UFZ Special

HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

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CHEMICALS IN THE ENVIRONMENT

Classing chemicals as “good” or “bad” depends on the dosage and route that a chemical takes from production, during consumption and after disposal and on the organisms that it comes into contact with along the way. Even if chemicals are no longer as foul-smelling and more environmentally-sound these days, there is still a long way to go for science, economics and politics, to make chemicals environmentally acceptable, to avoid their undesired adverse effects and thus to protect humans and the environment.

HELMHOLTZ
CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

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CHEMICALS IN THE ENVIRONMENT

Today's society produces, uses and spreads chemicals on a very large scale: whereas in 1930 approx. one million tons of chemicals were produced around the globe, today it is over 400 million tons.
Chemicals are both resources and products. They ensure that televisions, computers and mobile phones work and that pharmaceuticals and cosmetics are effective. They are found in textiles, furniture, paints and cleaning agents – they increase crops yields and are used in food preservatives. Chemicals improve our standard of living, but they also have adverse effects, against which we have to protect humans and the environment.

Even if the days of very visible pollution with their smoking chimneys and foul-smelling wastewater have long gone in many European countries – almost all chemicals that are used in industry, in the agricultural and transport sectors or in everyday products sooner or later end up in the environment in one way or another. Whether they are carried by streams or rivers and ocean currents, by the wind and the rain or enter the food chain, they manage to reach even the remotest parts of the world. In 1989 scientists found very high concentrations of polychlorinated biphenyls (PCB) in seal and whale meat that is consumed by the Inuit in the northeast of Canada. In 2009 UFZ researchers also discovered PCB in the snow of the 6200 meter high summits of the Andes. Once considered to be a technological wonder in the form of plasticisers, lubricants or fire protection agents, such substances have since been recognised as carcinogenic and have been prohibited since 2001. However, polychlorinated biphenyls (like many other chemicals) are

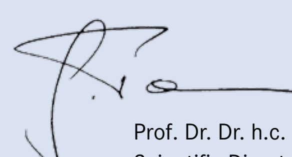
persistent, which means that they remain in the environment for a very long time – in soil particles, as suspended matter in water or on plants, as well as accumulating in the fatty tissue of organisms.

The potential risk of chemical substances for humans and the environment has been the source of a never-ending debate for decades. Individual substances consistently become the focus of public discussions or make headline news – often after the horse has already bolted, when substances are implemented and it turns out that they (or the products of their decomposition) have adverse effects that have not been investigated. Numerous international agreements have been made in an attempt to meet the world-wide use and trade of chemicals more systematically. Chlorofluorocarbons (CFCs) were prohibited through the Montréal Protocol in 1987 in an attempt to protect the ozone layer, whereas the Basel Convention that was adopted in 1989 prohibits the movement of hazardous wastes from the European Union to developing countries. Furthermore, in 2002 the international agreement SAICM (Strategic Approach to International Chemicals Management) was passed at the World Summit in Johannesburg with the goal of developing a common strategy for handling the most hazardous chemicals. Following that, a policy framework with over 200 measures was in fact adopted in 2006. As important as such agreements are, if a binding force and control mechanisms are still lacking, then substances that have long been prohibited in Germany and Europe will still be made available on the markets of growing industrial nations such as China and India and in numerous developing countries.

A central problem is that for most of the chemicals produced and traded in the world as well as for the products of their decomposition, there is either no or only insufficient information available about their properties and potential danger. This also applies to approximately 95 percent of the chemicals used in the EU. There is a particularly large knowledge gap about the long-term adverse effects and the so-called 'existing substances' that were marketed before 1981.
With the European chemicals regulation REACH (**R**egistration, **E**valuation, **A**uthorisation and Restriction of **CH**emicals) that came into force in 2007, the European Union aims to provide the requirements to avoid risks to humans and the environment through greater knowledge and information about 'existing' and 'new' chemical substances and to pave the way for innovative solutions in the future. This task – the road to sustainable chemistry – requires tremendous interaction between decision-makers in the chemical industry, politicians, authorities, environmental- and consumer agencies and scientists.

With one of its core subject areas "chemicals in the environment / health" the UFZ makes an important contribution to the sustainable handling of chemical substances for the environment and for human health. Over recent years the UFZ has developed its broad and internationally recognized expertise that is sought after by both agencies and authorities. More than 100 scientists are conducting research in the fields of environmental chemistry and ecotoxicology, in analytical chemistry and biology, in environmental immunology, molecular and systems biology as well as in environmental microbiology and environmental engineering with the perspective to understanding the interaction between chemicals, humans and ecosystems. Here the methods of tomorrow are being developed for science-based risk assessment, the management of chemicals and remediation technologies. Our research on chemicals is closely linked to water and soil research due to the fact that chemicals play a crucial role in the implementation of the European Water Framework Directive and the Soil Protection Act.

With the special edition of our newsletter "Chemicals in the environment" we would like to give you an insight into our current projects and into our main fields of research on chemicals and health at the UFZ. I hope that you will enjoy reading this special edition and trust that you will gain some new insights from it.



Prof. Dr. Dr. h.c. Georg Teutsch
Scientific Director of the
Helmholtz Centre for Environmental Research – UFZ

(Photo: © Alexander Raths / Fotolia.com)

MAKING CHEMICALS MORE ECO-COMPATIBLE

Whoever thinks that from simply observing, measuring and analysing the occurrence of chemicals in the environment they will master the situation, should think again. Phenological environmental chemistry and ecotoxicology conducted on the numerous substances used by today's society and counteracted by numerous observations is no longer sufficient. What is really needed is a basic research-oriented environmental chemistry and ecotoxicology that identifies mechanisms that determine the fate and effects of chemicals in the environment. This would open novel routes for projections and extrapolations that can be of use for mankind and the environment to manage chemicals.

This challenge is not purely scientific, but also addresses research policy. So far environmental chemistry and ecotoxicology have primarily been perceived as cost factors. Money is available for these fields of research when natural disasters and other unforeseen circumstances have already taken place. The fears following the Seveso disaster or oil spills helped environmental chemistry and ecotoxicological research along with a financial boost. As soon as public interest starts to subside however so does the financial aid. The lack of continuity in this field is counterproductive to the claim to systematically make chemicals more eco-compatible and avoid harmful effects from the onset. Nevertheless, continuous and systematic research will become indispensable in view of many facts and realities: 60 million chemicals are known to exist in the world of today. 100,000 synthetically-made substances are used in Europe alone as industrial chemicals. In addition there are thousands of active substances in plant protection products, pharmaceuticals and biocides, in washing- and cleaning agents, food additives and cosmetics, not to mention the transformation and reaction products of all of these substances in the environment. The production of chemicals is going to increase over the coming years – particularly in developing countries. The impacts that this will have on organisms and the quality of environmental resources such as air, water and soil, can only be assessed and managed based on well-founded scientific research.

Environmental chemistry and ecotoxicology – two relatively new disciplines

This task will be a tremendous challenge for both of the scientific disciplines 'environmental chemistry' and 'ecotoxicology', particularly because these are relatively new disciplines. After the Second World War when the chemical industry started to boom, promising prosperity and progress, concerns also grew about the harmful impacts of chemical substances in the environment. At the end of the 1960's the first discussions started about environmental protection. Both of the scientific disciplines 'environmental chemistry' and 'ecotoxicology' emerged from this background as interdisciplinary fields combining chemistry, biology and toxicology – shaped profoundly by the German chemist Friedhelm Korte and his "text book on ecological chemistry" as well as the French toxicologist René Truhaut, who introduced the term "ecotoxicology" in 1969. Scientific conferences and professional associations were only established after 1990.

