discovered

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Uranium, Plutonium & Co.

HZDR
HELMHOLTZ
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COVER ILLUSTRATION: Actinides are highly toxic and radioactive heavy metals whose spread must be safely prevented. HZDR scientists have been focusing on this in their work on repository research. Graphic: AVANGA

DEAR READERS,

To date there is no repository facility for highly radioactive and heat-generating waste in Germany. This politically "hot" topic is undeniably a very big, urgent problem in our society. The Helmholtz Association of German Research Centers is dedicated to developing scientific solutions for such issues. It looks back on 20 years of history: In 1995 the loosely organized collective bearing the name "Working Association of Large-Scale Research Institutes" (Arbeitsgemeinschaft der Großforschungseinrichtungen) became an association of now 18 research centers. These centers collectively work in a total of six research areas.

While the HZDR has only belonged to the largest research association in Germany since 2011, repository research was already on the agenda way back when the Rossendorf research center established itself in 1992 after the fall of the Berlin Wall. A good enough reason to examine the results from about 20 years of repository research in Dresden in more detail. In this issue of "discovered" we will take an inside look at radiochemical, radiogeological, and microbiological labs, look over the shoulders of researchers using the "Rossendorf Beamline" at the European Synchrotron Radiation Facility in Grenoble, and descend hundreds of meters into Finnish, Swedish, and Swiss research labs.

How do "uranium, plutonium, & co." react with mineral surfaces in environments that are low in oxygen or watery? How do they interact with microorganisms deep underground? And how can host rock or other materials be used as technical barriers to prevent the spread of radioactive substances? In order to answer these and further questions, the researchers of the HZDR use a wide range of spectroscopic methods. They expose test samples to lasers, infrared light, and X-rays or use the fluorescent properties of certain compounds to learn about the behavior of actinides on the molecular and atomic level. The results of this fundamental research constitute multiple individual puzzle pieces that make their way into databanks as tried and tested findings. This information is then freely available to scientists around the world as well as government agencies and future repository operators.

In an interview with the editorial staff of "discovered" Michael Sailer, CEO of the German Oeko-Institut: Institute for Applied Ecology, highlights the concern that personnel shortages could be a problem one day when construction is started on the repository for highly radioactive waste. The education of repository experts is therefore an important duty of universities and research institutions. He also emphasizes that with sound knowledge, science could make a significant contribution to an objective discussion of the matter.

As you have come to expect from us, we will also be introducing other work currently being carried out by the HZDR and its researchers. I would like to wish you happy reading

Christine Bohnet
Communications and Media Relations at HZDR

CONTENT

TITLE

RESEARCH

PORTRAIT

PANORAMA – HZDR NEWS

Photo: swisstopo | Comet Photoshopping GmbH | Béatrice Devènes

Photo: Oliver Killig

Photo: AVANGA

Photo: Klaus Tschira Stiftung gGmbH | Dietmar Gust

// The chemistry involved in repositories for highly radioactive material.

CORROSION HAS ITS ADVANTAGES

_TEXT . Roland Knauer

"We just assume the worst-case scenario," explains Vinzenz Brendler of the HZDR Institute of Resource Ecology. Anyone researching the chemistry involved in running a future repository for highly radioactive material should really take this pessimistic approach to heart. After all, the safety of a repository such as this, which would presumably be constructed deep beneath the Earth's surface contained in its own geological formation somewhere in Germany, must be guaranteed for at least one million years. Chemists like Vinzenz Brendler are well aware, however, that even the most improbable reactions can occur if given enough time. And one million years is a very long time. It is for exactly this reason that the 30 employees of the Surface Processes Division take into consideration anything there that could possibly react. And there is quite a lot to keep track of, since many of the elements listed in the periodic table of elements tend to occur in repositories.

"In our work we concentrate on reactions with radioactive elements. Our institute is especially well-prepared for this," Vinzenz Brendler reports. Chemistry not involving radioactive substances can just be researched in "normal" labs after all. This selection allows scientists to narrow down the enormous mountain of reactions considerably, but a great many of them still remain.

Mountain for chemists

The repository will mainly house the used up fuel rods from nuclear reactors. Originally they consist predominantly of uranium. Since only a small portion is burned up in the reactor, there is very little change in the rods even after they served their purpose. Contrary to popular belief, the overwhelming majority of material in the rods does not emit strong amounts of radiation. Uranium itself, however, is an extremely poisonous heavy metal and is therefore taken very seriously.

A small portion of the uranium is, however, split in the reactor. The fragments produced by this process have varying weights and consequently represent a wide variety of different elements that are now also contained in the fuel rod. Some products of the split, certain chlorine and cesium isotopes for example, are highly radioactive. In any case, a portion of this will decay relatively quickly. So after few decades in intermediate storage the radiation level will already be considerably lower. Nevertheless, there will still be plenty of highly radioactive elements in the used up fuel rods.

Enough time

Nuclear reactions in the reactor produce quite a few neutrons, many of which act as catalysts for the chain reaction and with others remaining trapped in uranium atoms. These will often trigger further nuclear reactions that in turn produce heavier and correspondingly highly radioactive elements such as americium, neptunium, plutonium, and curium. The researchers working with Vinzenz Brendler are also engaged in carefully tracking these "activation products".

But there are also a series of other compounds that play a role in the repository and that could be involved in chemical reactions. The uranium of the fuel rods is placed in a zirconium casing. This is a heavy metal with low toxicity that, unlike many other metals, corrodes only very slowly. All the same, there is still the possibility that it will react with the radioactive elements in its environment - it is sure to have enough time for that in the repository.

Ingredients for corrosion

As it currently stands, the plan is to place the fuel rods in special Pollux containers made of steel, which are placed in casings made of cast iron and graphite, which are then placed in the repository. Oxygen from the air could then oxidize the iron in these casings. And this gives Vinzenz Brendler and his team another substance to keep an eye on.

Once the repository is closed, the oxygen will slowly be used up, thus seemingly removing the basis for corrosion. It won't be long, however, until a fresh supply is available: The surrounding stones are sure to contain oxygen and perhaps even water - regardless of where the underground repository is located. These are the two essential ingredients that cause many metals to corrode. Especially when, as is the case in the repository, there is enough time. In time, rust could eat holes in the steel casings of the Pollux containers - at least if you assume the worst as Vinzenz Brendler does. What would happen in the repository then? The uranium in the fuel rods is present in the form of uranium dioxide, which is relatively inert. In this form organisms rarely absorb it and at first the heavy metal will hardly have any poisonous effects at all. This changes abruptly, however, when it oxidizes to a uranyl compound. Unlike uranium dioxide and the compounds it forms, these uranyl particles dissolve well in water. Not only can they be transported over long distances, but they can also easily be absorbed by life forms, thus poisoning them. →

MODEL SIMULATIONS: Vinzenz Brendler uses the computer to calculate how radioactive heavy metals and their compounds spread under real environmental conditions underground, and which layers they have a hard time penetrating. Photo: Oliver Killig

Rust bumps with advantages

But there's always a flip side. Corrosion can eat holes in the Pollux containers. Rust, however, has a much larger surface area than the iron from which it came. There's a good reason why a vehicle with such corrosion problems is called a "lump of rust" in the German vernacular. The significantly greater surface area thus emerges as an advantage, since chemical reactions work better when they have more space. "The larger surface area will therefore snap up many of the more aggressive compounds that have formed on the inside," Vinzenz Brendler explains.

Here the pragmatism of the HZDR researcher surfaces once more: Such a large, corroded surface may indeed hold back many compounds from the interior, but surely not all of them. Once they have left the container, the substances will come in contact with a whole mountain of possible reaction partners that are present in varying forms underground. Here, for example, it may come in contact with the common mineral calcite, which will react with the highly poisonous uranyl compounds. This produces, among other things, uranyl carbonate. This substance does not dissolve well in water, is therefore seldom transported further, and is only rarely absorbed by plants. →

Advantage for calcite

That's good news. So it seems highly improbable that dangerous uranyl compounds will make it back to the surface from the depths. Together with colleagues from around the world, HZDR researchers are working to illuminate such reactions and reveal the path taken by the resulting compounds by conducting a wealth of experiments, some of which are carried out in labs deep underground. Analysis specialists identify the substances formed using the latest spectroscopy methods, which involve measuring light beams emitted or influenced by the compounds. The results then end up in enormous databanks that can be accessed by researchers around the world.

With these lab experiments, however, HZDR researchers are only able to understand a fraction of the possible reactions between the plethora of compounds that could play a role in and around the planned repository. But that's hardly sufficient to meet demands for the highest level of safety possible. "Without running model simulations on the computer it would be impossible for us to gain a good understanding of this complex system," Vinzenz Brendler assures us. The host of possible reactions threaten to overwhelm even the most high-performance modern computers. Researchers solve this problem by excluding reactions that are obviously unimportant for the end result from their models.

In order to come as close as possible to real-life scenarios, they are also taking a look at the cap rock over the salt deposits of Gorleben. "Since this region has been well-researched, we can do some very good model simulations of the area," Vinzenz Brendler explains. "Our computers calculate how and under which environmental conditions radioactive heavy metals and their compounds spread through cap rock and which layers they have a hard time penetrating." It does indeed seem highly unlikely that actinides in the dry salt deposit that has existed for over 200 million years will end up in the cap rock made of clay at all. In order for that to happen, a great deal of water would have to get in.

Time and again the computers repeat these selective calculations, but with changes to important factors within their natural limits. So far results show that dramatic fluctuations in the silicate content or the number and electric charge of the ions present will not cause significant changes to the bonding of radioactive substances. Obviously the effect of these two factors is negligible in comparison to others and can therefore be excluded from future model simulations. If, however, the carbonate content or the acid concentration changes then uranium, plutonium, and co. will be contained in the cap rock. "We will therefore be examining these factors in greater detail in the future," Vinzenz Brendler explains. It is just such results that make the HZDR researchers main partners in the German Association for Repository Research (Deutsche Arbeitsgemeinschaft Endlagerforschung) founded at the end of 2013. "Researchers from different organizations have joined the association of their own accord in order to advance research on safe repositories," Vinzenz Brendler summarizes.

Funding

Vinzenz Brendler's research work is funded by the Federal Ministry of Education and Research (BMBF) as well as other organizations. Among these is THEREDA, an extensive and self-consistent thermodynamic reference databank for the geochemical modeling of solutions and interactions with granite, clay, and salt - which are currently being discussed in Germany as possible host rocks for repositories for highly radioactive waste.

The Federal Ministry for Economic Affairs and Energy (BMWi) finances the RES³T databank project, the Rossendorf expert system for surface and sorption thermodynamics, as well as the model work done for the ESTRAL project, which together with the Gesellschaft für Anlagen- und Reaktorsicherheit, GRS (Association for Facility and Reactor Safety) examines the true-to-life integration of sorption processes in transport programs for long-term safety analysis. This work has been carried on by the WEIMAR project starting in 2013 (further development of the "Smart K_d" concept for long-term safety analysis). The European Union is another important funding authority.

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// There is a wealth of microorganisms in the subsurface. They also play a role in repositories.

MICROCOSMOS: Microorganisms exist underground that are very good at protecting themselves against radioactive radiation. Photo: AVANGA

