds called sesquiterpenes play a prominent role in this process. Natural substances of mainly vegetative origin, sesquiterpenes are an important component of essential oils, whose aromas we pick up during walks in the woods, for example. Although very rare, their contribution to the formation of condensation nuclei in clouds is much greater than other compounds in the atmosphere. Dada's insight is helping to improve climate models and predictions.

Hope for kids with cancer

Very young cancer patients can particularly benefit from radiotherapy using protons. Fortunately, the Center for Proton Therapy at PSI has gained considerable experience in this field over the past two decades: its specialist expertise is in demand from children’s cancer clinics throughout Switzerland.

Text: Brigitte Osterath

Courage beads accompany children and young people with cancer on their journey through treatment. The colourful glass beads are made by volunteers.

The six-year-old boy on the patient bed sleeps deeply and soundly. A stiff plastic mesh in the shape of his head prevents him from moving in his sleep. The rotating irradiation device, called a gantry, is already aligned with the boy's head. The PSI radiology specialist checks one last time to be sure the child is lying correctly, then leaves the room. From the control room next door, she starts the proton beam.

Now the gantry's irradiation head emits a concentrated beam of protons and scans the tumour in the little patient's brain with millimetre precision. The high-energy particles destroy the genetic substance in the cancer cells, killing them. Proton therapy functions on the same principle as classic radiation therapy in hospitals, where X-rays are used. But protons have a crucial advantage over X-rays: they release most of their energy in a very narrow area in the body, within the tumour itself – where they essentially get lodged. Thus the healthy tissue surrounding the tumour is protected and is less likely to be damaged than in classic radiation therapy.

Children with cancer can especially benefit from proton therapy, explains Damien Weber, chief physician and head of the Center for Proton Therapy at PSI. "Children are still growing, and if healthy cells close to the tumour get damaged during radiation therapy, they can pass this damage along to more and more cells with every future cell division." Besides that, the likelihood of damage to a critical structure near the tumour, such as the spine or brain, is much higher in a small body than in the larger body of an adult.

Therefore children run a higher risk that conventional radiotherapy for cancer will cause long-term damage from which they will suffer for the rest of their lives, ranging from tumours that only develop as a result of the radiation, to hearing loss, impaired growth and learning disabilities. "If a child in Switzerland needs targeted radiation therapy against cancer, the irradiation method of choice is almost always this very precise proton therapy," says Damien Weber.

A success story

The Center for Proton Therapy has been treating young cancer patients since 1999. In 2004, for the first time, a small child was irradiated under anaesthesia: just over two years old, the patient suffered from a soft tissue tumour in the eye socket.

Unlike adults, such very small patients require anaesthesia. "Precise irradiation such as proton therapy is pointless if the person moves during the treatment," Damien Weber explains. "But small children find it extremely difficult to keep still during the entire irradiation period." Light anaesthesia ensures the children sleep and lie still while the tumour-destroying proton beam does its work. Overall, around half of all children and adolescents up to the age of 18 are irradiated under anaesthesia.

Since 2004, there has been close cooperation between the Center for Proton Therapy and the Department of Anaesthesia at the University Children's Hospital of Zurich. This collaboration guarantees the presence of a senior physician and anaesthesia nurse from the Children's Hospital at PSI every day: they initiate the anaesthesia, monitor the condition of the little patients, change bandages and generally ensure the best possible care.

"We take a lot of time for the children," says Ilka Schmidt-Deubig, senior anaesthesiologist at the Children's Hospital of Zurich. "They shouldn't encounter a typical hospital atmosphere here with us." That's why the team always books appointments so that the parents and the child can arrive in a calm setting, at least half an hour before the radiation treatment, in a playroom specially set up for this purpose. "Even traumatised children have come to trust us after one or two weeks."

At the start of the cancer treatment, the children receive a string with their first names spelled out in colourful letter beads. "Over the course of the cancer treatment, more and more beads are added, the courage beads," Ilka Schmidt-Deubig explains. For example, when the port catheter, through which the anaesthetist introduces medication, is inserted; a therapy band before the irradiation; an austerity band because the child may not eat or drink anything before the anaesthesia – not always easy if you're hungry or thirsty.