Environmental chemistry is concerned with the dispersal, conversion and the fate of chemical substances from natural and anthropogenic sources with respect to the biotic and abiotic environment. It develops scientific strategies and concepts to promptly identify and assess (and where possible avoid) the occurrence, fate and behaviour of chemicals in different environmental matrices. *Ecotoxicology* focuses on the effects of chemical substances on the living environment i.e. the effect on and the hazard to various organisms. It is obvious that both disciplines are interlinked. Furthermore, it is evident that both disciplines are closely related to different scientific disciplines such as biology, ecology, hydrology, agronomy, chemistry and toxicology. The emancipation of these two relatively new disciplines 'environmental chemistry' and 'ecotoxicology' still goes unnoticed however. This may be the reason why so far they have not found a very receptive audience as an independent field of research e.g. with the German research council or with the Federal Ministry of Research.

Action is required

It is a matter of fact that the societal and practical relevance of these disciplines continues to increase. Population growth, greater consumption and thus an increase in food-, resource- and energy requirements will lead to the fact that more chemical substances (both in quantity and numbers) will be produced, processed, traded and disposed of. This calls for national and international frameworks in order to protect the local, regional and global environment against the unwanted impacts from these substances. Assessments and management measures can only be substantiated if they are well-founded scientifically. The Water Framework Directive (WFD) and the European Chemicals Regulation REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) are two good examples of this. Neither of these can be realised without an efficient risk assessment of chemicals.

The Water Framework Directive example: In the meantime 90 percent of the rivers and lakes in Germany have achieved a good chemical status according to the WFD. However, the required good ecological status has only been met by about 10 percent of surface waters. These findings could make us believe that nowadays there are hardly any hazards from chemicals. It must be mentioned however that the standard 30 substances used as a basis for assessing water quality are hardly in use these days or have been prohibited for a long time. By contrast, thousands of substances, which currently get into the water in micro-quantities and as mixtures, have not been assessed so far from a toxicological aspect. Here the question should also be asked as to whether the occurrence of mixtures of substances could have different effects to those of only the individual substances. Such assumptions cannot be tested with classical chemical analytics. Here, a new research approach is required, which cleverly links chemical and effect-oriented analytics with one another. The large scope and close interlocking of different disciplines at the UFZ – modern chemical analytics, theoretical environmental chemistry, environmental microbiology as well as systemic and bioanalytical ecotoxicology – provide excellent prerequisites.

The chemicals regulation example: REACH makes it obligatory for manufacturers or importers to identify hazardous characteristics of industrial chemicals and natural substances, to assess their effects on human health and the environment and to inform people about these. This not only applies to new substances that are going to be brought onto and traded on the market, but also to an estimated 30,000 existing chemicals, which already came onto the market in quantities of more than one tonne per year prior to 1981. REACH wants to ensure that chemicals are properly managed from their production, through their consumption to their disposal. As is often the case however there is another side to the coin: In order to determine the toxicological effects of chemicals on human health and the environment, animal testing is often employed. At the UFZ various research teams are therefore pursuing the goal of replacing the standard test programs that normally rely on animal tests for the environmental risk assessment of chemicals with intelligent test strategies. By implementing alternative test procedures and theoretical methods as well as linking various approaches and information, the goal of reducing animal testing (in spite of the growing number of chemical tests) can still be achieved. As hopeful and economical approaches there are both experimental *in vitro* tests and computer-based models (QSAR, Quantitative or Qualitative Structure-Activity Relationships) as well as decision-making support tools (read-across procedures).

What if chemicals have already infiltrated into the environment?

To achieve the goal of optimally developing chemicals and their life-cycles in terms of their environmental characteristics, there is still a long way to go for science, industry and politics. This also applies to identifying chemicals, which have already got into the environment, making the remediation of contaminated sites necessary. How can pollutants be removed from soil or water? Under which conditions are ecosystems themselves capable of providing the service "pollutant degradation" for humans? How can these degradation activities of micro-organisms be used or supported? Where are innovative physical-chemical solutions necessary? To find the answers to such questions, *in-situ* tests are also required. Before good environmental technological solutions can be transferred to technologies ready for the market, they must be tested in-situ. For this there are also outstanding prerequisites at the UFZ with pilot facilities and research platforms such as SAFIRA and TERENO. Beyond that, scientific studies conducted at field sites provide the opportunity to understand the biological degradation of chemicals as an ecosystem service. Principles derived from that enable us to come closer to the vision of eco-compatible chemicals.

What if humans are affected?

When chemicals show unwanted environmental effects, humans are also often affected, because they are part of the environment: they live and work in the environment, use and consume environmental resources such as drinking water, air or food. Human reactions to environmental stress factors are frequently conveyed by the immune system. Therefore, in the context of health research at the UFZ, investigations are being conducted as to how chemicals in the environment affect the cells of the human immune system and contribute to environment-related illnesses such as allergies. Here, systems biology is gaining increasing significance in research. This relatively new scientific discipline combines biology, mathematics and physics in experimental and model-based approaches, to understand the biological processes in cells, tissues and organisms as a whole and to develop preventative strategies using this knowledge.

With the core subject *"Chemicals in the Environment and Health"* UFZ researchers want to contribute to chemicals becoming eco-compatible, and to more systematically assess their unwanted effects in order to protect both humans and the environment. This calls for excellent research, superior training of the next generation of scientists and a constant transfer of knowledge to society.

UFZ Contact person:

- **PD Dr. Rolf Altenburger**
Dept. Head of Bioanalytical Ecotoxicology

Speaker on the topic "Chemicals in the Environment" for the Helmholtz research programme "Earth and the Environment"

e-mail: **rolf.altenburger@ufz.de**


The use of pesticides like in this peach plantation in Italy leads to a reduction in the species diversity of an ecosystem. (Photo: © ermess / Fotolia.com)

DIGGING FROM BOTH SIDES

The collapse of bee colonies has been perplexing beekeepers for years. Nevertheless the causes have still not been clarified. In addition to infections with the parasitic mite Varoa destructor, the impacts of chemicals have also obviously played a major role. The combined effect of traditional stress factors with pesticides is probable. The most suspected of these are neonicotinoids – a group of new and commonly used insecticides that are used on agricultural plants. One of these for example is thiametoxam. As far as classical test procedures are concerned this is classed as a harmless insecticide because the insects investigated normally survived. There are several side effects however, as recently demonstrated by a group of French agricultural researchers in SCIENCE: The synthetically-produced substance with nicotine-like active ingredients leaves bees disorientated and unable to find their way back to their hives, which can have a dramatic effect on the existence of the colony.

As far as Dr. Matthias Liess from the UFZ is concerned, the example of neonicotinoids is symptomatic: "If the wrong parameters are tested in the laboratory, then such substances can appear to be harmless. It was only years later for example that DDT was found to cause reproductive harm. We must therefore be very astute and ask ourselves time and time again: What is going on in nature? What have we overlooked?" For Liess and his colleagues it is obvious that something is wrong: recently the ecotoxicologists from Landau, Leipzig, Aarhus and Sydney published a meta-survey in which they had analysed 111 different rivers from six different European countries as well as Siberia and Australia. The result: The existing assessment process is not sufficient to protect the river ecosystem sustainably against the effects of pesticides. With concentrations that are considered to be harmless according to standard procedures, the presence of sensitive organisms would be reduced by another 27 to 61 percent – depending on whether there were unpolluted river sections that could partially buffer the impacts. Researchers therefore do not only recommend a dramatic reduction in the levels of pesticides that enter water bodies but also buffer zones that could act as a refuge.