LIFE IN A MOUNTAIN

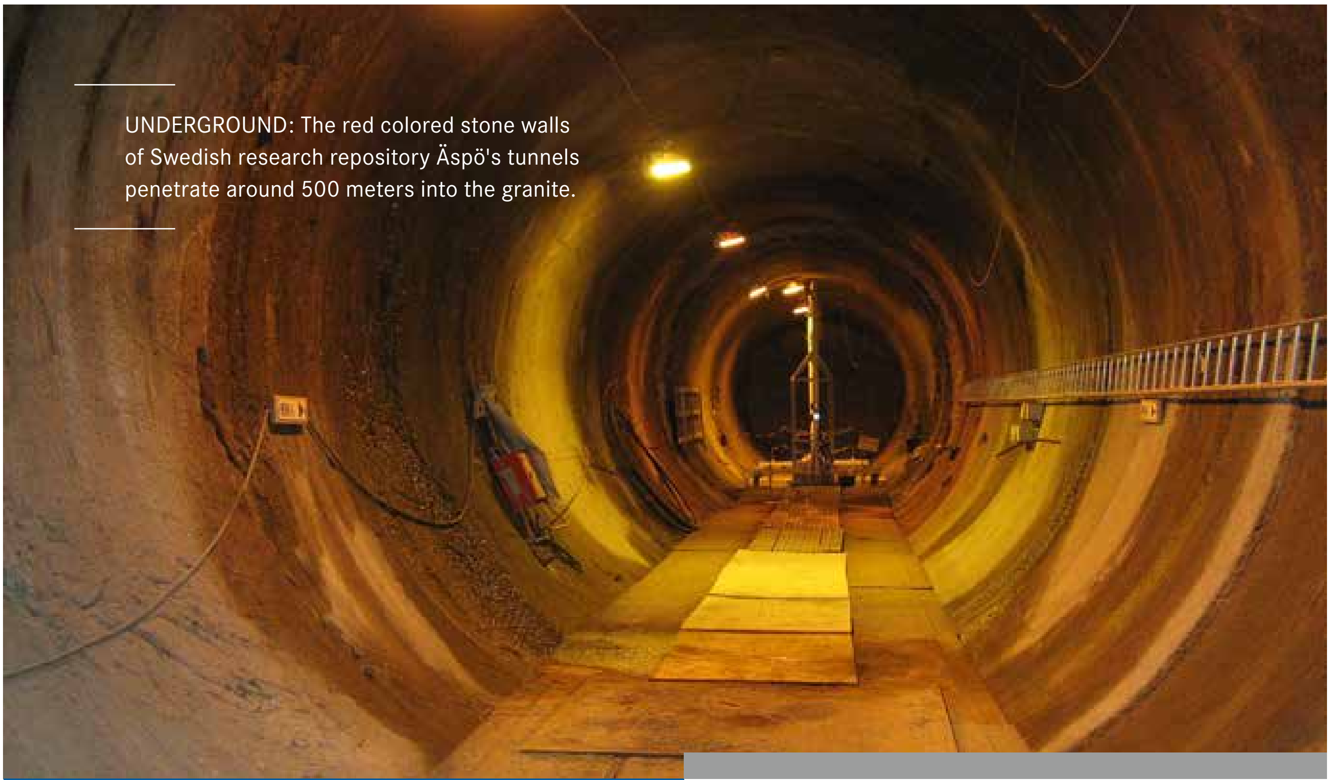
_TEXT . Roland Knauer

The wide tunnel twists in an enormous spiral reaching 3,600 meters down into the depths on an island near the skerry island coastal region in southeastern Sweden. As you head into the deep depths, you won't run into any weekend vacationers along the way, but will see scientists and engineers at work. After all, this tunnel isn't a public thoroughfare, but rather gives access to underground lab Äspö, where researchers investigate the processes that might take place in a repository for highly radioactive waste 500 meters below Earth's surface. Microbiologists have been a part of the team of geologists, physicists, chemists, and hydrologists for quite some time now. At these depths there are also unexplored life forms that haven't been pulled to the surface, but are at home down here.

"Even 500 meters down, our Swedish colleagues found microorganisms on the granite walls of the rocky shaft back in the 1990s," recalls Evelyn Krawczyk-Bärsch of the HZDR Institute of Resource Ecology. These organisms clearly grow and thrive quite well in the depths: "If we scrape some biomass off of the walls of the chasm in order to study it in our Dresden lab, the layer will grow back in the same place in just a few weeks," the researcher explains.

Microorganisms in clay and salt

The activity of underground life is not limited to granite. Henry Moll of the HZDR has also found microorganisms in the clay rock layer in which the Swiss repository may eventually be built. And researchers have even discovered microorganisms in the salt deposits near Carlsbad in New Mexico, which is evaluated as a repository. "These are often archaea that can not only cope with high salt concentrations, but at the same



UNDERGROUND: The red colored stone walls of Swedish research repository Äspö's tunnels penetrate around 500 meters into the granite.

time can also tolerate high doses of radioactive radiation very well," reports Andrea Cherkouk, who also does research at the Institute of Resource Ecology of the HZDR. In addition to bacteria, such archaea constitute an important domain of life on Earth.

Regardless of the host rock in which a nuclear repository is ultimately established, microorganisms can play an important role. And this of course makes the tiny creatures very interesting for repository researchers. So it is not surprising that these three scientists are currently actively involved in the recently launched MIND project of the European Union, which aims to take a closer look at life underground - and thus also in a repository.

Fractures in granite

A look at the geology of the underground environment of Äspö explains the origin of these microorganisms. The Scandinavian peninsula is comprised predominantly of granite rock that was formed as molten liquid magma gradually cooled below the Earth's surface and shrunk slightly as it solidified. Since granite took up less space than magma, crevices and fissures were formed. When the massive weight of thousands of meters of thick glaciers covered the land much later during the Ice Age, the underground landscape changed once more and additional cavities were opened.

But these fissures and crevices are nothing more than channels through which water can circulate. Not only is water one of the elements essential to all life, but it is at the same time an ideal medium for transporting microorganisms in particular. Water acts as a conveyor, carrying organisms throughout the underground environs. Although it may take time, microorganisms can reach a great many places over the course of millions of years.

Bacteria slime

Life in the depths is anything but unique: And in fact, researchers have come across microorganisms in almost all of the places they have looked underground. "But we didn't expect to find the rock walls in Äspö covered with slimy layers of bacteria," Evelyn Krawczyk-Bärsch recalls. Such "biofilms" can contain a diverse community of microorganisms. Researchers often start off examining the little life forms living in there using microbiological methods. →

DIVERSITY: "Biofilms", which form a rusty brown ferrihydrite sludge, grow on the tunnel walls as well as in and around the watery crevices of Äspö.

"Here we collaborate with Karsten Pederson of Chalmers University in Swedish Göteborg, who has been studying the microorganisms in Scandinavian granite rock since the 1980s," explains Evelyn Krawczyk-Bärsch. A diverse array of microbiological matter resides up to 500 meters beneath the Earth's surface. As part of a new project, the Swedish researcher is currently studying the organisms in future Finnish repository ONKALO. Just like his colleagues at the HZDR, Karsten Pederson first isolates the organisms' genetic material, DNA, which is made of the same building blocks in all organisms on Earth. Researchers then determine the sequences of these building blocks for the genetic trait for a component of the ribosomes called 16S-RNA and thus the tiny protein "factories" inside bacteria and archaea. They then compare these sequences with the 16S-RNA genetic material of other microorganisms stored in the databank in order to identify the life form present in the sample taken or determine which species it is most closely related to.

Microcosmos in the repository

Using this method, Karsten Pederson uncovered an entire microcosmos of organisms underground long ago. He has been discovering the great diversity of life in Äspö since the 1990s. It doesn't look much different in the ONKALO tunnel 300 kilometers northwest of the Finnish capital Helsinki, which is set to act as a repository for used up uranium fuel rods from Finnish nuclear power plants starting in 2022. His colleagues at the HZDR have seen similar success. Together with his Swiss colleagues, Henry Moll is searching for microorganisms in the Opalinus clay formation in the canton of Jura - and has also found a wide variety of different bacteria groups using DNA analysis. Andrea Cherkouk examines the microorganisms which are present in the salt deposits the "Waste Isolation Pilot Plant" repository (WIPP) in New Mexico. And her doctoral candidate Miriam Bader has recently teamed up with Julie Swanson of the Los Alamos National Laboratory to examine how the archaea that live in salt interact with radioactive substances.

Dead or alive?

The DNA analysis gives researchers an overall idea of what organisms are in each rock formation. Since under certain conditions the genetic material of an organism can be preserved after its death, the discovery of this material only tells scientists that the bacteria or archaea identified in this manner lived there once. Whether or not they are still active or at least can be brought to life again only becomes apparent when - like on the stone walls of Äspö - biofilms grow. Or if the scientists succeed in growing this bacteria in the lab.

Even doing that isn't at all that simple. "First of all, we usually don't know under which conditions the microorganisms grow," Andrea Cherkouk explains. What temperatures do the bacteria or archaea like, which degree Celsius will they just barely survive? How acidic can the water be, how much salt can be in it? What nutrients do the microorganisms need? Do these tiny life forms perhaps work together with other life forms, passing the torch back and forth in the form of lifegiving substances whose formation is distributed among multiple organisms? Since researchers have only examined samples of life underground at best, they don't know most of the answers to this multitude of questions. It is therefore necessary initially to produce the nutrient solution for growing microorganisms based on guesswork and using previous →

RESEARCH TRIP: Doctoral candidate Miriam Bader researched the interactions of microorganisms with radionuclides at the Carlsbad Environmental Monitoring and Research Center, a branch office of the Los Alamos National Laboratory. Photo: Julie Swanson

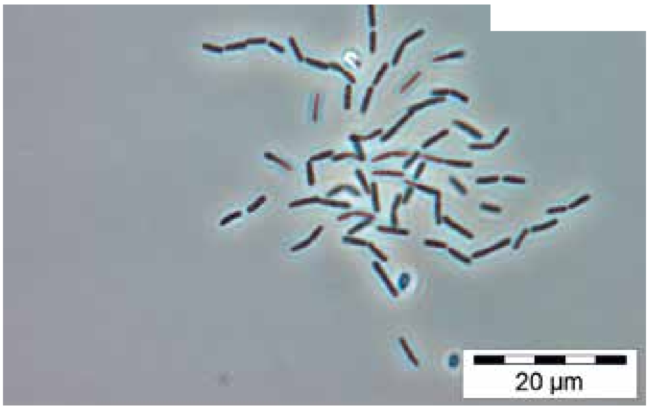
PROCLIVITY: *Halobacterium noricense* DSM 15987, a close relative of a microorganism found in the American repository WIPP, grows mainly in environments where high salt concentrations are to be found.

experience. Under such conditions, the cultivation of unknown bacteria isn't always met with any measure of success: "Only a portion of the microorganisms found in the rock can then be cultivated in the lab," as Henry Moll sums up the situation.

The unhurried life

Researchers also need a bit of patience when cultivating bacteria. Since resources are often scarce underground, the organisms there are used to working with very few resources and tend to grow very slowly. On the other end of the spectrum, *Escherichia coli*, the bacterium that lives in the human intestine, can reproduce in just 20 minutes under optimal conditions on the Earth's surface. Even if most other bacteria tend to be considerably slower, they would still be considered sprinters in comparison to life underground: Microorganisms in this underground environment often take days and weeks to reproduce. Geomicrobiologist Hans Røy of the university in the Danish Aarhus has estimated that in certain regions the bacteria 20 meters beneath the surface of the Pacific may take a good thousand years to reproduce.

Dresden researchers don't have that much time. Andrea Cherkouk has to wait several weeks until the microorganisms from the salt of a planned repository have grown in her lab. And the number of organisms from the clay of the planned Swiss repository will have doubled after just a few days. At least when Henry Moll cultivates it in a medium that meets its needs perfectly. In fact, he has found this perfect mix for a whole series of microorganisms from the clay belonging

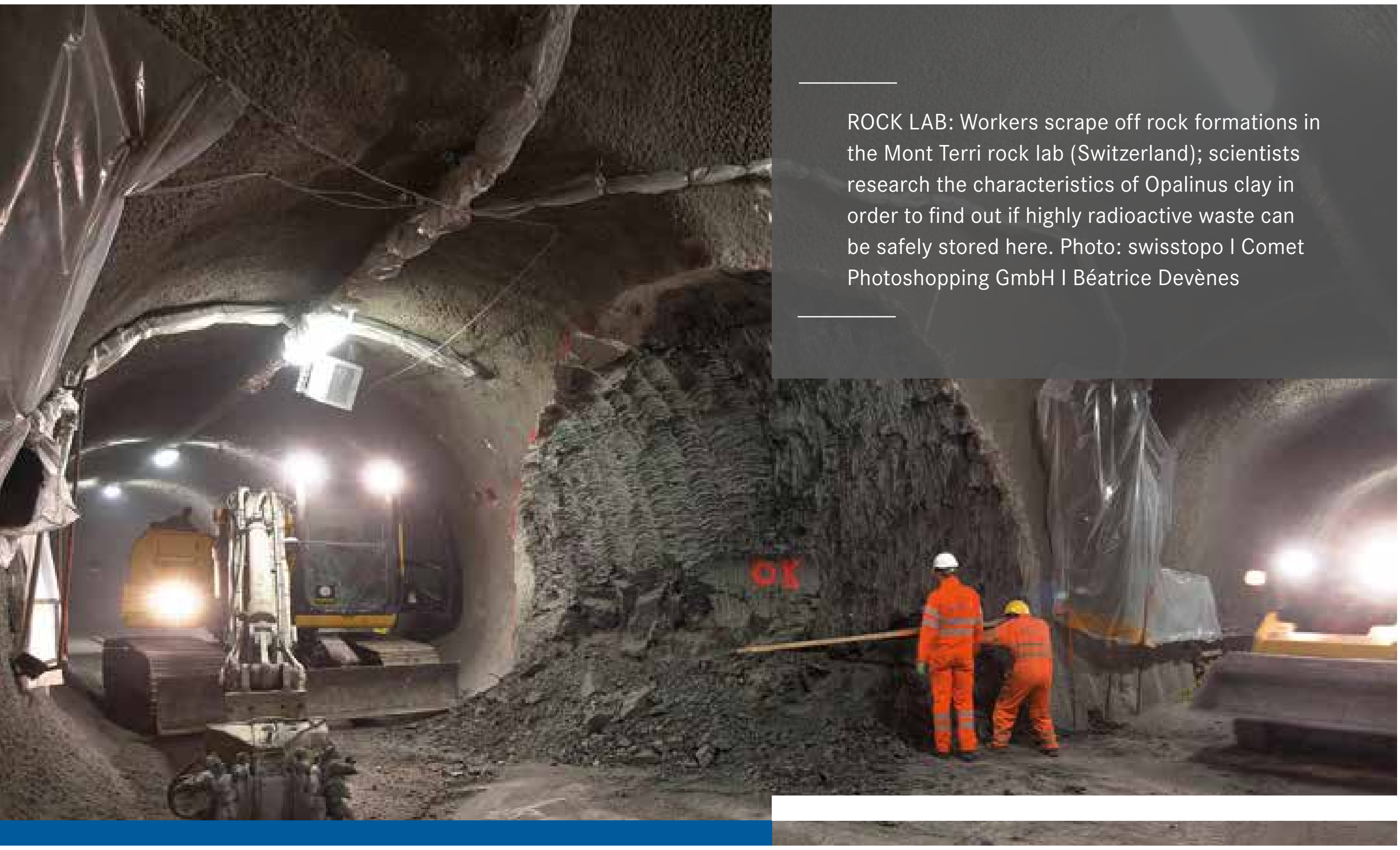


TINY LIFE FORM: The isolate *Paenibacillus sp.* MT-2.2 from the rock lab Mont Terri is capable of surviving in the Opalinus clay (picture taken with a phase contrast microscope).

to a variety of different bacteria groups such as *Paenibacilli*, *Sporomusa*, and *Clostridium*.