Every year 60 to 70 children and adolescents are treated at PSI; in all, there have been more than 800 to date. The majority of all these young patients suffer from tumours of the brain and spinal cord. The second most common are sarcomas, which are cancers that develop in connective, supportive or muscle tissue.

National centre of excellence for Switzerland

"Cancer treatment in children who require anaesthesia during irradiation calls for more planning," says Katrin Scheinemann, head of Paediatric Haematology and Oncology at the Children's Hospital of Eastern Switzerland in St. Gallen. "We are all the more glad that PSI offers such a highly specialised irradiation centre with so much experience. Compared to other countries, we have one of the oldest proton centres anywhere, also with a focus on treating children with radiation.»

Katrin Scheinemann is president of the Swiss Paediatric Oncology Group (SPOG), a network of all nine centres in Switzerland with a children's on-

Appreciates the collaboration with PSI and the head of the Centre for Proton Therapy, Damien Weber (right): Katrin Scheinemann, oncologist at the Children's Hospital of Eastern Switzerland in St. Gallen and President of the Swiss Paediatric Oncology Group (SPOG).

cology department. In addition to the Children's Hospital of Eastern Switzerland in St. Gallen, this network includes the university hospitals in Bern, Basel, Zurich, Lausanne and Geneva as well as the children's hospitals in Lucerne, Aarau and Bellinzona. As a nonprofit organisation, SPOG coordinates and takes responsibility for clinical studies and research programmes on cancer in children and adolescents throughout Switzerland.

One thing is guaranteed: the young patients are always treated in accordance with international protocols. "So it doesn't matter which of the nine centres the parents take their children to for treatment – they get the same – i.e. the highest quality - therapy everywhere."

PSI treats around 70 percent of all children in Switzerland who need targeted radiation therapy. This makes the Center for Proton Therapy the country's largest radiation treatment centre for children.

Hopeful prospects

The six-year-old boy has come through the radiation treatment successfully; the tumour in his brain was scanned with high-energy protons for around 20 minutes. The radiology specialist removes the face mask and takes the little one, who is still sleeping, to the recovery room, where his parents are already waiting. Here he can recover in peace as he fully wakes up.

The next irradiation session follows on the next day: for a total of six weeks, Monday to Friday. This is not an easy time for the children and their parents. But there is hope: the chances of curing childhood cancer have improved significantly in recent decades. According to the Swiss Childhood Cancer Registry, Switzerland's ten-year survival rate for children diagnosed between 1989 and 1998 was 76 percent – 20 years later, between 2009 and 2018, it had already risen to 85 percent. These numbers are expected to improve again over the next ten-year period. And the treatment provided at PSI's Center for Proton Therapy is certainly contributing to this success story. ◆

Pioneering studies

In addition to the paediatric studies it participates in, PSI also takes part in clinical studies on cancer treatment for adults. Currently participants are being sought for the European clinical study PROTECT, in which PSI is taking part jointly with the Clinic for Radio-Oncology at the University Hospital of Zurich. PROTECT compares side-effects of conventional radiation therapy for oesophageal cancer with those associated with proton therapy. If the clinical study yields evidence that proton therapy also offers advantages for treating this type of cancer, patients could routinely be treated at PSI. Oesophageal cancer would be permanently added to the Federal Office of Public Health list of indications, and health insurance providers would cover the costs of proton therapy.

Latest PSI research news

1 Study on climate-neutral air travel

Researchers at PSI and ETH Zurich have calculated how air transportation could become climate-neutral by 2050. They conclude that simply replacing fossil aviation fuel with sustainable synthetic fuels will not be enough. A reduction in air traffic would also be necessary. To make air travel climate-neutral overall, it's necessary to ensure that fuel production and the entire air transportation infrastructure, not just flight itself, put no additional burden on the climate. The study showed, however, that this cannot be achieved by 2050 through the climate-protection measures pursued so far in aviation operations. New engines, climate-friendly fuels, and extracting CO_2 from the atmosphere for underground storage (carbon capture and storage: CCS for short) will therefore not be enough to achieve the goal of climate-neutral air travel. In addition, air traffic as a whole must be reduced. One measure could be to raise the price of airline tickets. According to the study, a ticket would have to cost around three times as much as it does today to fully offset the actual climate impact.