Even if for example the European Union and the USA strictly test pesticides before allowing them onto the market, the use of chemicals in modern agricultural practices is obviously a factor, which threatens to reduce species and ultimately biodiversity. It is obviously a problem that the test organisms are investigated under optimized conditions during the approval procedure. The multiplicity of natural environmental factors that could amplify the effects of a pesticide in the natural environment cannot be tested in the laboratory. Furthermore, the amount of insecticides used in Germany has more than doubled over the last 15 years.

"Another problem is not only the quantity, but also the toxicity. The substances of today are much more effective than they used to be in the past, which although benefiting the farmer, harms the biodiversity on his land", explains Matthias Liess. The internationally renowned expert on pesticides, who advises the European Food Safety Authority among others, still sees another problem on the European level: Various EU-directives such as the Water Framework Directive, the Pesticides Directive or the Habitats Directive do not seem to learn from each other because different authorities are responsible for them. For an effective protection of biodiversity these would have to be better co-ordinated. But it is not only politicians and authorities that need to rethink their strategies. Decision makers depend on reliable information, which is where science comes in. "What we need is a paradigm change. It is not sufficient any more to conduct isolated experiments on the one hand that are far removed from nature in order to go on to estimate the impact on the entire ecosystem and to conduct non-specific surveys on the status of the environment on the other. If we want to improve the situation, then we need to bring together both approaches and interpret both controlled experiments as well as large-scale surveys collectively. The analogy of a tunnel springs to mind that turns out best if you dig from both sides", Liess appeals. In this respect the toxicologists could learn a lot from the ecologists, who revised their approach in this way many years ago. *Tilo Arnhold*

UFZ Contact person:

PD Dr. Matthias Liess
Dept. Head of System Ecotoxicology

e-mail: **matthias.liess@ufz.de**

The freshwater amphipod *Eulimnogammarus verrucosus* is endemic to Lake Baikal. These freshwater shrimps are an important part in the food chain of this UNESCO world natural heritage. Climate change and chemicals could mean that this Baikal specialist will be replaced in the future by its very adaptable relatives.
(Photo: Vasiliy Pavlichenko)

DOUBLE STRESS FOR SHRIMPS

Lake Baikal is a lake of superlatives. It is not only the deepest and the oldest lake on earth, but also holds an unbelievable amount of fresh water. Its water could supply the world's population with drinking water for half a century. Although Lake Baikal is remote and far away from the industrial centers of the world, it is not unaffected by global climate change. Indeed, the temperature of its crystal-clear surface waters is increasing. A rise of 1.2 °C over the past 50 years may sound little, but it could be too much for the unique ecosystem of the lake that has evolved under very stable conditions over millions of years.

There are over 1500 animal species living in the lake, two thirds of which are endemics. "That is one of the things that makes Lake Baikal so interesting for us as researchers" explains Dr. Maxim Timofeyev from the Baikal Research Center in Irkutsk. "Why do these endemics only occur here and why are the species normally found at these latitudes absent? We assume that the endemics are simply better adapted to the very specific conditions of Lake Baikal, but not to other water bodies." Russian scientists together with their German colleagues want to find out whether or not the specialized species here still have an advantage over the generalists in the face of climate change. In the LabEglo-project (**La**ke **B**aikal and biological **e**ffects of **glo**bal change) biologists from the UFZ, the University of Leipzig, the Alfred Wegener Institute for Polar and Marine Research (AWI) as well as the Baikal Research Center and the University of Irkutsk are working together. The project is funded by the Helmholtz Association and the Russian Foundation for Basic Research.

While the Russian biologists contribute data from decades of ecological surveys, both Russian and German partners use state-of-the-art laboratory techniques for genetic and physiological studies at the UFZ and at the AWI. "Taxonomic and ecological aspects of the Baikalean species that we investigate have been thoroughly studied, but very little is still known about their genetics. The use of high-tech could provide us with completely new insights", reports Dr. Till Luckenbach from the UFZ. One can't help but notice that the cell biologist who spent several years in the USA as a researcher is buzzing with excitement – the kind of excitement that takes a hold of researchers when they get the chance to discover a missing piece from a scientific puzzle. Luckenbach is interested in cellular changes evoked by chemicals in the environment. Cells have developed various mechanisms to protect themselves against chemicals or other environmental stressors, but some species lost the ability to defend themselves as they evolved. Arctic fish, for example, are lacking a particular protein, which keeps cells intact when the water temperature rises. "We assume that many of the endemic species are highly adapted to the extremely constant environmental conditions of Lake Baikal with exceptionally clean water and little temperature fluctuations and that these species have therefore simply lost the ability to tolerate temperature changes and organic pollutants." The changes that the lake is experiencing are not only a rise in water temperature but also increasing levels of nutrients and man-made chemicals in the water. One source of chemicals in the lake is the notorious pulp mill near Baikalsk. Furthermore, a change in land use in Mongolia, whose northwest river catchment area flows into Lake Baikal, also contributes to the problem.

To examine potential consequences of these environmental changes for the endemic Baikalean fauna more closely, the scientists perform studies with *Eulimnogammarus verrucosus* – a small, bluish-green freshwater amphipod that is endemic to this UNESCO world natural heritage and with its relative, *Gammarus lacustris*, that lives in waters in the entire northern part of Eurasia – with the exception of Lake Baikal. Freshwater amphipods make up a large proportion of the entire biomass of Lake Baikal, inhabit different environments of the lake ranging from close to the shore to great depths and constitute an important part of the food chain. Can the Baikalean endemics cope with the current environmental changes or will they allow amphipods that are otherwise ubiquitous in the northern hemisphere to conquer Lake Baikal? Should fears ring true, the specialist species in Lake Baikal will be replaced by its extremely adaptable relatives. But until that time *E. verrucosus* (a species previously only known to specialists) still has the chance to get into the history books of ecotoxicology. It could provide important basic knowledge about the risks that climate change and chemicals can have on the ecosystems of our planet, because this double stress will also apply to other organisms elsewhere. *Tilo Arnhold*

UFZ Contact person:
- **Dr. Till Luckenbach**
Dept. Bioanalytical Ecotoxicology

e-mail: **till.luckenbach@ufz.de**

Taking samples from the Bilina – a tributary of the river Elbe that flows through lignite mining areas in the Czech Republic. Scientists were surprised to find that the chemical triclosane (used in textiles as an antibacterial and antifungal agent) found in water and sediment posed a greater threat to the environment than high concentrations of polycyclic aromatic hydrocarbons (PAH). (Photo: André Künzelmann)

IS IT THE USUAL CULPRITS?

It should really be a cause for celebration: A good 90 percent of Germany's rivers and lakes have a "good chemical status". More unfortunately however only 10 percent of these are reported to have a "good ecological status". How can this be the case, when classical substances (such as atrazine, lindane or DDT) used for monitoring the status of the environment have actually been reduced. These hazardous substances along with 30 others (and 45 others as of 2012) are classed as priority substances, which are tested in accordance with the Water Framework Directive (WFD) to determine the "chemical status" of water bodies. A reduction in these substances is not really that surprising, given that the use of most of these substances has been prohibited for a long time. "It is no longer the usual culprits that are polluting our waters these days", Dr. Werner Brack from the UFZ is convinced. The environmental chemist wants to find out exactly which substances are having measurable impacts on the environment – a task that can sometimes be compared to searching for a needle in a haystack. In Europe alone there are more than 100,000 synthetic substances in use.