Nitrate eaters

Henry Moll feeds these microorganisms a carbon "pyruvate" compound, which plays an important role in the metabolic processes of many life forms. The bacteria don't just live in the lab, after all, but also in clay rock made up of carbon compounds. Since water and space are scarce here, the microorganisms tend to be more inactive. Not only that, →



ROCK LAB: Workers scrape off rock formations in the Mont Terri rock lab (Switzerland); scientists research the characteristics of Opalinus clay in order to find out if highly radioactive waste can be safely stored here. Photo: swisstopo I Comet Photoshopping GmbH I Béatrice Devènes but researchers still do not know exactly which carbon compounds the microorganisms live on. In any case it doesn't look like they will be going hungry anytime soon: Approximately one percent of the clay is composed of carbon after all.

We as human beings obtain energy in much the same way when we burn the carbohydrates from foods such as bread, potatoes, or fruit with oxygen. In many areas underground, however, pure oxygen is in short supply. Some bacteria adapted to this lack of oxygen long ago by burning carbon compounds using the abundance of nitrate compounds present, which are rich in oxygen. It is chemically bonded, however, and must be made usable for the bacteria through electrochemical reduction. But Andrea Cherkouk has found just such "nitrate reducers" in the connate water of the clay.

A casing made of uranium

The microorganisms in the clay also possess other characteristics that are of great interest for repository research: Apparently various elements of radioactive waste such as uranium, curium, and plutonium will adhere to the surfaces of the bacteria relatively quickly. "When this happens they presumably bond with the phosphate or carboxyl groups on the cell walls of the microorganisms," explains Henry Moll. This means that the bacteria could transport these radioactive substances throughout the underground environment and then deposit them again in very different locations. These processes have not yet been studied though. Is it possible that something similar would happen in the salt deposits from which Andrea Cherkouk has already isolated a few microorganisms?

Since there isn't any oxygen inside clay or salt deposits, researchers are careful about ensuring that neither the drilling cores nor the cultures containing microorganisms come in contact with oxygen. Andrea Cherkouk has discovered a wide variety of different survival strategies among these isolated microorganisms. Some of them produce methane, others digest organic compounds and still others sulphate compounds, which are also quite abundant in stone. The archaeas living in salt also adsorb uranium, clumping together in the process. In the HZDR junior research group "MicroSalt", Andrea Cherkouk and her colleagues are currently researching how this process might influence the transport of radioactive elements through salt deposits.

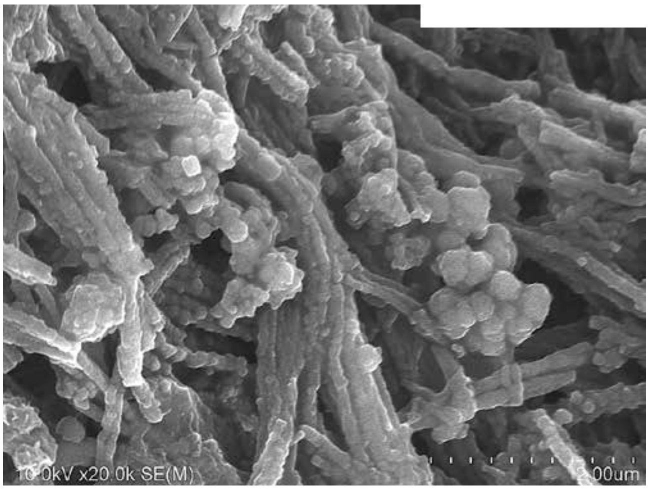
At home in gneiss

So repository research would do well to take microorganisms into account. Not only the USA, but also the Netherlands and Poland are considering eventually establishing a repository in a salt deposit. In addition to Switzerland, Belgium and France are also investigating the possibility of storing their highly radioactive waste in clay rock. Microbiological research makes the strongest case for the creation of a repository in granite rock. There are indicators suggesting that the first final resting place for highly radioactive waste in the world, or at least in Europe, could be commissioned in the gneiss of Scandinavia.

It is there, in the research repository Äspö, where Karsten Pederson has isolated the bacteria *Pseudomonas fluorescens*. His colleague Evelyn Krawczyk-Bärsch in Dresden is growing the microorganisms in the form of biofilm in her lab at the HZDR. These bacteria are able to cope very well with uranium and use it in their cells to form the mineral calcium uranyl phosphate. In this form the uranium is bound and is no longer free to move through the environment.

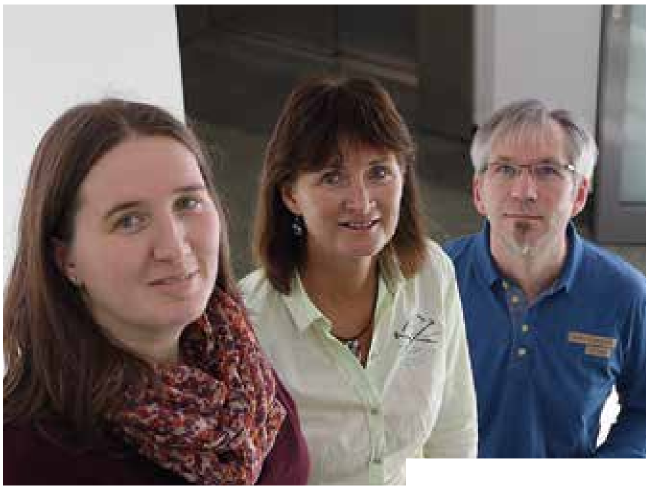
Biofilm in fast forward

Living together with *Gallionella ferruginea* in biofilms on the walls of Äspö is another bacteria. This microorganism obtains energy from the oxidation of iron(II) compounds to iron(III) compounds. Among bacteria this form of sustenance is actually quite common, since iron happens to be the fourth most common element in the Earth's crust. Once it has been produced, the iron(III) is quickly precipitated as ferrihydrite. "With the help of microorganisms this process occurs 60 times faster than it would otherwise," explains Evelyn Krawczyk-Bärsch. This yields large quantities of a rusty brown ferrihydrite sludge.



BACTERIA: *Gallionella ferruginea* lives off of iron, which precipitates as ferrihydrite after oxidation (picture taken with a scanning electron microscope).

A student took a closer look at this process in the HZDR labs during the course of completing her master's thesis: The bacteria first forms stalks on which little ferrihydrite beads develop. "This ferrihydrite offers a number of sites to which uranium and other radioactive elements such as neptunium can bond," as Evelyn Krawczyk-Bärsch explains the next reaction. Ferrihydrite will absorb almost all dangerous uranium(VI) and neptunium(V) compounds from a solution in this way. →



RESEARCH UNDERGROUND: Andrea Cherkouk, Evelyn Krawczyk-Bärsch, and Henry Moll track down life in the rock and thus in the repository (left to right).

But such results are only the beginning of research on microorganisms in the repository. In any case, the HZDR scientists have also been working on another project together with colleagues from other countries in Europe for quite some time now: Which other microorganisms are important in the repository? What will happen to the *Gallionella ferruginea* bacteria once all the highly radioactive waste is underground, the repository is closed, and the oxygen these organisms need to survive is eventually used up? As long as there are these and a number of other such questions for researchers to answer, these miniature life forms underground will continue to be a hot topic.

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EU Takes a Closer Look at Microorganisms in Repositories

Until now, microorganisms haven't been given much consideration in the research conducted by natural scientists on possible repositories for high- and intermediate-level radioactive waste. That all changed when scientists - HZDR researchers among them - discovered underground microcosmoses existing in uranium mines as well as in the different rock formations under consideration as possible repositories. Since such microorganisms could affect the mobility of the radioactive waste deposited in underground environments, 15 research groups from eight European countries will be researching the possible ramifications that this life in miniature could have for the next four years. The EU is providing over four million euros of financing for activities encompassed in the project "Development of a Safety-related Knowledge Base for the Influence of Microbial Processes on the Geological Storage of Radioactive Waste" or "MIND" for short.

"There are a number of processes in which microorganisms could play a role," geochemist Thuro Arnold of the HZDR Institute of Resource Ecology explains. As part of the MIND project, HZDR researchers are therefore working together with Spanish, British, and Czech colleagues to study how such microorganisms interact with the organic components of radioactive waste. This could, for example, include paper tissues used in a clinical institute or research lab to wipe up radioactive substances.

Additionally, Thuro Arnold and his colleagues will also be taking a more in-depth look at the influence of microorganisms on highly radioactive waste such as used up fuel rods from nuclear power plants. If these were, for example, stored in granite rock, then a geotechnical barrier would be used to prevent the radioactive substances from entering other layers. Bentonite, which usually forms from weathering of volcanic ash, is a material that could possibly be used as a barrier preventing the penetration of ground water. The clay mineral montmorillonite contained in this rock swells as soon as it comes in contact with water, thus sealing possible cracks and fissures in the barrier. The presence of microorganisms, however, could cause the montmorillonite to transform into another clay material, such as illite. Since this material does not swell at all, the bentonite barrier would lose its swelling capacity. HZDR researchers are also planning to look into this during the course of MIND.

// The plan is to dispose of radioactive waste in repositories deep beneath the Earth's surface. HZDR scientists are researching how radionuclides interact with the surrounding rock formation in such storage areas and thus how they can be prevented from spreading uncontrollably.

SPECTROSCOPY: Laser spectra can tell Moritz Schmidt and his colleagues from the junior research group a lot about the bonding properties of actinides with minerals and the surrounding rock formations. Photo: AVANGA

BOUND IN THE DEPTHS: ROCK KEEPS RADIONUCLIDES CONTAINED

Text . Uta Bilow

More than 30 countries use nuclear power plants to generate power worldwide. This comes with the important responsibility of disposing of the radioactive waste generated from the operation of these power plants. Used up fuel elements have to be locked up until their degree of radioactivity has sunken to safe levels. This could take 100,000 years or more. In long-term safety analyses the time span of one million years has even been considered. During this time the radioactive waste will have to be kept away from humans, animals, and plants. The plan is to store highly radioactive waste up to 1,000 meters below the Earth's surface. Various geological formations, such as salt deposits, clay layers, or granite are being considered for this. The surrounding stone should be capable of ensuring that the radioactive substances do not migrate, even if technical barriers such as containers or cement lids give out physically over time or if water gets into the repository. It is this issue that Moritz Schmidt's Helmholtz junior research group examines in their research work. The group members study the geochemistry of actinides, which are radioactive elements such as plutonium.

They are especially interested in the interactions between minerals and radionuclides. Minerals can form a natural barrier preventing them from spreading. What happens on the molecular and atomic level when a radionuclide solution comes in contact with a mineral surface is very complicated, however, and until now the details of what happens have remained largely unknown. Radionuclides generally tend to attach themselves to the mineral surface. Here they could be more or less safely bound as "naked" ions directly attached to the surface and/or covered by a layer of water molecules. Radionuclides may also be incorporated into the crystal lattice of the host mineral. Many actinides also form a larger compound, a so-called colloid, that is attached to the surface, but also displays a very different behavior.

Mineral and actinide in a tube

Moritz Schmidt and his colleagues are taking a very close look at these processes in the lab. Under what conditions are bonds formed, what is the coordination sphere for the radionuclide, which concentrations are reached? As they explore this, HZDR researchers take a look at different host minerals such as calcite, a calcium carbonate mineral. Since, as Moritz Schmidt explains it: "Calcite is quite common. It is also a product of decomposing concrete, which is used to build repositories." Another geological host formation chemists are researching is muscovite, a mineral containing silicate that is also very commonly found and is especially prevalent in granite. In order to take a closer look at the interactions between a mineral sample and the radionuclides, researchers have to recreate the conditions present underground in the lab. Schmidt: "We seal the mineral and our actinide in a little plastic tube. It is then shaken constantly and samples are taken regularly."