Further information:
https://psi.ch/en/node/58104

Circa **3.5** percent: share of global warming caused by air travel

Circa **20** percent: share of pure CO_2 emissions in climate impact

Circa **0.8** percent: annual reduction in air traffic needed between now and 2050

2 Insight into 3D printing

3D printing can be used to produce highly complex forms. But printing ceramics using a laser proves to be difficult. In a world first, PSI researchers have used tomograms to reveal what happens at microscopic level during this fabrication process. With this method, the material is applied as a fine powder on a substrate and then a laser beam passes over the powder, melting it to form it into the desired shape. The next thin layer of powder is deposited and is in turn melted by the laser. The component is built up sequentially in this way, layer by layer. Exactly what happens during this laser powder bed fusion has already been investigated using X-rays at the Swiss Light Source SLS at PSI and fellow research institutes , but up to now these microscopic insights had yielded only two-dimensional images. Now experiments on the SLS beamline TOMCAT are providing new three-dimensional insights into this promising manufacturing process, and the findings should help to improve it.

Further information:
https://psi.ch/en/node/59299

3 Better batteries for electric cars

PSI researchers are using neutrons to visualise changes in electrolytes, the electricity-conducting liquids in batteries. With experiments at the Swiss spallation neutron source SINQ, they have been able to track physical and chemical changes at different temperatures. To do this, they varied the temperature several times between minus 20 and plus 50 degrees Celsius. This confirmed that the liquid solidifies at low temperatures. That has been known for a long time, which is why batteries in electric vehicles are warmed up before charging in the winter. What's new is that the PSI experiment makes it possible to understand precisely how and where in the battery this process takes place. The spectroscopy images even show how two organic components of the liquid separate at low temperatures, with one fraction sinking downwards. The measurements also provide, for the first time, spatial information about which electrolytes exhibit this phase transition and at what temperatures. The analysis is helping to better understand the physical and chemical processes and to develop batteries with better properties.

Further information:
https://psi.ch/en/node/60002

4 Reprogramming tissue mechanically

Researchers at PSI and ETH Zurich have taken connective tissue cells that had been mechanically reprogrammed to resemble stem cells and transplanted them into damaged skin. In their laboratory experiment, they were able to show that this can promote wound healing. The researchers did not resort to genetic engineering or chemicals, but reprogrammed the cells entirely through mechanical stimulation. It might even be possible to regenerate muscle or brain cells as well as skin tissue. This is consistent with the trend towards personalised medicine, in which substances are individually tailored to the patient. In this case, these are in fact the patient's own cells, and no foreign substances are introduced.

Further information:
https://psi.ch/en/node/60488

Ideas with flair

The research carried out at PSI tends to be extremely complex and often difficult to describe. We gave researchers a tricky assignment: Sketch the basic idea of your research in a simple drawing. They produced clever results with flair, which give a better idea what it's all about than a thousand words would. See for yourself.

Text: Christian Heid

Radiopharmaceuticals

Cristina Müller does research at the Center for Radiopharmaceutical Sciences. Radiopharmaceuticals are radioactive substances that are injected into the blood stream to fight cancer cells. The molecules are constructed in such a way that one part, the ligand, docks onto the surface of tumour cells, like a key in a lock. Another part carries the drug, a radioactive atom that emits electrons during radioactive decay. In the tumour cell these form aggressive radicals, highly reactive substances that attack and destroy the cancer cell's genetic material. Her goal is to develop radiopharmaceuticals that target and kill tumour cells more precisely and thus prevent the formation of metastases.