Even if many authorities measure more than the stipulated priority substances, there is a high risk that some new chemicals might slip through the net. The solution to this dilemma cannot simply be to monitor all chemicals. The fact that for most of these substances, data about their toxicity is either not available or not accessible does not help the matter. Furthermore, the pace at which political processes move to start monitoring new substances and to provide criteria for the quality of the environment is much slower than the pace of innovation in the chemicals industry.

Werner Brack therefore suggests a more comprehensive approach to monitoring water bodies, in which the chemical analysis of individual substances is linked to bio-tests to analyse impacts. For this, a water sample extract, which can potentially contain some 10,000 individual substances, is divided up into different groups of substances. In the next step these individual groups are examined in terms of their impact on water organisms such as green algae, water fleas, fish embryos, bacteria or cells. If scientists come across a particular group having an impact, then that group is investigated further until only the true culprits are left in the end i.e. all of those substances that are having a particularly negative effect in the water body. This approach has a great advantage: If for example a pesticide is taken out of the game and replaced by a new one with a similar impact, this will be recorded in such an impact-related monitoring process even if it defies the chemical analysis. "This helps us from being conned into thinking that the chemical water quality has improved", says Werner Brack, supporting his theory with current investigations in the Bilina – a tributary of the river Elbe that flows through lignite mining areas in the Czech Republic. For the scientists it came as no surprise when they discovered high concentrations of toxic polycyclic aromatic hydrocarbons (PAH) because these are natural components of coal and oil. What was surprising however was the fact that a very different substance posed a much greater ecological hazard and that was triclosan. This chemical has been on the market since 1972 and it was not until 1998 that the first serious effects of it were discovered. Until now triclosan has been used as an antibacterial and antifungal agent in toiletries and sports clothing, but it is still not monitored in many parts of Europe. Monitoring data from Saxony have shed some light on the fact that triclosan ranks sixth as one of the particularly harmful substances in the rivers of Saxony. As a result of this and other studies, triclosan has now found its way into the prioritisation process for monitoring water bodies.

A success story indeed – but there still needs to be more of them: With the EU training network EDA Emerge that he coordinates, Werner Brack hopes to develop a more efficient identification of substances through screening and fingerprint analyses (EDA) while at the same time providing training for a new generation of international scientists in this field. An extensive spectrum database will also assist in the identification of substances, which is being developed by Brack and his colleagues from Europe in the context of the network NORMAN. He also hopes that the Water Framework Directive and the European Chemicals Regulation REACH will increasingly benefit from each other. Access to the extensive pool of data from REACH would make it easier to put the WFD into practise whereas the monitoring results from the WFD could also assist REACH.

Doris Böhme

UFZ Contact person:

Dr. Werner Brack
Dept. Head of Effect-Directed Analysis

e-mail: **werner.brack@ufz.de**

The chemist Dr. Bernd Manfred Gawlik is head of the environmental monitoring laboratory "MAPLE" at the Institute for Environment and Sustainability (IES), one of the seven head offices of the Joint Research Centres (JRC) of the European Commission. MAPLE (Monitoring across Policies and Environmental Media) accompanies the development, implementation and monitoring of European legislation with targeted and independent measurements of environmental chemicals. His work particularly focuses on the implementation of chemical monitoring in accordance with the Water Framework Directive (WFD) and its accompanying and adjoining directives. (Photo: André Künzelmann)

"WE NEED A BETTER NETWORK OF CHEMICAL DATABASES"

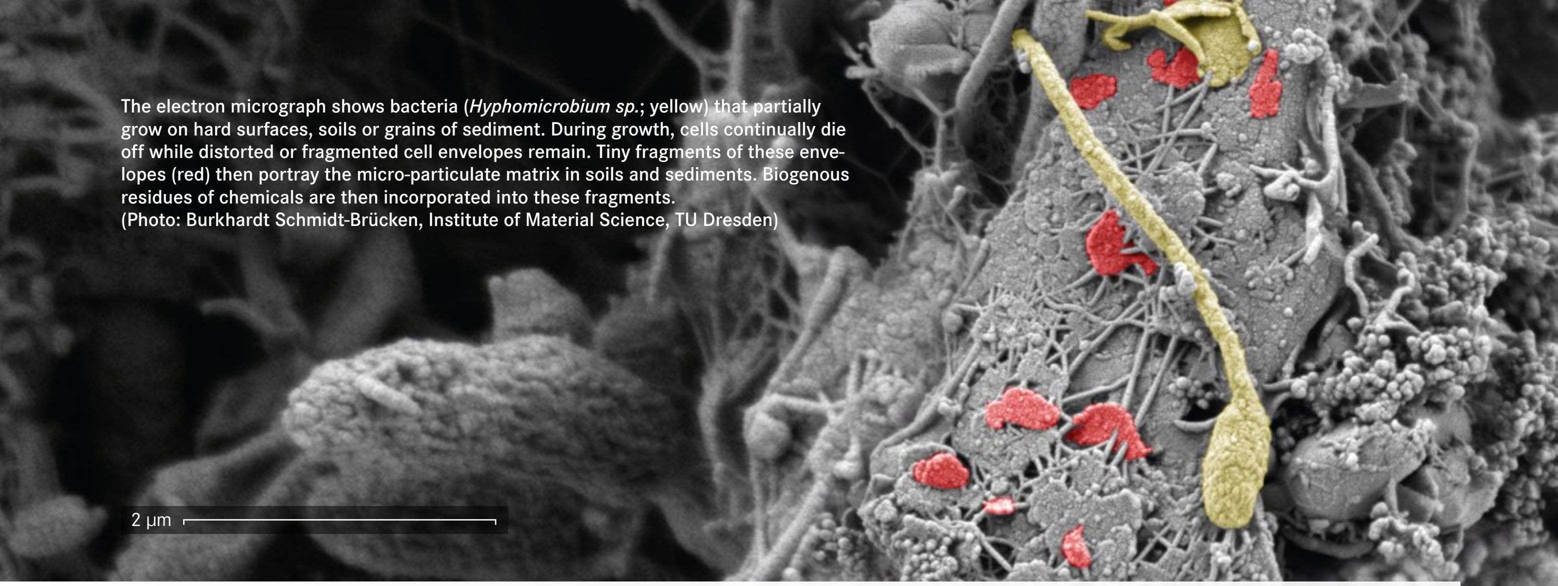
The EU published a revised list of priority substances in the field of water policies on 31st January 2012. What implications will this have for implementing the Water Framework Directive (WFD)?
The WFD specifies a set of priority substances, whereby environmental quality standards are determined for these in surface waters i.e. the maximum concentration levels, which if exceeded will pose a risk to the ecological quality of a water body. A regular revision of this list is intended and has been entrusted to the Commission. The list that has now been published is a result of this process and has been submitted for enacting to the European parliament and the Council. Even though this list could still be changed over the course of this procedure, it is important to note that on the one hand more substances are now being monitored. On the other hand, environmental quality standards are now also being introduced for the first time for alternative matrices (i.e. sediments and biota).