Cutting-edge infrastructure is at their disposal for the analysis of the samples. One of these devices is so-called time-resolved laser fluorescence spectroscopy, which experts refer to as TRLFS for short. Samples are excited with laser light possessing a frequency that is changed at very small intervals. These samples will then begin to emit characteristic fluorescence light. The measured curves recorded from the ultra cold samples provide information about aspects such as how an ion is coordinated, how many water molecules form its shell, how much attaches to the mineral surface, and how strong its bond with the mineral is. →

BEAM TIME: HZDR researchers are currently using the "Advanced Photon Source" at the Argonne National Laboratory in Chicago, but are also constructing their own measuring station in Grenoble.

From the group of actinides, Schmidt and his young colleagues are focusing mainly on the four elements of plutonium, americium, curium, and neptunium. "These transuranic elements are especially long-lived and radiotoxic," the chemist explains. But there have also been experiments with the homologous elements europium or yttrium. "Curium fluoresces very strongly," Schmidt says. "This enables us to identify it even at very low concentrations and determine how it interacts with the mineral." Yttrium, however, is not radioactive, but displays similar chemical behavior to that of actinides and is therefore a good alternative for basic investigations.

How curium bonds to calcite

In experiments with the radionuclide curium, scientists were able to use TRLFS to determine that curium bonds with calcite in three different ways. "We see three bands that occur for different excitation wavelengths. Each belongs to a different species, and these differ from each other in the type of coordination, symmetry, and water content," Schmidt explains. His work group also discovered that minimal traces of nitrate drastically change adhesion behavior. If nitrate is present, a soft, gel-like layer will form on the calcite's surface. "This weakens the radionuclide's bond considerably," according to Schmidt. Now researchers want to study the mechanism of surface modification in order to see if the ions of other materials such as sulfate or phosphate could experience a similar effect.

Another analysis method used frequently by HZDR scientists is surface X-ray diffraction. While X-ray diffraction is normally used to determine the regular three-dimensional arrangement of atoms in a crystal, the method used by Schmidt and his colleagues is especially sensitive to surface effects - the atoms inside the mineral are faded out so to say. Using this process, researchers can precisely observe how the presence of nitrate fosters the formation of a gel-like layer on calcite. The process requires highly intense X-rays from a synchrotron source. "We currently take our measurements in Chicago at the Advanced Photon Source of the Argonne National Laboratory," Moritz Schmidt reports. "It will soon be somewhat easier, because we are currently constructing a measuring station for the ROBL Beamline at the European Synchrotron Radiation Facility ESRF in Grenoble. Then it won't be necessary to transport samples as far from the lab in order to measure them and we will get results back more quickly."

PUBLICATIONS:
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H. Geckeis, J. Lützenkirchen, R. Polly, T. Rabung, M. Schmidt: "Mineral–water interface reactions of actinides", in Chemical Reviews 2013 (DOI: 10.1021/cr300370h)

JUNIOR SCIENTIST GROUP: Chemists Erik Johnstone, Stefan Hellebrandt, Sascha Hofmann, Moritz Schmidt and Sophia Hellebrandt (left to right) will soon be getting backup.

Start Young...

Since October 2013, Moritz Schmidt has led a Helmholtz junior researcher group at the HZDR focusing on the topic "Structures and Reactivity at the Aqueous/Mineral Interface." For five years he receives on average a quarter of a million euros each year from the Helmholtz Association for the purpose of building his group. With this funding, the Helmholtz Association aims to support the early independence of exceptional junior scientists.

Three doctoral candidates and one post-doc scientist work in the junior research group. Currently, Moritz Schmidt, who previously researched at the Karlsruhe Institute of Technology (KIT), is expanding his team. He regularly gives lectures on the chemistry of actinides at the TU Dresden, hoping to thus draw new junior researchers to Rossendorf.

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// Barriers, transport, and containment – how fundamental research is contributing to the safe storage of high-level radioactive waste.

NEAR AND FAR

_TEXT . Christine Bohnet

INSTITUTE DIRECTOR: Thorsten Stumpf. Photo: AVANGA

In principle, waste and the pollutants it contains should not be allowed to leak out of a waste disposal site and into the environment, and thus the biosphere. It is for this very reason that Germany has a waste disposal site regulation that specifies a multibarrier concept. It applies to household and industrial waste, but also dictates that multiple barriers must ensure that highly radioactive waste stays safely contained for several hundred thousand years. The "Repository Search Law" adopted in 2013 even requires proof that it will be safely stored away for one million years.

"From a historical perspective we are not capable of thinking so far into the future for such a long period of time, but if you base it all on geological processes, it would seem possible that the nuclear waste would remain safely contained for a million years," says Thorsten Stumpf, institute director at the Dresden Helmholtz center. All European countries faced with the task of disposing of waste from nuclear power plants rely on the safety of such a geological storage facility deep underground. Stumpf: "The repository must be capable of surviving multiple ice ages. This places very high demands on construction."

Technical barriers may start to break down after just a few thousand years. This is the case with containers made of steel, for example, which could be encased in cast iron or graphite. These containers, together with the surrounding fill material made of concrete, bentonite, or salt grit, count as part of the immediate environment. Repository experts consider the surrounding host rock, however, to be part of the distant environment and this must be composed of geologically stable rock layers in order to ensure the safety of the repository for as long as possible - even if water seeps in that could possibly transport the radioactive heavy metals such as actinides and other waste materials into the environment.

Repository research at the Helmholtz Association

"Here at the Helmholtz Association we have divided the work between Jülich Research Center, the Karlsruhe Institute of Technology, and the HZDR in order to find solutions for the most important aspects of a future repository that are as stringent as possible," explains Stumpf, who worked as a radiochemist at the Karlsruhe Institute of Technology (KIT) before being called to work as the director of the Institute of Resource Ecology at the HZDR. This way, the research program known as "NUSAFE" covers a broad spectrum of issues, with the focus being on the behavior of radionuclides in repositories. But there are also other topics of concern when it comes to the disposal of radioactive waste.

"All of our work ultimately revolves around the aspects of migration and retardation," Stumpf explains. "The mobilization of radioactive substances can be prevented using intelligent barriers, but also through processes that occur without our intervention." This could be chemical bonds between molecules and complexes, or electrostatic processes involving the exchange of ions on surfaces. A bond is always considered to be especially stable if the actinides are firmly incorporated into the mineral.

Today repository research is investigating these processes on the molecular level. "It used to be that in the lab you would mix a solution, shake it for a while, and then figure out the distribution curve," Stumpf explains. This was used to estimate the dispersion of individual materials. If, however, a single parameter such as temperature changes, then the result would be invalid. "In the past we have generated some relevant examples that weren't included in the dispersion calculations." It is for this reason that Thorsten Stumpf is convinced that reliable conclusions can only be drawn by understanding the system as a whole. The findings on nuclear repositories from the research of the Helmholtz Association are made available to scientists around the world as well as government agencies and future repository operators in freely accessible databanks.

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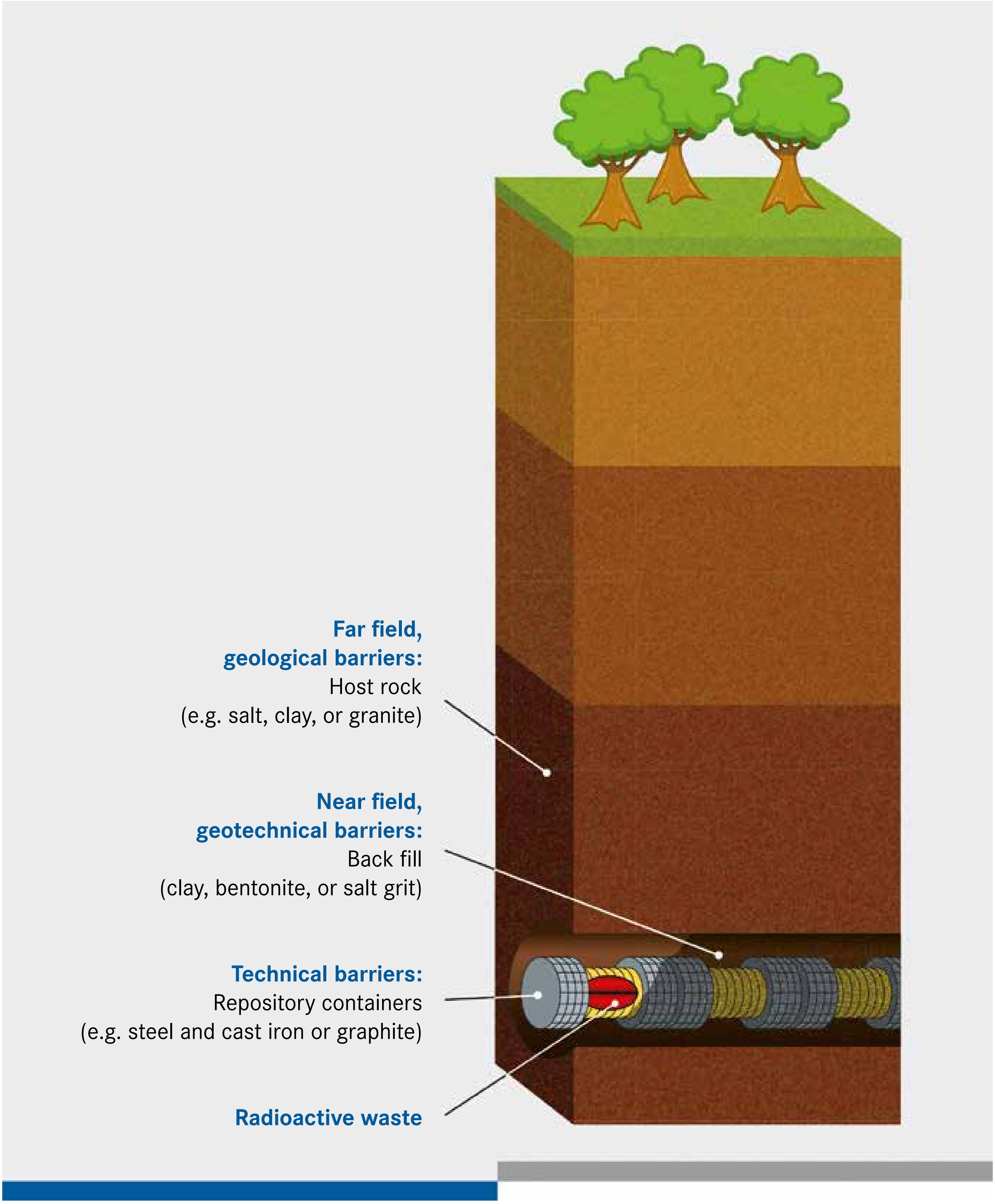
UNDERGROUND STORAGE FOR HIGH-LEVEL RADIOACTIVE WASTE: MULTIBARRIER CONCEPT

_DIAGRAM . Schmidt & Schumann



GERMANY IS UP TO THE TASK; THE STORAGE OF HIGHLY RADIOACTIVE WASTE

_Interview . Christine Bohnet

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Chemical engineer Michael Sailer is CEO of the Oeko-Institut, with offices in Freiburg, Darmstadt, and Berlin. Before taking this position in 2009, he led the institute's division "Nuclear Technology and Plant Safety". He has contributed his expert knowledge on the topics of reactor safety and the storage of nuclear waste to several commissions: He is the chairman of the "Nuclear Waste Management Commission" that advises the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety and is a member of the "Commission for the Storage of Highly Radioactive Waste," which is usually referred to as the "Repository Commission" for short. He was also a member of the "Reactor Safety Commission" for 15 years.

As he emphasizes in his interview for "discovered", informing the public is important to him: "Science has an inherent duty and obligation. We have to explain scientific results to the public in general and politicians in particular, but we also have to clarify why there are different viewpoints for a certain topic." For him reactor safety is a prime example of this. For a long time there was simply one pro and one contra perspective on the subject. "Today it is really important to me to inform others of the risks and not to polarize them. We must provide this information to society in such a way that people are able to use it to make important decisions."

Mr. Sailer, when will a repository for radioactive waste be put into operation in Germany?

If we really pull ourselves together, the first container of highly radioactive waste could find its way "under the Earth" between 2045 and 2050. All of the highly radioactive waste from Germany would fit in a single repository. For low to medium radioactive waste yielded from the operation of nuclear power plants as well as from medical or research institutions, the approved repository Schacht Konrad will be opening in a few years.

But let's get back to highly radioactive waste, which by law has to be safely stored for one million years. The decision of where to put the facility will be made following a nationwide, incremental selection process in 2031. It would then be possible to obtain a building permit for such a geological underground storage facility after 2035. From the research that has been done we know by and large how repositories work. What's really important, however, is that all essential powers work in concert to realize the facility.

What special challenges do you see arising for research institutions?

Germany has a big nuclear waste disposal problem and it isn't glaringly apparent yet, but over the next few years it will reach fever pitch. There aren't enough trained professionals to meet demand. The problem is twofold. On the one hand we need an education initiative at universities and research establishments in order to get the right people in the right place at the right time. The selection process alone will require a great deal of expertise, but the situation will get really desperate in 2031 when it's time to start with concrete preparations for the construction of a repository for highly radioactive waste. Where will the experts familiar with repository research who can carry out safety studies, safety reviews, or analyses of scientific findings be? There will be a need for experts to work for repository operators, but there will also be plenty of demand in authorization agencies, federal offices, or ministries - and at inspection agencies as well.