RADIOLIGANDEN
THERAPIE
KREBSZELLE
TOTE ZELLE
ZELLE
RADIONUKLID
LIGAND
REZEPTOR

Intelligent microrobots

Laura Heyderman, head of the research group for Mesoscopic Systems at PSI and professor at ETH Zurich, develops micromachines like the robotic bird sketched in the middle of this drawing. These mini-machines can perform a variety of actions. For this, researchers magnetically program tiny magnets in components of the microrobot and then use a magnetic field to control the various movements. Such machines, measuring just a few tens of micrometres, could one day be put to work in medicine, for example to carry out small operations in the human body.

Carculator

"Electric is already the right choice today," Christian Bauer said around four years ago. The scientist works in the Laboratory for Energy Systems Analysis at PSI and specialises in life cycle and sustainability analyses. He and his team developed the web tool Carculator, which compares the environmental performance of passenger cars in detail. The program determines the ecological balance of vehicles with different size classes and powertrains, and presents the results in comparative graphs. The entire life cycle of passenger cars is taken into account, including vehicle manufacture as well as environmentally relevant emissions while driving.

https://carculator.psi.ch/

The proton radius

How big is the proton radius (R_p)? To a large extent, this question defines the research career of Aldo Antognini, a scientist in the Laboratory for Particle Physics. In the early 2000s he carried out initial experiments in a way that is only possible at PSI, because his research approach requires an adequate supply of slow muons, and this is the only facility worldwide where these are available in such quantities. The principle: the electron (e), which orbits the proton (p), is replaced by a muon (μ). Negative muons are elementary particles similar to electrons, but 200 times heavier. This means the muon orbits closer to the proton, and the proton has a stronger effect on the muon. Antognini's approach has made it possible to determine the proton radius more precisely than ever. The result: our model of the atomic structure, the fundamental interactions between elementary particles and the proton structure are being put to the test and need to be more precise.

Structural change

Valérie Panneels is a scientist in PSI's Laboratory for Biomolecular Research and investigates what happens when light hits our eyes. These processes are among the very fastest that happen in nature, involving changes that occur within a fraction of a billionth of a millionth of a second. These can be examined only at large research facilities such as the X-ray free-electron laser SwissFEL at PSI. The focus is on the protein rhodopsin, a light receptor, and its component retinal, a molecule that deforms when exposed to light. The biochemical processes that are triggered through structural changes in the retinal are to be studied down to the last detail and, if possible, recorded at SwissFEL in a kind of ultrahigh-resolution video. This should help researchers fully understand how these light-sensitive proteins work.

Network as a huge advantage

Torsten Tritscher works as an engineer for the US company TSI, which develops devices for measuring air quality and markets them worldwide. He learned much of what he needs for his job during his doctoral research at PSI. But above all, he established a great many contacts from which he still benefits today.

Text: Jan Berndorff

There's one scene Torsten Tritscher will probably never forget. The 44-year-old can't help smiling when he recalls how he got his job, in which he has felt right at home for 12 years now. Under the Florida sun, on the sidelines of a research conference in Orlando, he spoke to his current boss as he was on his way to the beach in flip-flops and shorts. A job interview of a whole other kind, so to speak. "He was totally open and completely uncomplicated. We agreed that I would send my CV and we arranged to meet again in Europe." And then everything moved very quickly, thanks not least to a commitment Tritscher made before attending the conference: a doctoral thesis at PSI and ETH Zurich, where he made many contacts that helped advance his subsequent career.

Today Tritscher is a senior application engineer at the US company TSI, which develops technologies for measuring air quality and markets them from branches worldwide, including Aachen. He was born in Remscheid, in North Rhine-Westphalia, and went to school in Wermelskirchen, near Cologne. His parents had a plant nursery where he often lent a hand. Interested in natural sciences, he studied landscape ecology in Münster after graduating high school. "I wanted to keep open the option of getting into the nursery business after my studies. But then my brother did that, and I ended up specialising in research on climate, atmosphere and aerosols."