Which criteria are used to determine these substances?
The criteria that are taken into consideration include aspects of persistence, accumulation and (eco)toxicity, as well as other information. The exact procedure has been derived scientifically and strictly agreed upon with the EU member states. A greater problem here is not so much the procedure itself but rather the availability and the quality of the underlying experimental data among others from environmental monitoring. This leads to rather high safety factors that are needed for risk protection, which in turn lead to an extremely low quality of environmental standards that again take us to the limits of feasibility in the analytical routine, which is one aspect that we don't consider enough as scientists in my opinion.

Chemists want to use modern analytics to their heart's content, while biologists call for biomonitoring. Scientists at the UFZ call for a comprehensive approach – chemical analytics in order to find out which substances are present in which quantities combined with biomonitoring to determine the effect of chemicals on organisms in water bodies. Which strategy is being pursued by the EU?
The ultimate goal of the WFD is a "good ecological status of surface waters", which represents a collective viewpoint. The dilemma about chemicals is that heaps of information is generated for substances that are regulated anyway. New substances are rather "discovered" by means of explorative monitoring whereas information covering large areas is rare. The difference between the chemical and biological approaches mentioned above does not really exist; to understand biology, we need a wealth of information from chemical analytics and I can only encourage the UFZ in its approach. I am convinced of the fact that in particular a directed generation of environmental monitoring data by means of a wide range of methods like for example effect-related analyses or non-target screening for manageable but representative test data sets can help to resolve our dilemma.
In other words we need to experimentally focus European competencies within this field on the same samples and then link and integrate this information. This is also the approach that we pursue at the Joint Research Centre.

The European chemicals legislation REACH delivers a huge quantity of data on the chemicals that are produced. How is this knowledge used to implement the WFD?
Of course, REACH is an important source of information, and the ecotoxicological data from it were an important contribution to the Comission's list of priority substances. Unfortunately REACH does not cover all areas. For example pharmaceuticals or food additives or substances used in toiletries are often overlooked. It is these very domains however that have attracted a lot of attention from environmental researchers over recent years and that have been an increasing cause of concern among citizens. In order to improve the flow of information and also to be able to better assess mixtures of chemicals in terms of their ecotoxicological effects the Commission suggests linking different databases in the form of a "Chemical Data Centre". In this way the data available from REACH could be used in a better way.

The interview was conducted by Doris Böhme.



The electron micrograph shows bacteria (*Hyphomicrobium sp.*; yellow) that partially grow on hard surfaces, soils or grains of sediment. During growth, cells continually die off while distorted or fragmented cell envelopes remain. Tiny fragments of these envelopes (red) then portray the micro-particulate matrix in soils and sediments. Biogenous residues of chemicals are then incorporated into these fragments.
(Photo: Burkhardt Schmidt-Brücken, Institute of Material Science, TU Dresden)

TRACING RESIDUES

Some chemicals are used to protect plants and animals from diseases and parasites. In many cases they were even developed specifically for this purpose. The only thing is that these chemicals rarely disappear completely from the environment, but can be found in very different concentrations long after their use: For example as residues in waterbodies from traces of antibiotics used on farm animals that get into farmyard and liquid manure, in the soil as a result of pesticide residues from agricultural practices or even in meat as pharmaceutical or antibiotic residues that produce multi-resistant microbes. It is for this very reason that the implementation of many biocides like for instance the insecticide DDT or the herbicide atrazine have been prohibited by law in Europe for some years now – and not without reason. Firstly, residues can form in the soil and secondly, other new hazardous intermediate products can form or build up in the environment through the food chain. In the meantime, new, so-called biodegradable pesticides have taken over the market because they are able to degrade biologically in the soil. But even these should still be applied with precaution, as there is still an element of risk involved. They might partially form residues for example and the conversion of some substances is still not yet completely understood as is the case with the phenoxy herbicides 2,4-D (2,4 dichlorphenoxyacetic acid) or MCPA (2-methyl-4-chlorphenoxyacetic acid). For this reason the German Federal Office for the Environment (UBA) intends to provide improved procedural instructions.

For Prof. Dr. Matthias Kästner of the UFZ this general risk classification is outdated. "What we need is a differentiated view", he says. For example the phenoxyacetic acid 2,4-D is used as a generally biodegradable herbicide on crops, for orchards and on meadows and pastures against knotweed, chamomile or thistle. Indeed, the substance itself could no longer be detected thereafter on the fields in its original form, which could not be said for its residues, the structure of which has not been identified so far. "We were able to demonstrate that a large amount of the carbon contained in 2,4-D or MCPA changed into microbial biomass when degraded", explains Kästner. The residues in this case were therefore not critical and can remain safely in the soil. This possibly also applies to the residues of a number of the 400 other pesticides that are used around the world. "The general risk assumption for these residues must therefore be tested in order to avoid uncertainties, prohibitions of use and unnecessary costs", says Kästner.

For several years now Kästner and his team have been working to explain the structure and the risk assessment of residues from pesticides, pharmaceuticals and chemicals in the environment. The main focus thereby is with non-extractable residues on transformation into biomolecules. The researchers were successful in identifying the chemicals of these residues early on and proving that they form residues. They made a methodical discovery in a very complex procedure: They divided the contents of soil samples into individual molecular components. If one marks the substance under examination with stable isotopes then the UFZ biotechnologists can prove whether or not it has been transformed into non-hazardous microbial biomass. "From the enormous accumulation of substances we were then able to selectively fish out isotope-marked proteins and other components of the biomass", explains microbiologist Kästner.

The methodological know-how that Kästner's department has gained in the meantime from analysing residues cannot only be applied to pesticides.
Research about the hazardous nature of pharmaceutical residues has already come a long way. He has already had new projects approved for other molecular structures of pesticides and pharmaceuticals from the German Research Council, says Kästner.
The assessment of residues is indeed a pressing issue, whereby the authorities depend on the contributions from the UFZ researchers. Due to UFZ research results, the UBA changed its assessment strategy last year for non-extractable residues. Meanwhile residues are differentiated according to a type 1 for toxic and a type 2 for naturally biogenous. "That is a clear progress towards a differentiated assessment and concomitantly towards a better prevention", says Matthias Kästner. *Benjamin Haerdle*

UFZ Contact person:

Prof. Dr. Matthias Kästner
Dept. Head of Environmental Biotechnology

e-mail: **matthias.kaestner@ufz.de**

At the UFZ it is being investigated whether, how and to what extent plants absorb contaminants e.g. arsenic from the soil via their roots. The mechanisms of absorption, distribution and decomposition have not yet been explained in many cases for water-soluble contaminants such as medicinal products for veterinary use or pharmaceuticals. These can depend on a number of factors such as the plant species and the properties of a substance. (Photo: André Künzelmann)

KEEPING AN EYE ON SOLUBLE SUBSTANCES

The chemical triclosan has actually benefited many people: It prevents bacteria from spreading in households, helps to disinfect doctor's practices and extends the lifetime of cosmetics. People are well aware about its direct negative effects: direct contact with the chemical can lead to strong skin and eye irritations. By contrast however very little is know about what happens for example when chemicals such as triclosan get into agricultural land through sewage sludge and eventually into agricultural crops. This could happen on many of the EU's agricultural sites, because approx. 40 percent of the EU's sewage sludge ends up being used in agriculture. Chemistry Prof. Dr. Thorsten Reemtsma from the UFZ is therefore keeping an eye on those sites where vegetables are cultivated where chemicals from sewage sludge can come into direct contact with roots or leaves.