On the other hand it is essential that research efforts be bundled. The topics that the Gesellschaft für Anlagen- und Reaktorsicherheit, GRS (Association for Facility and Reactor Safety), together with a total of three Helmholtz centers and some select universities, are working on are very important. But I doubt that they will succeed in systematically addressing all questions related to the transport and containment of radioactive materials. In the repository search process, especially when the time comes to choose a concrete location, there are always more and increasingly detailed questions to answer. How exactly do the radioactive substances spread? How does the specific geological situation influence mining operations underground? What microorganisms live there and what role might they play in containment?

Is more research needed in Germany?

The reality is that repository research is financed by a variety of different sources. Three different federal ministries for different sectors have support programs. I would argue in favor of better coordination and integration of the programs. →

Without a systematic approach and critical assessment of what we already know, it won't be possible to address all of the necessary fields in the future. The Nuclear Waste Management Commission, for example, convened at a two-day workshop last year to discuss the current state of research in Germany and the research that still has to be done.

In my opinion practical large-scale biological and chemical experiments will have to supplement the more common test tube research. Added to that, in the future an incremental approach will take on a great deal of importance, so that we can gradually achieve an in-depth understanding of concrete scenarios. For this process as well, someone has to define the research that is important and essential.

How is Germany doing in comparison to other European countries?

In other countries the interplay of actors is, in part, organized better. Take Finland, Sweden, Switzerland, or France for example. These countries are already in the advanced stages of determining where their repository will be and applying for the necessary approvals. And they have succeeded in bundling their resources in research. The construction permit for the Finnish repository is already set for 2016 or 2017. So from our European neighbors we can learn to ask the really meaningful questions and continue to ask ourselves which answers we will need in 10, 20, or 30 years.

Please give a short description of the current working conditions and tasks set for the Repository Commission.

The current situation looks like this: The dispute surrounding the Gorleben location tore a rift through Germany, but more than 30 years later this seems to have healed for the most part. For the past two years the great majority has been in agreement that we need to search and find a repository location and be open to what happens. The "Law for the Search and Selection of a Location for a Repository for Heat-Emitting Radioactive Waste," or "Repository Search Law" for short, that was adopted in the summer of 2013 was approved by the vast majority of members of the Bundestag and the Bundesrat approved it unanimously. Everyone sees the necessity of achieving a solution by storing highly radioactive waste in the deep geological layers of the Earth. This widespread acceptance in politics has clearly taken on a new quality in my opinion.

The goal and duty of the 33 members of the Repository Commission is to evaluate the Repository Search Law of 2013 once more themselves, make a judgment call on the criteria and safety requirements this law establishes, and put together the search criteria. In any case, the law specifies a very operationalized course of action. Our report must be ready by the middle of 2016 - and that is doable. I am optimistic that this is the basis the Bundestag and Bundesrat need in order to give the go ahead to search for an actual location by the end of 2016 or beginning of 2017.

Does the Repository Commission's duty end there?

Yes, since the law specifies that a project developer – probably the Federal Office for Radiation Protection – should organize the actual location search. The new Federal Office for the Regulation of Nuclear Waste Management will then emerge as a regulating body. All actors must also make sure that they actively engage the public in these processes. Before the final location is legally confirmed, the Bundestag and Bundesrat will have to make several decisions in a stepped process. So the trick will be to maintain a high level of cooperation from politicians over the course of the next several years.

↗ www.oeko.de

RECOGNIZED: Michael Sailer is an expert in reactor safety and nuclear waste storage. Photo: Oeko-Institut

// At the Rossendorf Beamline ROBL in French Grenoble, the sharp minds of researchers enhance the safety of repositories for radioactive waste - and in the past they have thus even disproved some hypotheses from the experts.

DOWN TO THE ATOMIC LEVEL

_TEXT . Simon Schmitt

REALISTIC: Marisol Janeth Lozano Rodriguez investigates the ability of materials to permanently bond to actinides. Photo: AVANGA

Johann Wolfgang von Goethe already knew that the devil is in the details - or as put in the words of the great German poet: "To revitalize the whole, you'll have to see the smallest bits of it." This old quote fits almost perfectly to the current state of repository research. Andreas Scheinost estimates that about 95 percent of the most important questions are clarified. "However, the remaining five percent encompasses questions of detail that play a decisive role in ensuring that a repository is safe for the storage of radioactive waste." Just as Goethe advises, the HZDR researcher wants to address even the tiniest details that make up the whole - the quest for a safe repository.

In order to do so, he has to take a look at processes on a molecular level. And since these occur in extremely small dimensions, Andreas Scheinost is using a "microscope" the size of a soccer stadium: the European Synchrotron Radiation Facility ESRF in Grenoble. On the ring-shaped racetrack with a circumference of 844 meters, electrons are sped up until they are traveling nearly at the speed of light. This process produces X-ray radiation that is 100 billion times more intense than that used in hospitals. This radiation enables scientists at the ESRF to gain deep insights into the structure of matter at more than 40 experimental stations, so-called beamlines.

What happens in the repository?

Only one of them offers the necessary conditions for nuclear repository research: the Rossendorf Beamline ROBL. "Apart from us, there is only one other beamline in Europe where radioactive samples can be investigated," Andreas Scheinost explains. Accordingly, time slots for performing experiments are in high demand by researchers from all over the world. "On average we tend to be overbooked two to three times over," the director of the "Molecular Structures Division" adds: "Even though ROBL operates around the clock for 200 days a year."

The molecular processes occurring in a nuclear waste repository are the focus of the scientific work. "We still don't know precisely how the actinides and other radioactive elements behave in the environment of a future repository," →

Scheinost explains. "Will they be captured by microorganisms, thus becoming mobile? How do the radioactive compounds interact with the host rock and with technical barriers? What happens when the steel barrels rust?" Such questions are decisive for the long-term safety of a repository site, which is expected to be capable of storing waste from nuclear power plants for one million years.

X-rayed for atomic precision

In order to answer these questions, researchers have to decode the chemistry of radioactive elements and their compounds. ROBL provides a valuable tool for this task: X-ray absorption spectroscopy. During the experiments, the samples are exposed to the intense light produced by the synchrotron. Scientists measure to what extent the X-rays interact with the atoms in the sample. "We can derive very important information from the energy-dependent absorption spectra," Scheinost explains. "For example, what is the predominant oxidation state of the atoms, where exactly are they located on surfaces of minerals, for instance, and which type of bonding they form."

DEEP INSIGHTS: Andreas Scheinost exposes radioactive samples to intense X-rays at the European Synchrotron Radiation Facility ESRF in Grenoble. Photo: AVANGA

These properties determine the mobility of the radioactive compounds – if they will be retained in the repository or released into the ground water that may occur in the host rock. "These are questions of detail," Scheinost summarizes. "But often with significant effects." And anyone who takes a closer look will discover new relationships. Experiments at ROBL have thus already disproved assumptions made by experts, as the French facility offers another big advantage. "Unlike in most experiments, we can simulate environmentally relevant conditions very well. One example is the exclusion of oxygen from the air, which will of course be the case in a repository."

The smallest details yield new discoveries

Scheinost and several international colleagues were able to demonstrate that, under conditions prevailing in a repository, the radioactive and highly toxic heavy metal selenium-79 – a fission product found in burnt-up nuclear fuel – is less mobile than previously thought. "By conducting experiments on samples in the absence of oxygen, we were able to ascertain that selenium-79 remains bound to steel containers, even if they have rusted through due to the possible contact with water," Andreas Scheinost explains. "The minerals that encase the future repository will offer further protection. They will ensure that radionuclides do not pose an increased risk to the safety of a repository."

Scheinost and his colleagues achieved a similar result in experiments with the radioactive element plutonium. Actually, researchers had expected that reactions occurring in the absence of oxygen reveal increased mobility of the heavy metal. As measurements taken at the Rossendorf Beamline have shown, the plutonium will remain firmly sorbed at the →

STADIUM SIZED "MICROSCOPE": At the ESRF in Grenoble researchers use HZDR's beamline ROBL to decode the chemistry of radioactive elements and their compounds. Photo: ESRF/Ginter

surface of the iron-based minerals which are present in the granite or clay, but also in the ground water and the rust on the waste containers. "All of this knowledge is taken into consideration when designing possible repositories and helps to make them safer," Scheinost concludes. A sharp eye for the smallest of details thus forms a more solid foundation for the whole.

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// Chemist Peter Kaden researches the bonding behavior of certain radioactive waste materials using nuclear magnetic resonance spectroscopy. The knowledge he obtains will be used to further the research in Rossendorf - one of the few locations worldwide engaged in such research.

UNDERSTANDING THE LITTLE THINGS MAKES A BIG DIFFERENCE

_TEXT . Sara Schmiedel

ELUCIDATION: Chemist Peter Kaden makes use of NMR (nuclear magnetic resonance) spectroscopy for his research. Photo: Oliver Killig

To date there is no repository for highly radioactive, heat-emitting waste from nuclear facilities in Germany. Due to the federal government's National Repository Program, the future repository must ensure the best possible safety for a time period of one million years. It is for this very reason that plans are being made to deposit nuclear waste several hundred meters underground to shield the biological environment and the biosphere from it. "If we construct a repository in a rock layer underground, then we have to know how the radioactive elements will act in case water, for example, gets into the repository," says Peter Kaden of the HZDR Institute of Resource Ecology. He and his colleagues are interested in finding out how the radioactive metals from nuclear waste interact with organic and inorganic materials from their environment. This knowledge could lead to a better understanding of transport processes and help to establish effective barriers in repositories. This could serve to prevent the spread of radioactive materials in case of an emergency.

Challenging proof

The process of energy generation in nuclear reactors produces so-called actinides from the fuel uranium - elements such as plutonium and americium. Lanthanides are a group of elements that are physically and chemically similar to the actinides, they are predominantly not radioactive and therefore considerably easier to study. They can help scientists understand the chemistry of actinides as well. But not entirely. Peter Kaden and some of his former colleagues from the Karlsruhe Institute of Technology (KIT) showed for the first time that there are considerable differences in the bonding behavior of trivalent actinides in comparison to lanthanides. Theoretical considerations of the matter are already twenty years old. All that is lacking is clear experimental results to support these theses. →

The researchers working with Peter Kaden use NMR, or nuclear magnetic resonance spectroscopy, a technique that was developed as early as the 1940s and is used to determine the components of a sample as well as in fields such as medicine. A strong magnetic field is applied to orient the nuclear spin of the elements being studied, while at the same time radio-wave pulses are stimulating them. The behavior of the nuclear spin will change depending on the chemical environment, before ultimately returning to its initial state. This process can be measured and analyzed. Scientists are interested in aspects such as the influence of the actinides on the nuclear spin of nitrogen atoms in organic and inorganic compounds that could serve as bonding partners. "We see a dramatic shift in the signals for the nitrogen, which cannot be fully explained by electrostatic interaction alone," says Peter Kaden. From this researchers conclude that electrons are exchanged between neighboring atoms, meaning that a chemical bond has been established. "This is very recent research, so now what we urgently need is support from theoretical chemistry," the chemist emphasizes. "Not only the experiments, but also the theoretical calculations for actinides are very demanding." Such calculations are incredibly cost-intensive and run for years.

PROOF: Doctoral candidate Claudia Wilke analyzes the NMR spectra in order to better understand the properties of radioactive heavy metals and thus be able to better describe the interaction with organic materials. Photo: Oliver Killig

From small to large

Evidence of this special type of bond in actinide compounds is fundamental. NMR spectroscopy helps researchers to understand the properties of radioactive heavy metals and thus be able to better describe their behavior when they come in contact with organic materials for example. "Once we have successfully understood the interactions on the molecular level, we can later support reliable dispersion calculations," the Helmholtz researcher says. It would then be possible to predict the reactions of radioactive actinides in case of an emergency - What mobilizes them, what do they bond to, and most of all: How can they be immobilized again?

Strengthen expertise on-site

Actinides are radioactive - and generally remain so for a very long time. Alpha radiation is especially dangerous if it makes it into the body. For this reason, only a handful of research institutions nationwide are allowed to study radioactive heavy metals. "Very strict safety precautions are necessary," says Peter Kaden. "Moreover, the substances themselves, even in the smallest amounts as we use them, are very expensive since even just preparing and purifying them is extremely costly."

The chemist has been working in Dresden-Rossendorf for just a few months now. Previously, he was the specialist in charge of NMR spectroscopy of actinide compounds at KIT. Now he brings this expertise to HZDR. "The conditions here are excellent, there are so many opportunities. The HZDR is very interdisciplinary, has just about all relevant measuring devices available, and has an established specialist on-site for every method." In addition to Peter Kaden, institute director Thorsten Stumpf is currently hard at work surrounding himself with more actinide experts from around the country and abroad. "We want to strengthen the expertise we already have here at this location," he emphasizes. The HZDR will then become one of the few institutions worldwide working to shed light on the world of actinide chemistry using a variety of spectroscopy methods.