Finland tipped the scales

This research field grabbed him for good at a summer school in Finland: ten days in Hyytiälä in the middle of the Finnish forest and lake landscape. "In the aerosol scene, this place is known for the natural formation of numerous particles," Tritscher says, meaning it's a wonderful place to investigate the diverse tiny particles nature produces and releases into the atmosphere. These are primarily plant metabolic products such as isoprene and terpenes, as well as oxygen-containing compounds, but also dimethyl sulfide, which arises from the ocean. Under the sun's influence, they react and combine to form larger particles, which then can serve as condensation nuclei for the formation of cloud droplets. Thus aerosols have a crucial influence not only on the weather, but also on the climate of the future. The processes are so complex, however, that it remains unclear how and exactly where they will have a warming or cooling effect in the future. That's why aerosols are currently a very hot topic in climate research.

After the summer school, it was clear for Tritscher: "That's what I want to do!". So he looked around for suitable positions for a doctoral thesis in this area. He found what he was after at PSI. "Naturally I also looked in Germany, but there they wanted either physicists or engineers for comparable positions. In Switzerland, on the other hand, at PSI's Laboratory for Atmospheric Chemistry, they found someone coming from an interdisciplinary science such as landscape ecology quite interesting."

Ideal conditions in Switzerland

At PSI there were two positions that might have been suitable – one involved more chemistry, the other more physics. "The chemistry-oriented job was taken by my colleague Claudia Mohr after a stay in the USA – today she is the head of the Laboratory for Atmospheric Chemistry," Tritscher says. He was awarded the contract for the other job.

Tritscher spent four years at PSI. "It was a great time," he recalls. In addition to his doctoral thesis – for which he investigated the physical properties and in particular the water absorption of a variety of aerosols – he took part in a number of other exciting research projects. He did a lot of work in PSI's smog chamber, a high-tech laboratory 27 cubic metres in size. Here atmospheric researchers from all over the world can simulate diverse gas-particle reactions under controlled air conditions to investigate the mechanisms. "We took measurements during the day, analysed data in the evening, and

“At PSI they found someone coming from an interdisciplinary science quite interesting.”

Torsten Tritscher, senior application engineer at the US company TSI

often went out together or made trips on the weekend – skiing in the winter, hiking in the summer. It was great fun."

Above all during this time, Tritscher was getting acquainted with many colleagues from the worldwide "aerosol scene" as well as the numerous technologies they use for their experiments. "My boss still tells me to this day that this network is a huge advantage I brought with me," Tritscher explains. "When I want to visit a new international customer, I always know someone who can give me some tips in advance."

Beyond the network, there are other ways Tritscher benefits enormously from his time at PSI: "I am always amazed that I can use what I learned there almost every day." The engineer demonstrates that in the TSI laboratory in Aachen, at a so-called differential mobility analyser (DMA), a cylindrical device made of stainless steel that can be used to measure the size distribution of particles in ambient air. Wearing disposable gloves, Tritscher carefully unscrews the head with the measurement electronics and pulls a polished stainless-steel rod out of the housing. The rod is the electrode, and the housing is the earth or ground. Into the cavity between them flows air whose particles have previously been charged in a defined manner. Under the influence of an applied voltage, these particles then drift either inwards or outwards depending on the electrical polarity. The particles' electrical mobility is directly related to their diameter, and his is how they are separated. In the end, only particles of a certain size in the nanometre range flow out through a gap and can then be counted. During his doctoral research, Tritscher himself built a device consisting of three DMAs using very similar measurement technology: a hygroscopicity-volatility tandem differential mobility analyser (HV-TDMA). And naturally, he became extremely familiar with all the components.

Together with the associated computer and analysis programs, this is valuable, highly advanced technology produced for extremely specialised applications in research and industry. So it pays to send an engineer along with delivery to customers all over the world to show the correct way to install it and the optimal way to use it – or to advise new customers on which device is the right one for their project.

Highly specialised measurement stations

These are precisely Tritscher's main tasks at TSI. "In all, we offer more than 200 different devices. Around 40 of them, which are mainly used to count or characterise airborne particles, fall into my area." Application areas include, for example, environmental measurement stations, exhaust measurements on the engine test bench a car factory, emissions testing of new printers and the measurement of air quality at an airport.