Dr. Reemtsma's research group has been investigating these processes using the example of carrots. They have found out that triclosan is able to bind with other substances in carrots like sugars to form glycosides. "We have found seven metabolites of this kind in carrot cultures" says Dr. Reemtsma. That does not sound so worrying at first, given that glycosides are harmless. What is uncertain however is whether or not the harmful triclosan can be released in the stomach once the carrots have been consumed. "This potential form of contamination has been completely neglected until now", says Dr. Reemtsma. Triclosan is only one example of a harmful substance where analysts at the UFZ are testing whether or not it can be detected later in the vegetables that we eat. Dr. Reemtsma's department has also been investigating the uptake of arsenic in rice. Until now it was considered that the toxic metalloid is deposited in the roots and stems of the rice plant. The fact that this general assumption should not be made, has been demonstrated time and again with an increased number of arsenic cases in grains of rice. On the basis of modern methods of chromatography and mass spectrometry UFZ researchers have now found out that arsenic can occur in different forms that are also distributed differently in plants. Similarities with plant nutrients such as silicate, phosphate or borate also play an important role.

Dr. Reemtsma who changed positions last year from the Federal Institute for Risk Assessment (BfR) to the UFZ, particularly wants to encourage research on water-soluble substances in the future. Potential hazardous sources are numerous: whether it is medicinal products for veterinary use that are spread over agricultural fields through liquid manure and muck or pharmaceuticals and the residual substances of cosmetics that can get into fruit and vegetables via purified waste water – there is a tremendous scope for research. "The mechanisms of uptake and transformation depend on many factors such as the plant species and the properties of the substance and often remain unexplained" reports Thorsten Reemtsma. His research results could play a major role in particular for Mediterranean countries. Water reserves will become scarce there in the future and therefore there is likely to be more focus on the use of purified wastewater for the irrigation of agricultural land. The search for water-soluble contaminants that can get into the vegetables we eat from wastewater irrigation and may enter the human body, was not a focus of health protection until now. In this area, unlike with microbes or salts there are no quality requirements for irrigation water. With the use of purified wastewater for agriculture, the requirements for water quality could increase considerably.

But still many questions remain unanswered: which substances could be hazardous to which plants? Under which conditions of use are contaminants transferred? How and where are they distributed within the plant? To find the answers to these questions, the UFZ analyst initiated a project with researchers from Israel and Jordan. From his point of view water-soluble substances need to be given much more attention in the future.

Benjamin Haerdle

UFZ Contact person:

Prof. Dr. Thorsten Reemtsma
Dept. Head of Analytical Chemistry

e-mail: **thorsten.reemtsma@ufz.de**

The effects of complex chemical mixtures are different to those of individual substances. In order to be able to predict the effect of such 'cocktails', UFZ scientists are developing different model approaches.
(Photo: © Rade Lukovic / Fotolia.com)

MYSTERIOUS COCKTAILS

If you mix alcoholic with non-alcoholic beverages to produce a cocktail, then you expect the cocktail to have a very different combined effect compared to the effects of the individual drinks on their own. What you don't know is whether or not the effect of the cocktail will be stronger or weaker? Normally, you won't find out the answer until the following day. Ecotoxicologists however don't want to wait for such consequences. They want to predict the effects of chemical mixtures before any potentially harmful effects can occur. The problem is that "the knowledge about individual substances alone is not sufficient for environmental assessment", says private lecturer Dr. Rolf Altenburger, who has been conducting research in the field of bioanalytical ecotoxicology at the UFZ since 1995. How for example can one estimate the potential danger looming in a sewage works from a mixture of detergents, pharmaceuticals and weed killers?

Ecotoxicologists in Leipzig are following up this assessment problem. They are investigating which of the models adopted last century in pharmacology and human toxicology can provide the best results in ecotoxicology to predict the effects of chemical mixtures. Two different model approaches have been established that are referred to as Concentration Addition (CI) and Independent Action (IA). Researchers generally prefer to use the concept of 'Concentration Addition', when chemicals in a mixture are similar. "If they have a similar effect and the same effect mechanism, then the effects of an entire mixture can be formulated based on information about the individual components", explains Dr. Altenburger. Each component contributes to the overall toxicity of the mixture, no matter how high its concentration is. If however the effect of the individual substances is different, then the substances work in different places and via different effect mechanisms, then it makes more sense to apply the model of 'Independent Action'. In this case, only those components contribute to the harmful effect of a chemical mixture, which would also be found to be toxic on their own.

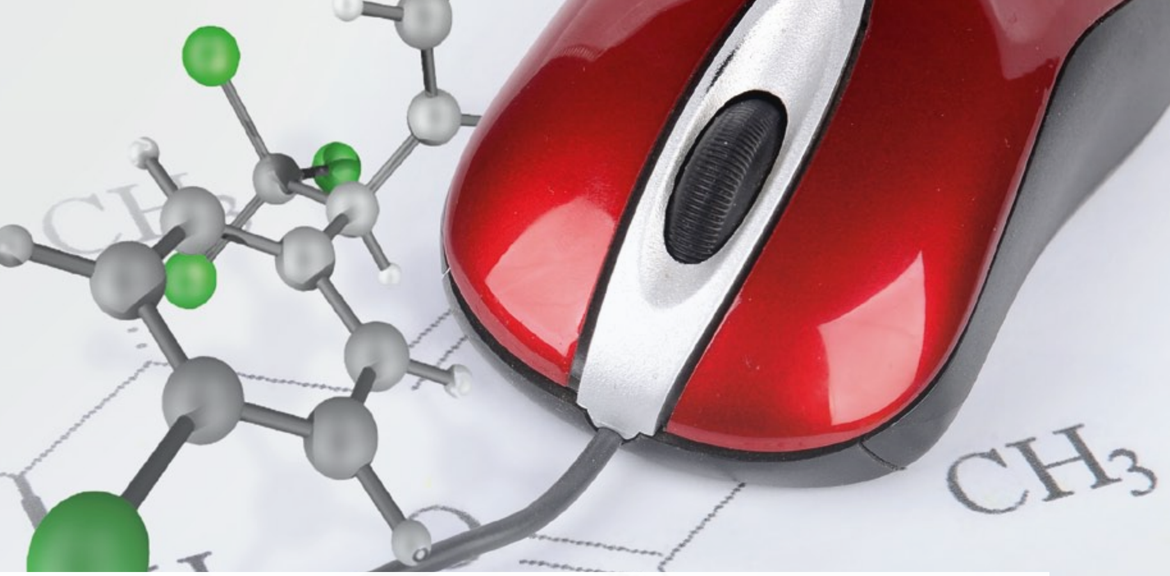
As a result of numerous experiments using algae, fish eggs and luminous bacteria for various groups of substances, Dr. Altenburger's team of ecotoxicologists have now found that the toxic effect of chemical mixtures can be predicted rather accurately using both methods. The number of components that are mixed, their constituency and the time that the mixture has already been standing are all irrelevant factors for the model's predictive power. There are some slight differences however. "With 'Concentration Addition' a somewhat higher toxicity can usually be predicted compared to the model of Independent Action", the biologist Dr. Altenburger accounts for. Forecasts can be made relatively easily, particularly with combinations of harmful substances, in which individual components can be found in very low concentrations. The danger of underestimating the toxicity of a mixture is consequently lower with the model of 'Concentration Addition'. It is therefore important to implement such test procedures in the product assessment of chemicals, which are contained in biocides such as wood preservation agents or the so-called antifouling paints that are used in shipbuilding for example to prevent mussels and barnacles from growing on the outside of the ship."The effects of anti-fouling agents are often wrongly assessed on the basis of an individual substance, even though the products consist of several chemical substances", says Rolf Altenburger.