PUBLICATION:
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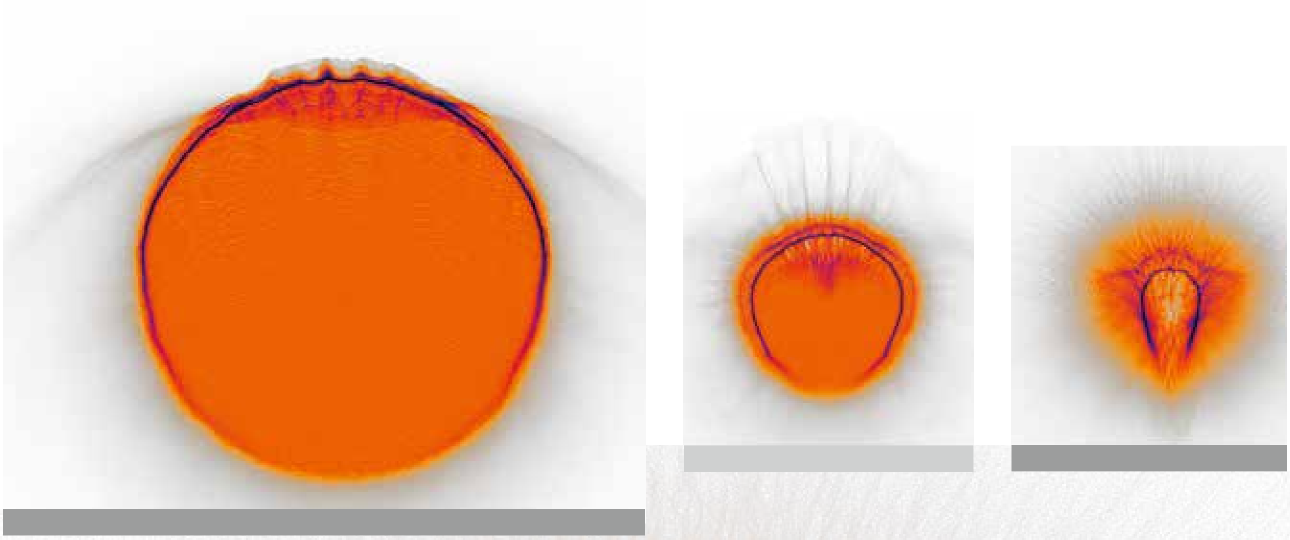
// Super-fast, scalable, and free – what started as a project for the German high-school student competition "Jugend forscht" is now one of the most powerful program codes for calculations in astro- and plasma physics.

FAST CALCULATIONS FOR PLASMA SLOW MOTION

_TEXT . Christian Döring



IN ACTION: : A laser beam hits a spherical target. A plasma made up of electrons and ions is formed. Just like an explosion, the plasma expands and the electrons fly away from it, followed by the ions.

A high-power laser shoots, a piece of metal foil crackles, and a bit of steam rises - that's just how simple a description of the laser particle acceleration process can be. But a glance at the physics of what is happening is much more impressive: The hundred trillion watt laser at the Helmholtz center in Dresden propels quadrillions of electrons forward, thus forming a kind of hot cloud composed of charged particles. In the same time it takes an electron to orbit its atomic nucleus, all matter is ripped apart, leaving just its fundamental constituents intact - a so-called high-energy plasma is produced. "For us as physicists that is a very interesting state of matter. The interactions between electrons and ions are so amazingly complex that our basic research requires exact, reviewable computer models from the very start," explains Michael Bussmann, head of the junior scientist group "Computational Radiation Physics" at the HZDR.

The Dresden junior researchers have developed "PIConGPU" to enable them to calculate such models. This special simulation code is so powerful that it even gives the American super computer "Titan" a run for its money. With its 18,688 graphics processing units (GPU), Titan is not only currently the second fastest computer in the world, but also especially well-suited for such work: "GPUs are capable of simultaneously analyzing the movement of an amazing number of particles - and that's exactly what it comes down to when extremely complex processes of laser particle acceleration have to be modeled within a very short amount of time," says Michael Bussmann.

Following one electron out of 100 billion particles

Dresden scientists therefore don't have their procedures carried out by normal main processors as usual, but rather by graphics cards. These solve differential equations using the particle in cell method (PIC), which correlates the evolution of electric and magnetic fields with the movement of particles in plasma. At a record value of 7.1 quadrillion calculations per second (PFLOPs/s), this method is used to create physical 3D models of the ultra-fast particle chaos in the plasma. So the code can be used to view everything in a kind of slow motion: Even in a group of 100 billion particles, researchers can track a single electron and calculate its influence on the system as a whole.

The real advantage is the high scalability of the code. This means that the computing power of the code increases proportionally to the number of graphics cards used. Something that can't be taken for granted, as Heiko Burau, a graduate student in Bussmann's group, emphasizes: "Even the smallest unused waiting time during data processing could be significantly detrimental to GPU computing power." So for optimal performance, the graphics processors must work as independently of each other as possible. The fact that thousands of cards work together processing the models poses a challenge: How could the slow data transfer between individual graphics cards be compensated for? The simple, but effective solution is: New calculations are initiated while the transfer to other cards is taking place. This ensures that waiting times are put to good use and all graphics cards are operating simultaneously.

Whether it's the cosmic jets of astrophysics, the study of laser-driven fusion, or laser particle acceleration - now just about any calculation involving high-energy plasma can be carried out with this code. Data obtained this way can, for example, help to make accelerator systems for proton therapies used against cancer more compact and cost-effective.

Thanks to its high level of flexibility, in the future the code will also include atomic physics models important for studying processes in plasmas at the new Helmholtz International

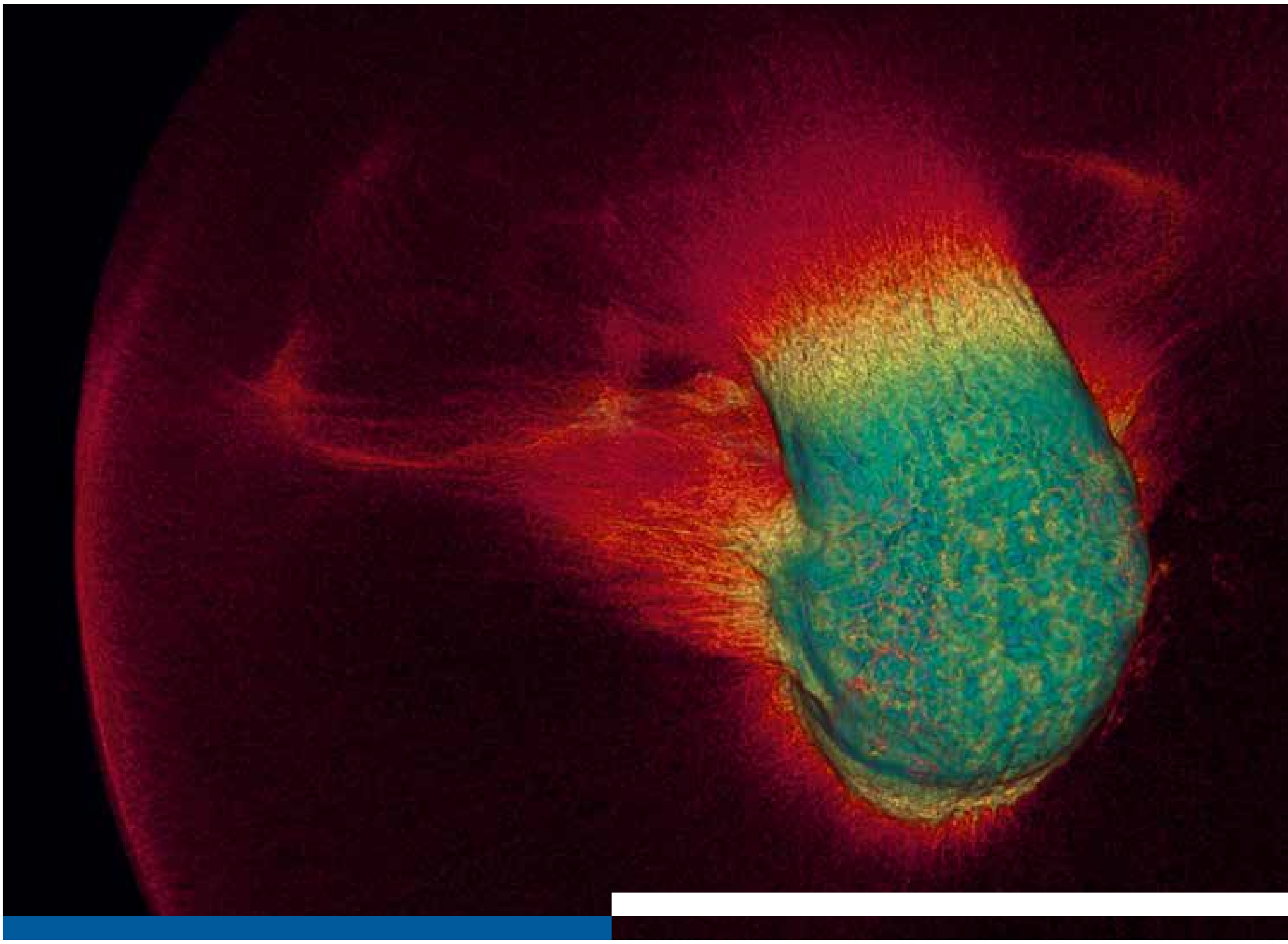
TITAN: Currently the second fastest computer in the world, super computer "Titan" resides at the Oak Ridge National Laboratory in the US state of Tennessee. Photo: ORNL | U.S. Dept. of Energy

Beamline for Extreme Fields (HIBEF) at the European XFEL in Hamburg. As part of this process considerably more parameters will be taken into account, right down to the quantum physics level. This does make the code run more slowly, but at the same time allows for simulations that wouldn't have been feasible before. Bussmann's dream is to use this with the analysis of experimental data: "That way one and the same code could pave the way from the model to experimental testing and onward to an improved model."

The group leader is proud that his trust in the capabilities of his junior researchers has paid off: "It isn't unusual for me to be skeptically confronted at conferences with: 'With students? That would never work.' But it has worked - not despite, but rather because of the students." This fostering of outstanding junior scientists continues to this day: In September 2015, Daniel Grassinger – another winner of the "Jugend forscht" contest – worked as a new intern in the group. He developed a new process that can be used to read the data from different codes in the same open format, OpenPMD. As a result of his work the predictive capability of the HZDR code can now be compared with other plasma codes for the first time, thus working to improve them. External researchers are also very eager to see such an →

The flexibility of the code makes it suitable for use in the new Helmholtz extreme lab in Hamburg

Heiko Burau is the inventor of PIConGPU: After winning the student competition "Jugend forscht", in 2009 he received the opportunity to research his topic "Graphic Card Programming" at the HZDR. After just six weeks, the then 17-year-old had already programmed the first version of the code for a single GPU in collaboration with other young researchers in the group. Bit by bit other students also began to participate and added on to PIConGPU until it ultimately became one of the most powerful codes for laser plasma physics that there is today.



DENSE – DENSER – SUPERDENSE: Simulation on TITAN showing the proton density after laser impact on a spherical target. The intense electro-magnetic field of the high-power laser rips electrons apart from their ions and creates a plasma. Simulation/theory: Axel Huebl (HZDR, TU Dresden) | Visualization: David Pugmire (ORNL) | Experiments: Peter Hilz (LMU)

optimization take place, since PIConGPU is an open source code that any scientist can use free of charge and can adapt to suit his or her own models. HZDR researchers are convinced that the reciprocal exchange of information will drive progress, which is why they actively urge others: "Please steal our code!"