"Our Aachen location serves customers in Europe, Africa and the Middle East." And this involves more than just mastering the material in practice and theory to be able to speak with users from research and technology on an equal footing. Interpersonal sensitivity is also called for: "When I talk with inexperienced students, I have to explain things very differently than I would to an official from the district office or a meticulous professor who wants to know everything precisely down to the third decimal place," Tritscher says. That's exactly what is so appealing to him: variety and new challenges, which don't necessarily have to be human or technical in nature. For example, if he travels to a remote customer location in a country where language issues make communication difficult, and then his suitcase doesn't arrive. "You have to be flexible and able to improvise."

It is also important to Tritscher that he has found a home base in Aachen. He is always happy to return there from his many trips abroad – especially since he now has a family with two children and a house of their own. His wife, too, is an atmospheric scientist. They met in Münster at the end of their studies. She then moved to Switzerland with Tritscher and completed her doctorate at ETH Zurich in parallel with him, after which she was called to Virginia for a three-month project. "This time it was my turn to accompany her," Tritscher recalls. And this led to the previously described encounter in Florida: "While we were in Virginia, my PhD advisor Urs Baltensperger invited me to attend the Annual Aerosol Science Conference in Florida."

The young couple accepted the invitation and combined it with a vacation trip along the east coast of America. Baltensperger emphasised the opportunity to speak with Oliver Bischof from TSI at the conference. And so it was that the foundation of Tritscher's career was established through personal contacts.

"On such occasions today, I'm in a position to make contact with doctoral candidates, drink a beer, pass along experiences and possibly find new recruits for a job at TSI." Thus the journey that started with his doctoral research at PSI comes full circle. ◆

From our base in Aargau we conduct research for Switzerland as part of a global collaboration.

5

large research facilities that are unique in Switzerland

800

scientific articles a year based on the experiments performed at PSI's large research facilities

5,000

scientists from across the globe perform experiments at our large research facilities every year

5232 is Switzerland's prime address for experiments on large research facilities. The Paul Scherrer Institute PSI even has its own postcode, a distinction that seems justified for an institute that extends over 342,000 square metres, has its own bridge across the River Aare, and has around 2,200 employees – more people than in most of the surrounding villages.

PSI is situated on both banks of the River Aare in the canton of Aargau, in the municipal areas of Villigen and Würenlingen. Its main areas of research are in the natural sciences and engineering. Funded by the federal government, it belongs to the domain of the Swiss Federal Institute of Technology (ETH Domain), which also includes ETH Zurich, ETH Lausanne (EPFL), and the research institutes Eawag (Swiss Federal Institute of Aquatic Science and Technology), Empa (Swiss Federal Laboratories for Materials Science and Technology) and WSL (Swiss Federal Institute for Forest, Snow, and Landscape Research). We conduct basic and applied research and thus work on sustainable solutions for central questions from society, science and business.

Complex large research facilities

Switzerland's federal government has given PSI the mandate to develop, build, and operate large, complex research facilities. These are the only such facilities within Switzerland, and some are the only ones in the world.

Running experiments at our large research facilities enables many scientists from the most diverse disciplines to gain fundamental insights for their work. The construction and operation of these kinds of facilities involve so much time, effort, and cost that comparable measurement equipment is not available to academic and industrial research groups at their own institutions. That is why we keep our facilities open to all researchers worldwide.

To obtain a time slot to use the experimental stations, however, both Swiss and foreign scientists first have to apply to PSI. Selection committees comprising experts from all over the world assess the scientific quality of these applications and recommend to PSI which candidates should be given measurement time. Even though there are around 40 measuring stations where experiments can be carried out at the same time, there is never enough capacity for all of the proposals submitted – around one-half to two thirds have to be rejected.

Around 1,900 experiments are performed every year at PSI's large research facilities. Time slots are free of charge for all researchers working in academia. In a special process, users from private industry can buy time to carry out proprietary research and use the PSI facilities for their own applied research. For this, PSI offers special research and development services.