For the practical test in the environment however there is an additional assessment problem: For a large number of complex chemical mixtures it is still unclear as to how they will actually react in real ecosystems and not only under laboratory conditions. Besides which, researchers have still not yet developed a procedure as to how they can model pollutant loads successively and interactions with other stress factors such as UV-radiation. "The knowledge about the effect mechanisms of environmental chemicals has been extremely limited until now", says Altenburger. Thus there will still be plenty of scope for research for the ecotoxicologists in Leipzig. *Benjamin Haerdle*

UFZ Contact person:

PD Dr. Rolf Altenburger
Dept. Head of Bioanalytical Ecotoxicology

e-mail: **rolf.altenburger@ufz.de**



At the UFZ, scientists opt for integrated testing strategies as an alternative to animal testing in order to assess the hazardous effects of chemical substances. To this end, they combine different alternative methods that also include computer models and interpolation procedures. (Photo: © Xuejun li / Fotolia.com, montage: Marie-Sophie Wilde, UFZ)

INTELLIGENT TESTING AND INTEGRATED ASSESSMENT

To evaluate the hazardous effects of chemical substances, animal testing is often still standard practise in the chemical industry. The European chemicals legislation REACH that entered into force in 2007 was supposed to change that. Its intention is to use alternative methods as often as possible for the hazard assessment of industrial chemicals. In practice however, this is not always the case: "Industry is still a long way from carrying out safety precautions for handling chemical substances without some form of animal testing", says Prof. Dr. Gerrit Schüürmann from the UFZ. Together with his co-workers he has introduced a set of alternative methods that could clearly reduce the need for animal testing.

Schüürmann's procedures are important for implementing REACH, because the regulation builds on a new assessment approach that uses the instrument of Integrated Testing Strategies (ITS). Instead of the continued application of routine animal tests, selected combinations of several alternative methods should be increasingly used. "With this kind of method combinations we want to avoid missing information that could otherwise have been obtained from animal testing", says Schüürmann. He and his team have developed computer-based instruments that enable Quantitative and Qualitative Structure-Activity Relationships (QSARs). One example is the computer program "ChemProp". It can be used for calculating evaluation-relevant properties of substances, and for certain areas it can also predict the potency and mode of action of ecotoxicological effects. ChemProp thus allows researchers to judge the toxicity of a chemical for the environment. The software does not only use methods known from the scientific literature, but also calculation schemes developed at the UFZ. Examples are the solubility of organic substances and its implication for their uptake in aquatic organisms as well as their acute toxicity to fish.

An important new approach for computer models is 'read-across', i.e. data interpolation from similar substances. Here scientists assume that the hazard potential of a substance can be predicted from experimental findings on similar substances that are already available. To search for similar substances, Schüürmann's UFZ team developed algorithms and successfully tested them for predicting different properties of substances. "The new procedure usually enables predictions with an accuracy of approx. 80 percent", says the chemist. This is considered to be a good standard value that can even be improved to more than 90 percent if this approach is combined with further alternative approaches. The recently published method has already been applied by the scientists to a long-term study for estimating the toxic effects on fish from chemical substances identified in the rivers Elbe, Weser, Aller and Ems.

The scientific know-how for computer models as components of an ITS assessment of chemical substances thus already exists. However, it is the political break-through that is still lacking. The European Chemicals Agency (ECHA) that is responsible for the authorisation of chemical substances is still not completely convinced by the alternative procedures. According to Schüürmann, QSAR has so far been used by ECHA more as proof of the presence of toxicity than of its absence. If QSAR predicts a substance to be harmless, the authorities are often not satisfied with this result but still demand additional animal testing. If on the other hand alternative methods suggest the chemical to have negative effects on humans and the environment, animal testing can usually be omitted. But even if the authorities are still somewhat reluctant about the new approach, "intelligent testing strategies including QSAR will eventually become generally accepted" Schüürmann is convinced. The reason for this is clear: If industry used alternative models instead of animal testing, it would have to spend significantly less money for implementing the REACH legislation. Furthermore, computer models can also be used to assess substances that are still in the stages of conception. Consequently, chemical structures that are extremely toxic could be avoided from the very onset. *Benjamin Haerdle*

UFZ Contact person:

- **Prof. Dr. Gerrit Schüürmann**
  Dept. Head of Ecological Chemistry

e-mail: **gerrit.schuurmann@ufz.de**

POINT OF VIEW: ALTERNATIVE METHODS FOR ENVIRONMENTAL RISK ASSESSMENT

Dr. Stefan Scholz is biologist and has been conducting research for more than 20 years on the topic of replacing animal testing with alternative test methods. He has been employed at the UFZ since 2002 and has been working as a scientist and head of the working group "molecular biology" in the Department of Bioanalytical Ecotoxicology since 2008. He is also a member of the DIN working group 'biotests' as well as being a member of the HESI[1] animal alternatives in the environmental risk assessment project committee steering team. ([1]Health and Environmental Sciences Institute Washington, USA)

e-mail: stefan.scholz@ufz.de

If chemicals are to be certified for the market, they have to undergo an environmental risk assessment, of which animal testing is an integral component. About 100,000 vertebrates, mostly fish, are used annually in the European Union for animal testing for the environmental risk assessment of industrial chemicals, pesticides, biocides, pharmaceuticals, or feed additives. From both an ethical and economic point of view that is a substantial amount of animal tests, even if this seems relatively small compared to the overall number of 12 million vertebrates used for experimental and other scientific purposes every year in the European Union. With the European chemicals legislation REACH the number of tests on animals will probably continue to increase because until 2018 all substances that have so far been insufficiently characterized and are already on the market are to be tested.

Animal testing is supposed to help assess the potentially negative environmental impacts of chemicals and therefore any potential danger to the environment. Hence, if one is to criticize the use of animal testing, then it is necessary to consider some alternatives. One solution is to reduce the rate of animal testing by simply changing the test design. Furthermore, the structural, physicochemical properties of chemicals can be analysed comparatively to derive the biological effect of an unknown substance. New experimental approaches are based on the analysis of molecular mechanisms as well as the use of embryos, eggs or the cells of fish. They are regarded as a replacement for animal testing according to the "EU directive on the protection of vertebrates used for scientific purposes". So far the German waste water dues law provides the only legal regulation, in which an experiment on animals (the acute fish test) has already been replaced by an alternative (the fish egg test).

How can the introduction of alternative methods be accelerated?
One will have to hold one's breath for a long time before alternative methods are established as this will require international harmonization and validation. Harmonization means that national interests in the OECD committees (Organization for Economic Cooperation and Development) have to be agreed upon in order to reduce both the time and effort of multinational enterprises spent in developing and authorising alternative methods. Validation means that the results of the alternative methods between different laboratories have to be both transferable and reproducible and that the application domain has to be specified. Validation usually depends on the voluntary participation of industrial and research laboratories. *Additional financial support* could increase the motivation to take part in validation studies and thus to accelerate the authorisation of tests that replace animal testing.