PUBLICATION:

M. Bussmann, H. Burau, T. Cowan, A. Debus, A. Huebl, G. Juckeland, T. Kluge, W.E. Nagel, R. Pausch, F. Schmitt, U. Schramm, J. Schuchart, R. Widera: "Radiative signatures of the relativistic Kelvin-Helmholtz Instability", in Proceedings SC13: International Conference for High Performance Computing, Networking, Storage and Analysis 2013 (DOI: 10.1145/2503210.2504564)

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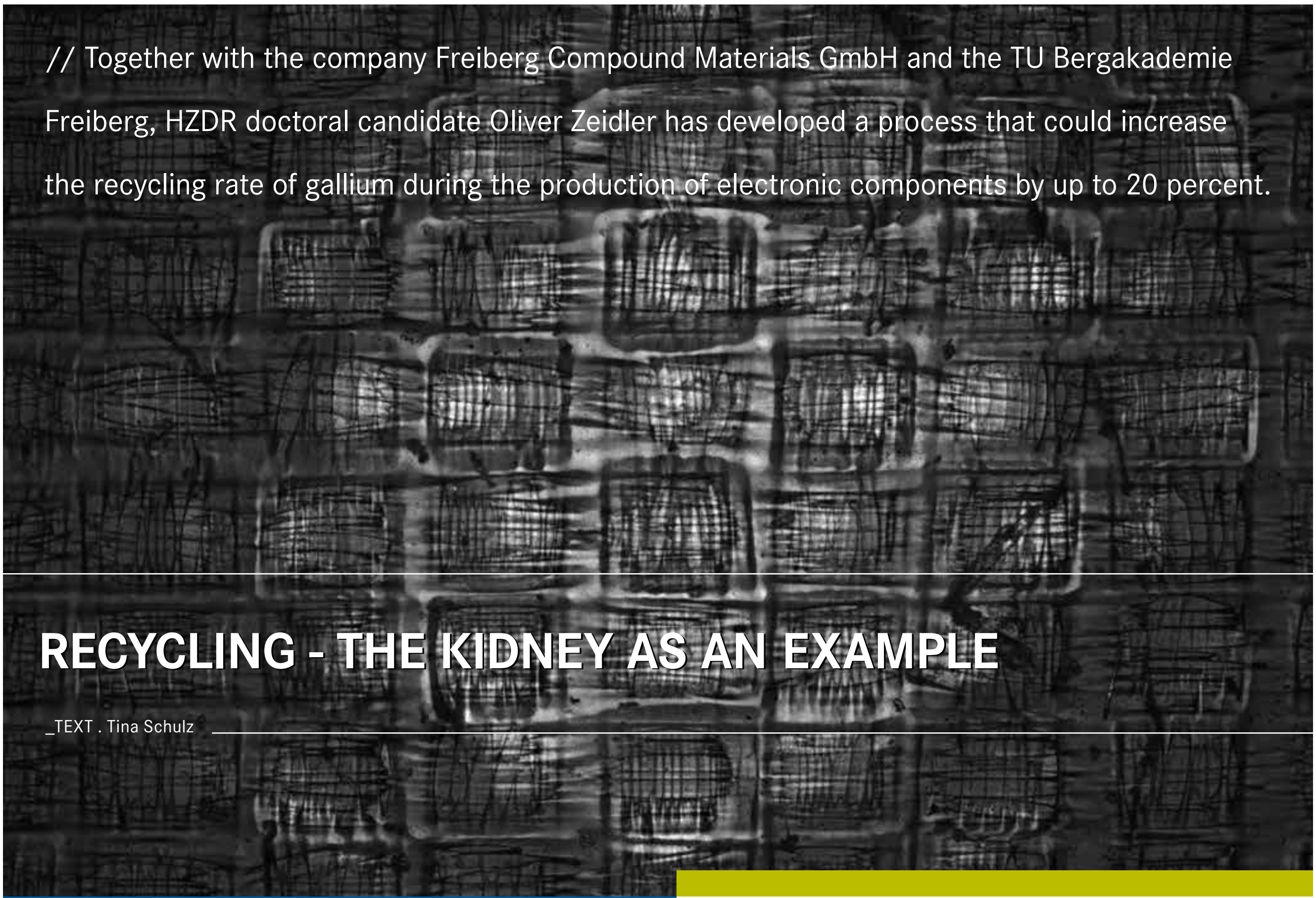

// Together with the company Freiberg Compound Materials GmbH and the TU Bergakademie Freiberg, HZDR doctoral candidate Oliver Zeidler has developed a process that could increase the recycling rate of gallium during the production of electronic components by up to 20 percent.

RECYCLING - THE KIDNEY AS AN EXAMPLE

_TEXT . Tina Schulz

DIFFUSION: Water hits the membrane, the resin swells, the pores are closed. Arsenic acid passes through the membrane unhindered and is thus separated from the gallium (picture taken with a reflected-light microscope at 50 times magnification).

Although these days most computer chips and solar cells are made of silicon, there is a semiconducting material that transports electrons more quickly and transforms sunlight into energy much more efficiently: Gallium arsenide. Compounds composed of gallium and arsenic are superior to silicon in regards to the switching speed for transistors as well as the energy output of solar cells. Beyond that, the material is also indispensable for the construction of light-emitting diodes or for use with the lasers that carry information through fiber optic networks.

Since gallium arsenide enjoys such high popularity, the need for gallium is growing fast. Unfortunately, the silvery white material with its typical blue sheen is considered a "rare metal". Not just because it is especially rare - in the Earth's crust there is about as much gallium as there is lead - but also because the metal is only present in very low concentrations in ore. So in many cases the technical cost required for extraction stands in the way of great profits.

For this reason, and since the metal is somewhat irreplaceable, the search for cost-effective recycling methods is an urgent task. During the production of gallium arsenide wafers alone about 60 percent of the gallium used falls by the wayside as waste. In production cylindrical crystals are grown from this material and cut in millimeter-thin disks using a mechanical cutting process. Today almost half of all waste, such as sawed off crystal ends or defective disks, makes its way back into production without a problem. Things get more difficult, however, if the wafer surfaces have to be cleaned with water or polished with an acidic pickling solution. Then the costly metal will end up in different types of wastewater that have to be reprocessed in a variety of different ways.

Poisonous arsine

The reprocessing of pickling solutions is especially costly. The metal can be extracted from such wastewater by electrolysis. In order to do this, it first has to be pretreated. Without this pretreatment, the electrolysis process would release an extremely poisonous gas: Arsine, which is made of arsenic-hydrogen that blocks the nerve receptors and impedes the transport of oxygen through the body. If you want to eliminate this poisonous malady at its chemical source, you will have to remove a completely different material from the mix: Arsenic acid. This compound, which contains oxygen atoms as well as hydrogen, is the source material for arsine. It emerges when gallium arsenide dissolves in the acidic pickling solution. Chemists deal with the problem by adding limewater - a calcium hydroxide suspension - to the wastewater in order to increase its pH value. This decreases the solubility of the calcium ions as well as the arsenic acid. →

Arsenic can be safely removed from the liquid with the resulting solid matter. The disadvantage of this method lies in the fact that the volume of the liquid is significantly increased once the chemicals necessary for this treatment have been added. The concentration of gallium in the solution drops so dramatically that any attempt to extract it becomes uneconomical. A completely different solution is, therefore, needed in order to separate arsenic acid from gallium.

An award-winning idea

In December of 2014 this idea was recognized with the German Raw Materials Efficiency Award and 10,000 euros in prize money. The most efficient aspect of this research is as follows: Different types of production wastewater can be processed in just one step and without the costly use of chemicals. This increases the recycling quota for gallium waste from the previous 45 percent to up to 65 percent. HZDR engineer Oliver Zeidler, who has been working on his doctorate degree since 2012 at the Helmholtz Institute Freiberg for Resource Technology, has developed a novel dialysis process for this. It was conceived in collaboration with the company Freiberger Compound Materials GmbH (FCM) and the TU Bergakademie Freiberg. The tall Leipzig native modeled his concept after a very specific organ: "Similarly to how a kidney filters uric acid out of the bloodstream through a membrane, arsenic acid can be removed from process waste water."

The process operates according to the simple principle of diffusion: Particles tend to distribute themselves equally throughout a space. If there is a higher concentration of particles in a particular area, then they move to balance out this difference. This occurs without the addition of energy and is therefore especially efficient. But how exactly is arsenic acid separated out from gallium? The solution, as with a kidney, is a selective membrane that only allows certain compounds from the original solution to pass. For this process to work, the membrane has to be acid-resistant. This is because in order for all of the wastewater to be treated at the same time, it is necessary to dissolve the residue with aqua regia – a mixture of several strong acids.

Opposites attract

Oliver Zeidler uses ion-selective membranes with a layer of positively charged functional groups for the dialysis system. That way only negatively charged ions such as those in the arsenic acid are able to pass through the membrane unhindered. And the positively charged gallium ions? The aqua regia transforms them into negatively charged gallium chloride complexes. The trick to this is that such complexes aren't especially stable. If the concentration of chlorine compounds in the environment decreases, then they will disintegrate, thus releasing the positively charged gallium ions. This occurs in the moment when the complexes pass out of the chloridic starting solution through the membrane and into the chlorine-free wash solution. It is in this way that the gallium and arsenic acid are separated while also preventing the formation of poisonous arsine gas.

The materials scientist was able to demonstrate his results on a test system with the help of transport models capable of predicting the processes that will take place at the membrane. The process is very promising: Once put into practice, it could succeed in saving up to two and a half tons of gallium during wafer production with a market value of approximately a half a million euros.

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DIALYSIS: In 2014 this recycling method received the "German Raw Materials Efficiency Award" of the Federal Ministry for Economic Affairs and Energy. Photo: BGR | Uppenkamp

// HZDR visiting scholar Jenny Feige has succeeded in using deep sea sediments to detect ancient star explosions. With her popular science article "Astronomie unter dem Meer" (Astronomy Under the Sea), she won the Klaus Tschira Award for Achievements in Public Understanding of Science in Physics 2015 and 5,000 euros.

ASTRONOMY UNDER THE SEA

Text . Tina Schulz

In her doctoral thesis at the University of Vienna, Jenny Feige proved that when it comes to astronomy it is important to not only observe the sky, but to also look beneath the sea. There, the 34-year-old Brandenburg native studied special, long-lived radionuclides in two to three million year old sediment layers from the Indian Ocean. The radionuclides are a result of nuclear reactions that take place during supernova explosions in space. If such a cosmic explosion were to occur near our solar system, then the radionuclides would reach the Earth as stardust and accumulate in the sediments. "The deep sea archives have a kind of geological long-term memory that stores traces of star explosions that happened a long time ago," the astrophysicist explains.

Jenny Feige analyzed her samples using accelerator mass spectrometry - a method that detects individual atoms - in Vienna, at the Australian National University in Canberra, and at HZDR. In certain parts of the sediment cores, her analyses verified the existence of ^{60}Fe – an iron isotope that does not occur naturally on Earth. In massive stars, it is produced only shortly before and during a supernova. Jenny Feige spent a total of six months in Dresden under the supervision of nuclear chemist Silke Merchel. Here, she mainly made use of the chemical labs to prepare her samples and the accelerator facility DREAMS (DREsden Accelerator Mass Spectrometry). "The detection of ^{60}Fe alone is not sufficient. We also need to know the exact age. This is why Jenny Feige measured the beryllium isotope ^{10}Be here as well," Merchel explains. This isotope is produced in the Earth's atmosphere and gradually makes its way down to Earth, where it then decays. "Every sediment layer has more ^{10}Be atoms than the one below it, in which the decay of the isotope is already more advanced. This can be used to determine the age of the sediments."

And Jenny Feige was indeed able to conclusively prove that the ^{60}Fe had been found only in those sediment layers that are 1.7 to 3.2 million years old. Thus, she also disproved the assumption that only one supernova has occurred near our solar system. "In fact, the signal results from an overlap of multiple supernova remnants," according to Feige. For her doctoral thesis she received the Doctoral Thesis Award of the Nuclear Chemistry Section of the German Chemical Society (GDCh) last year.

In her article "Astronomie unter dem Meer", Feige fascinatingly explained an area of research that until now has been widely unknown to the public: deep-sea astronomy. On October 8, 2015 she received the Klaus Tschira Award for Achievements in Public Understanding of Science in Physics for her publication. The Klaus Tschira Foundation has been awarding the prize since 1997 to young scientists who present their results in an especially well-written and generally understandable article.

> "The iron isotope ^{60}Fe is produced at temperatures ranging from 500 million to 2 billion degrees Celsius - conditions that aren't even present at the core of our sun."

PUBLICATION:

J. Feige et al.: "AMS measurements of cosmogenic and supernova-ejected radionuclides in deep-sea sediment cores", in European Physical Journal Web of Conferences 63, 2013 (DOI: 0.1051/epjconf/20136303003)

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↗ www.dresden-ams.de
↗ www-astro.physik.tu-berlin.de/
↗ www.klaus-tschira-preis.info

A GUEST: Astrophysicist Jenny Feige used the DREAMS facility at the HZDR to analyze her sediment samples. Photo: Klaus Tschira Stiftung gGmbH | Dietmar Gust

PANORAMA – HZDR NEWS

RAW MATERIALS FOR THE HIGH-TECH INDUSTRY

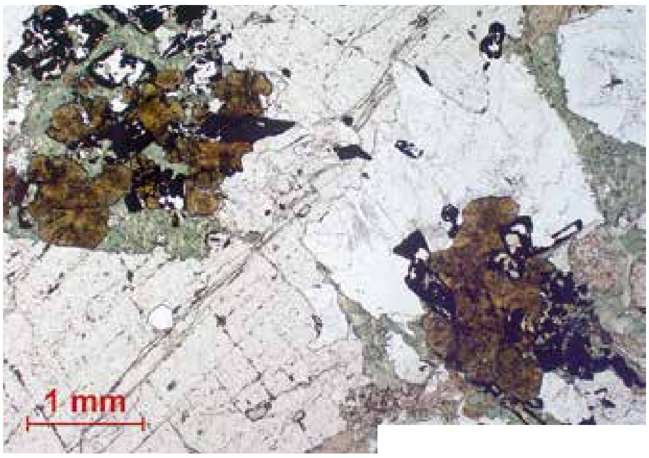
Since May 2015, the Helmholtz Institute Freiberg for Resource Technology (HIF) has been coordinating four research projects receiving 5.5 million euros in funding from the German Federal Ministry of Education and Research (BMBF). These projects are being carried out under the subject "r^4 – Innovative Technologies for Resource Efficiency – Research for the Supply of Raw Materials of Strategic Economic Importance" as part of the overall program "Research for Sustainable Development" (FONA). Within the context of this project, funding is provided mainly to support the development of innovative processes for exploiting, processing, and recycling mineral and metalliferous raw materials.