PSI operates five large research facilities in total where the internal processes of materials, biomolecules, and technical devices can be explored. Here scientists use different beams to "illuminate" the samples they want to investigate in their experiments. The beams available for this range from particles (neutrons or muons) to intense X-ray light from a synchrotron or X-ray laser source. The different types of beams allow a wide variety of material properties to be studied at PSI. The high complexity and cost of the facilities is due to the massive size of the accelerators needed to generate the different beams.

Four main areas of research

However, PSI not only acts as a service provider for researchers, but also carries out an ambitious research programme of its own. The findings produced by PSI scientists help us to understand the world better, and also lay the foundation for developing new types of equipment and medical treatments.

At the same time, our own research is an important prerequisite for the success of our user service programme for the large research facilities. Only researchers personally involved in current scientific developments in the fields external researchers are working in can support them in their investigations and further refine the facilities to ensure they continue to meet the needs of cutting-edge research in the future.

Our own research is concentrated on four focus areas. In the area of Future Technologies, we investigate the diverse properties of materials. With the knowledge this yields, we create the foundations for new applications – whether in medicine, information technology, energy production and storage, or new industrial production methods.

The goal of our work in the focus area Energy and Climate is developing new technologies for a sustainable and safe energy supply, as well as for a clean environment. Also in this area, we are investigating interconnections within Earth's climate system.

In the focus area Health Innovation, researchers are looking for the causes of diseases as well as for potential therapeutic methods. In addition, we operate the only facility in Switzerland using protons for the treatment of specific cancer diseases. This special technique makes it possible to destroy tumours in a targeted way while leaving the surrounding health tissue largely undamaged.

In the area Fundamentals of Nature, researchers are seeking answers to fundamental questions about the basic structures of matter and the functional principles of nature. They investigate the structure and properties of elementary particles – the smallest building blocks of matter – or clarify fundamental processes in living organisms. The knowledge gained in this way opens up new approaches to solutions in science, medicine and technology.

The brains behind the machines

The work at PSI's large research facilities is challenging. Our researchers, engineers, and professionals are highly specialised experts. It is important for us to foster this expertise. So we want our employees to pass on their knowledge to the next generation, who will then put it to use in a variety of professional positions, not just at PSI. Around a quarter of our staff are therefore apprentices, doctoral students, or postdocs.

PUBLISHING DETAILS

5232 – The magazine of the Paul Scherrer Institute

is published twice a year.
Issue 1/2024 (March 2024)
ISSN 2674-1261

Publisher
Paul Scherrer Institut
Forschungsstrasse 111
5232 Villigen PSI, Switzerland
Telephone +41 56 310 21 11
www.psi.ch

Editorial team
Monika Gimmel, Martina Gröschl, Christian Heid, Sebastian Jutzi (Lead), Benjamin A. Senn, Dr. Mirjam van Daalen

Translation
Patrick Regan

Editor
Graeme High

Design and Art Direction
Studio HübnerBraun

AI image generation with Midjourney
Cover, pages 2–5, 8–20:
Studio HübnerBraun

Photos
Paul Scherrer Institute / Markus Fischer, except:
pages 22/23: Paul Scherrer Institute / Manuela Reisinger (courage beads);
page 25 above left: Kinderkrebs Schweiz; page 25 right:
Scanderbeg Sauer Photography;
pages 26–27: Adobe Stock;
pages 35–37: Steffi Ratzke;
page 41: Adobe Stock.

Illustrations and graphics
Studio HübnerBraun, except:
pages 6 / 7: Daniela Leitner.

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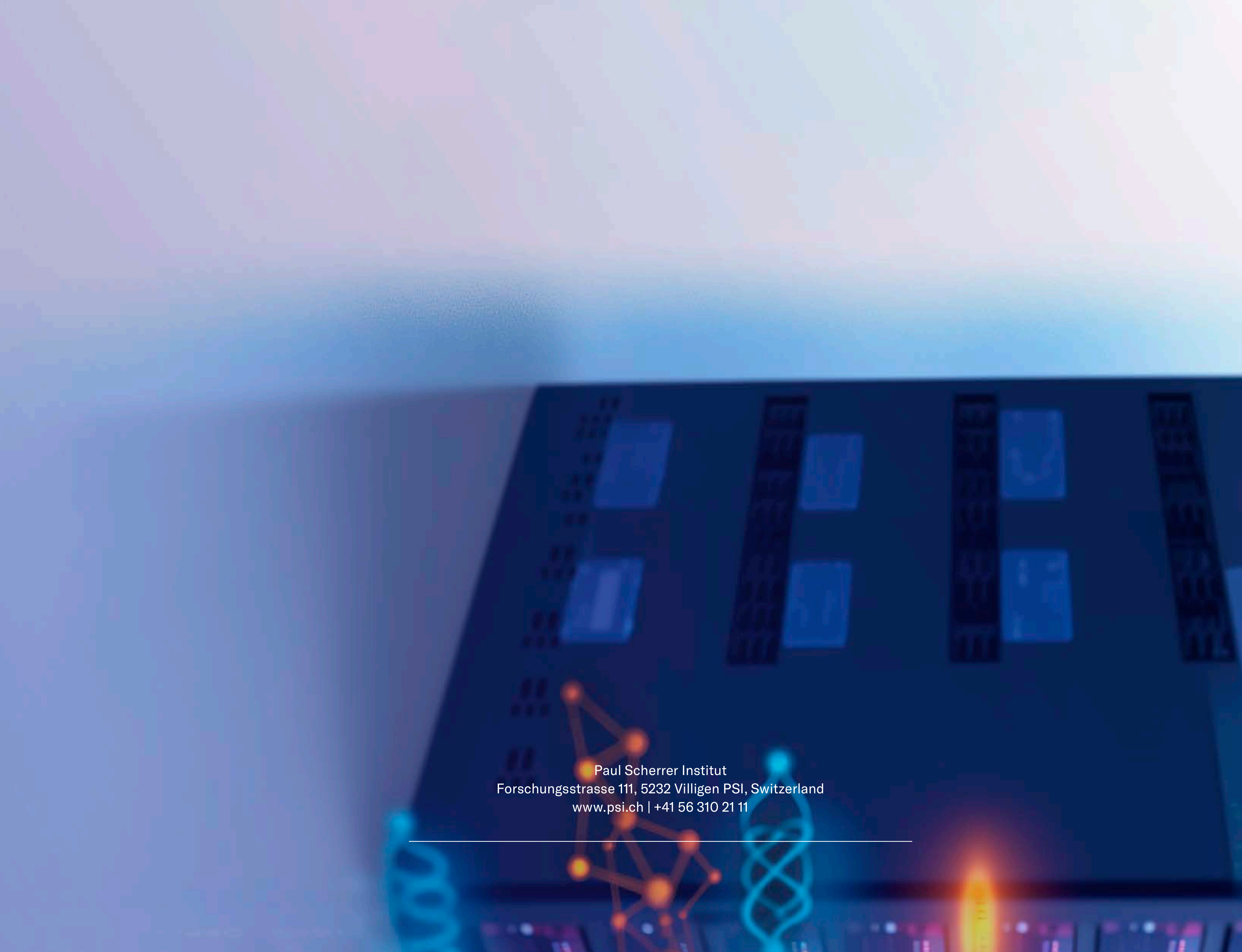
PAUL SCHERRER INSTITUT
PSI

Coming up in the next issue

Air traffic is to become climate-neutral by 2050. Sustainable aviation fuels (SAFs) are key to achieving this goal. PSI researchers are searching for new processes and materials to ensure that these can be produced. But there's still more to climate-neutral flying, since airports and their entire logistics, the production of aircraft and their eventual disposal, are just as much a part of the aviation industry's climate footprint as ticket prices and their regulating effect. Researchers are also analysing this complex structure using the unique possibilities that PSI offers them. The results so far show: climate-neutral aviation is possible.



Paul Scherrer Institut
Forschungsstrasse 111, 5232 Villigen PSI, Switzerland
www.psi.ch | +41 56 310 21 11