Molecular containers for the extraction of rare earth elements

As part of the BMBF project "SE-FLECX", experts from the research and industrial sectors aim to test if so-called calixarenes can be used as an alternative extraction medium in industrial extraction processes. The organic macromolecule, also known as a container molecule because of its special chemical structure, is expected to simplify the extraction of metals and considerably decrease the usage of process chemicals.

Processing of complex ores

New concepts for the processing of complex ores from known natural mineral deposits in the Ore Mountains (Erzgebirge) are the focal point of the "AFK" project. The ore, which is composed of a variety of fine-grained and closely integrated valuable minerals, has until now been considered difficult or even impossible to process.



Indium, copper, iron, fluorine, or tin can be finely distributed throughout a complex ore. Processing these materials is very costly and difficult.

The goal is to develop technical solutions for processing the different value minerals both in an economic and energy-efficient way. In order to achieve this, the entire process chain from the crushing of the ore to the production of a marketable mineral concentrate must be analyzed and optimized.

Investigation of local mineral deposits

Using extensive models of the geological formation and distribution of mineral deposits in Germany, the HIF and its project partners aim to reassess raw materials potential here in Germany. The results will also serve as a base for exploring other raw material deposits. Additionally, with the joint project "ResErVar", the partners plan on establishing a graduate school to foster junior scientists in geoscience.

GERRI
German Resource Research Institute

Virtual raw materials institute

The "German Resource Research Institute" (GERRI) aims to gather all national raw materials competencies, infrastructures, and strategies in one virtual institute for the very first time and purposefully coordinate these. This is meant to drive research along the entire added value chain for non-energetic mineral raw materials internationally as well.

The r^4 program picks up right where the funding program "r^3 – Innovative Technologies for Resource Efficiency - Strategic Metals and Minerals", which is currently set to expire, leaves off. Among the project partners in Saxony are TU Bergakademie Freiberg, Beak Consultants GmbH, Sachsenzinn GmbH, Saxore Bergbau GmbH, University of Leipzig and the UVR-FIA GmbH. Other national partners include the Fraunhofer Project Group IWKS, BASF SE, CMI UVK GmbH, Eberhard Karls University in Tübingen, RWTH Aachen and the TU Clausthal. _TS.

↗ www.hzdr.de/hif
↗ www.fona.de/de/16664

Bruno Merk has been teaching and researching in Great Britain since October 2015. Photo: University of Liverpool

From Dresden to the British Isles

Bruno Merk accepted a call by the University of Liverpool. After nine years at the HZDR Institutes of Safety Research and Resource Ecology, he has taken over as research chair for "Computational Modelling for Nuclear Engineering", run jointly by the National Nuclear Laboratory, the Royal Academy of Engineering, and the university. During his time at Dresden-Rossendorf, Bruno Merk worked on the development of modern calculation and simulation methods for the design and safety of nuclear reactors and on strategies for nuclear waste management.

In his most recent publication, the nuclear technology expert also addresses the question of whether or not it would be theoretically possible to almost fully burn the plutonium produced in light water reactors in a new type of reactor. With this he touches on a central issue concerning the handling of highly poisonous and radioactive residue produced by the nuclear generation of power.

PUBLICATION:
B. Merk et al.: "On the burning of plutonium originating from light water reactor use in a fast molten salt reactor - A neutron physical study", in Energies 8, 2015 (DOI: 10.3390/en81112328)

New Trade Meeting in Dresden

The first "Materials Week" functioned as an industry meeting place for developers, producers, and users. The invitation of the German Society for Materials Science drew almost 2,000 registered participants who attended the trade fair "Materials of the Future" as well as the accompanying symposia, seminars, and learner's forums in Dresden from September 14 to 17, 2015. It surely wasn't by chance that Dresden was chosen as the location, since 20 university, non-university, and industrial institutions have been collaborating closely within the Material Research Association Dresden (MFD) for many years.

Researchers from the HZDR actively participated in the conference program and offered an excursion to Rossendorf. Visitors saw the Ion Beam Center IBC and the labs of the Institute of Fluid Dynamics, where the topics solar silicon, steel and light metal casting, flow measurement in liquid metals, and solidification as well as contactless influence of solid structures were the focal point. Plans are in place to continue this successful materials week in the future.

What's on?

Upcoming events

28.05.2016 | 10 a.m. - 5 p.m.
Open House Day
Dresden-Rossendorf research campus

10.06.2016
Dresden Long Night of the Sciences

24.06.2016
Long Night of the Sciences Leipzig

Scientific events

19.-22.04.2016
3rd ODISSEUS Workshop & 3rd International Workshop on ODS Materials
Dresden | HZDR Institute of Ion Beam Physics and Materials Research

20.-23.04.2016
54th Annual Meeting of the German Association for Nuclear Medicine | 60 Years of Radiopharmacy
Dresden | HZDR Institute of Radiopharmaceutical Cancer Research

10.-15.07.2016
10th International Biometals Symposium | Biometals 2016
art'otel Dresden | HZDR Institute of Resource Ecology

31.08.-02.09.2016
Annual Meeting of the European Cluster of Advanced Laser Light Sources (EUCALL)
Dresden | HZDR Institute of Radiation Physics

Radiation protection courses at the HZDR research site Leipzig

26.04.2016 | 25.05.2016 | 27.09.2016 | 10.11.2016
Continued education courses

12.-14.04.2016
Technical qualification (Module GG, FA)

Dipjyoti Deb is dedicated to promoting international collaboration inside and outside of the lab. Photo: cfaed | Jürgen Lösel

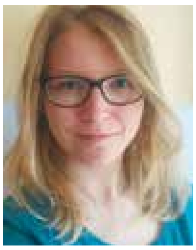
Off to the Falling Walls Conference with the TU

In his doctoral thesis at the HZDR and the cfaed, the "Center for Advancing Electronics" of the TU Dresden, Dipjyoti Deb deals with fabrication and characterization of silicon nano-wires. Establishing new contacts is also a task that he takes on with great gusto in the real world. In this vein, he is currently working on putting together a joint master program between the TU Dresden and the University College Cork in Ireland. "The idea for the project arose during a research trip to Cork," says the physicist, whom everyone simply calls DJ. At the "Falling Walls Conference" on November 8 – 9, 2015, in Berlin he also got the chance to prove that communication is another of his strengths. He had appeared as the international ambassador of the TU Dresden at previous events. The university itself was recognized for its ALUMNI work by the "Action Alliance for Research Marketing" conceived by the German Federal Ministry for Education and Research (BMBF) and invited to the conference for this reason. So the nomination of this smart doctoral candidate was an obvious choice. "That's how the Alexander von Humboldt Foundation ended up paying my ticket," DJ says, pleased about the role as specialist for ALUMNI questions in Germany bestowed upon him.

At the conference Dipjyoti Deb invited several conversation partners to Dresden, but also had a lot of questions to answer on the current atmosphere in the city and on Pegida: "I had some very intense discussions with Naila Kabeer, a writer and researcher at the London School of Economics, about gender issues in science and with French sociologist Nilüfer Göle, who promised to visit the TU Dresden if I organize a program for her." He also spoke with physics Nobel Prize winner Wolfgang Ketterle as well as science journalist Ranga Yogeshwar and leading representatives from industry and politics.

↗ **www.falling-walls.com**
↗ **www.cfaed.tu-dresden.de**

1st Poster Prize for Sonja Schellhammer



Doctoral candidates from the clinically oriented HZDR Institute of Radiooncology took part in the central doctoral seminar of the HZDR for the first time. The meeting took place in the Ore Mountains at the beginning of November 2015, and was a great success. Medical physicist Sonja Schellhammer won first place for the best poster presentation. What's special about this? She'd only been working on her research topic for one month then.

At the Institute of Radiooncology and under the guidance of the Dutch researcher Aswin Hoffmann, Sonja Schellhammer is investigating the physical aspects of therapeutic ion beams inside a strong magnetic field of a magnetic resonance imaging (MRI) device, in particular the deflection of the beam by the Lorentz force. Electrically charged particles – the ions – play an increasingly important role in cancer therapy. The lightest ion is a proton. It is comprised of a hydrogen atom from which an electron was extracted.

"Unlike conventional radiation therapy with high-energy X-rays, the use of protons for cancer therapy offers a highly conformal dose profile," Schellhammer explains. This means that the protons will give off very little energy as they make their way through the patient's body - and thus cause minimal damage to healthy tissue. At the spot where they come to rest, however, the particles will deposit all of their remaining energy as ionizing dose, hence sparing the tissue behind the tumor. This would therefore make it possible to further reduce side-effects and even apply higher radiation doses to the tumorous tissue. However, proton therapy is very sensitive to organ motion and tissue deformations originating from breathing, digestion, or a heartbeat.

"My goal is to investigate the feasibility of integrating real-time MRI into proton therapy so that anatomical changes during irradiation can be registered and compensated for," says the young doctoral candidate. She is therefore working on backing up her theoretical model for the deflection of proton beams in MRI magnetic fields with measurements. The master's program she graduated from at the OncoRay National Center for Radiation Research in Oncology in Dresden has given her the perfect foundation for this.

↗ **www.oncoray.de**

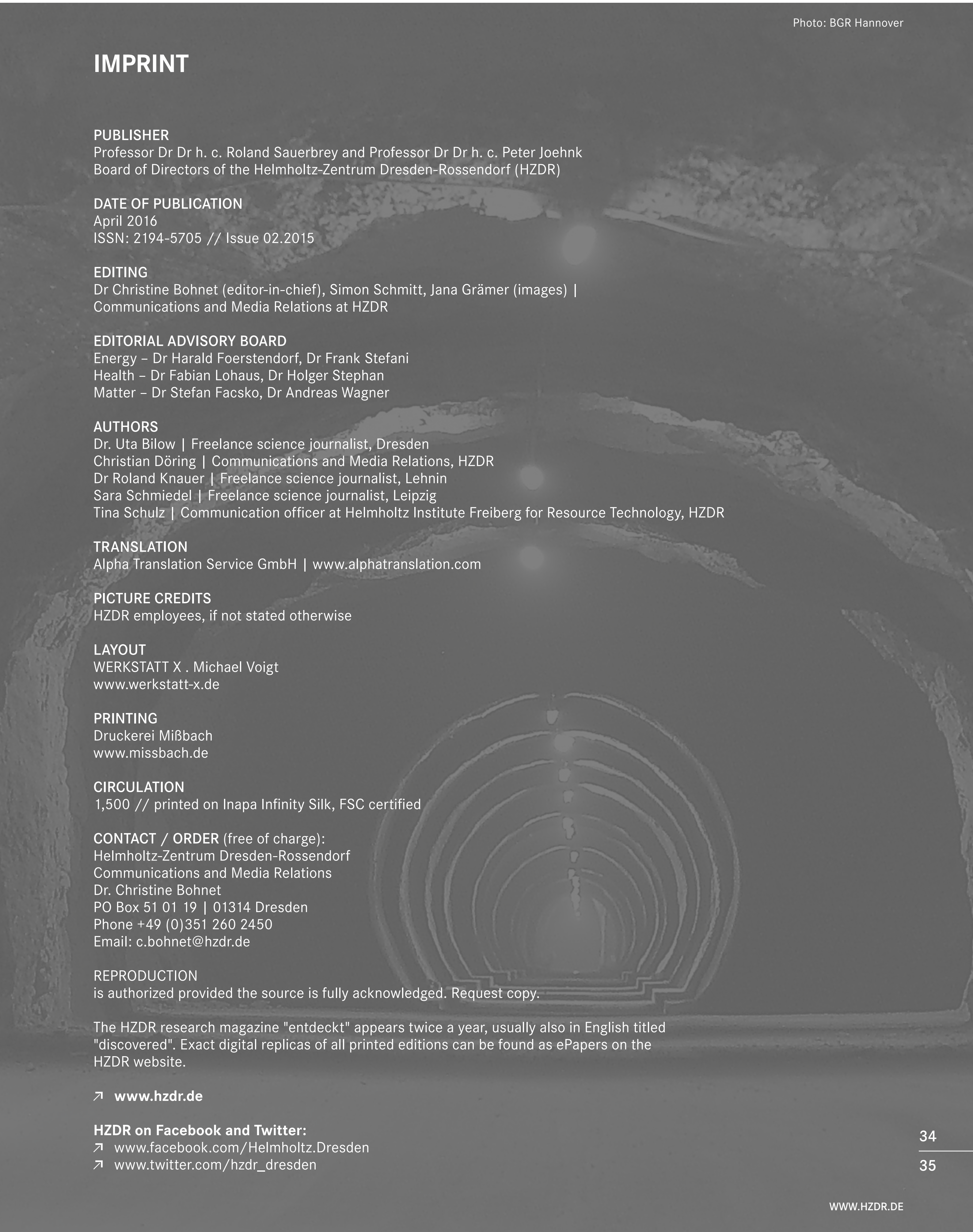


Photo: BGR Hannover

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↗ **www.hzdr.de**

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