Are there too many hurdles for alternative methods?
Frequently it is criticized that established experiments on animals would fail under the same set of criteria that are required for alternative experiments and hence that there are unnecessarily too many hurdles for alternatives. By reversed conclusion however it surely does not make sense either to reduce the requirements for substitute methods. Rather, existing animal tests should be urgently re-examined and optimised because they represent the reference procedures for the development of substitute methods – and it is only the availability of *reliable, reproducible data* with high quality which will enable an alternative method to be established in the long run and thus the number of tests on animals to be reduced. Beyond that data and/or data sets on animal testing have only partially been available due to copyright regulations and even coded data would not alleviate this problem. An easy and less bureaucratic access to animal test data is required – in particular for scientific institutions. Fortunately the OECD, ECHA (European Chemicals Agency) and other organisations have now established a database and search tool to facilitate access to existing data (www.echemportal.org).

A new way of thinking is required for authorities and users
The introduction of alternative test strategies also requires a practical implementation of new concepts, e.g. the frequently discussed use of information about (molecular) effect mechanisms. For this a rethinking is necessary particularly among authorities and users (i.e. in industry or contract laboratories), which could be promoted by the appropriate training of personnel. It cannot usually be expected that one single method will be able to completely replace animal testing. It will rather be the case that a complex combination of different procedures from test-free approaches to the identification of effect mechanisms and molecular interactive effects will enable a comprehensive risk assessment of chemicals.

The chemist Dr. Petra Greiner is head of the Department for International Aspects and Pesticides in the Division of Chemical Safety at the Federal Environment Agency (UBA) in Germany. She is an expert on the environmental risk assessment of chemicals (among others biocides and pesticides) as well as on the international management of chemicals and sustainable chemistry. For 13 years now she has been the national coordinator for the OECD Test Guidelines Programme. With these test provisions, chemicals are tested among other things in terms of their impact on the environment on both a national and an international level. (Photo: André Künzelmann)

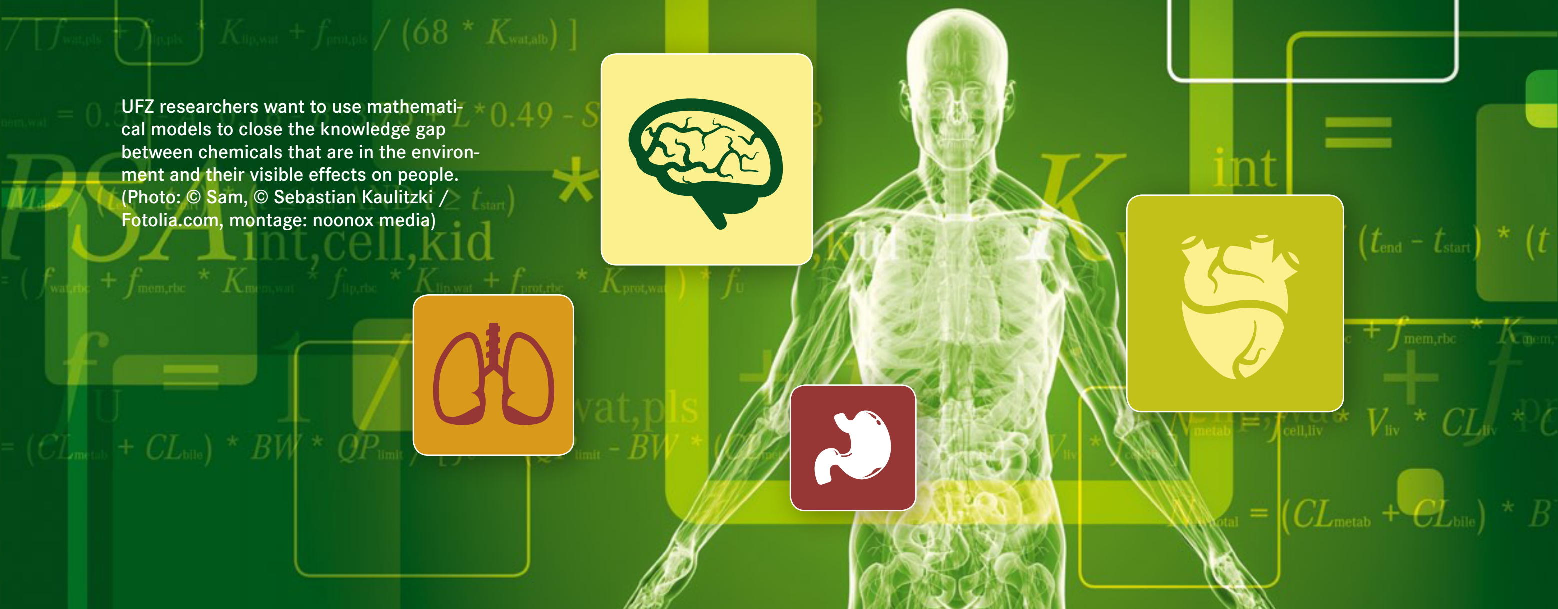
"ALTERNATIVES DO NOT WORK WITHOUT EXPERT KNOWLEDGE!"

How has the total number of animal tests to examine chemical substances changed since 2007 as a result of the REACH legislation?
We cannot really see any trend that relates to REACH. According to current statistics of the Federal Ministry for Consumer Protection the total number of vertebrates used in animal testing in Germany increased from the year 2000 to 2010 from 1.8 million to 2.8 million. Fish tests (mainly used for the environmental safety assessment of chemicals) decreased substantially between 2001 and 2003, which was certainly due to the authorisation of the fish egg test as a replacement for the acute fish test in the waste water supervision. In 2010 the number of fish tests was 166,000, which equals approx. six percent of all tests on vertebrates in Germany. In 2010 about 8.7 percent of the 12 million animals used in experiments in the EU were used for toxicological safety tests.
The majority of animal tests are thus carried out for fundamental biological research such as experiments in genetic engineering.
It is interesting that the number of animal tests did not dramatically rise as a result of REACH as was predicted by many. Until now less chemicals have been registered and less testing proposals have been submitted than expected from prior notifications.
Why is this the case? It is most likely to be a combination of overestimation, the use of existing data and taking advantage of the options provided by REACH to omit certain types of testing. Perhaps it is also partly down to a kind of market adjustment.

How far are we in replacing animal testing in environmental risk assessment?
Driven by the cosmetics industry, *in vitro* methods (i.e. outside of the living organism) have often been used over the last two or three years in the field of human toxicology as alternatives to animal testing with endpoints such as skin and eye irritations. However, these endpoints are much easier to describe and perform *in vitro* than for instance the complex organ-, development- or reproductive toxicity. Thus, *in vitro* methods cannot replace animal testing in all cases. At the OECD-level, Germany, the Netherlands and the US have successfully committed for the approval of the extended one-generation reproductive toxicity study. If the test on the second generation can be omitted in the future, then this will probably have the greatest impact on reducing the number of test animals. This study is now to be adopted as quickly as possible as part of the European Union's Test Method Regulation. It took the UBA years to get the fish embryo test approved as an alternative to the acute fish toxicity test and to get the bioaccumulation test using fish revised. The OECD-project "Fish Testing Framework" will be adopted in 2012 and will contribute to more targeted testing and consequently less fish testing. Germany is also very active in developing and applying non-testing methods that are based on quantitative structure-activity relationships (QSARs) i.e. analogies of similar substances.

And still the approval of alternatives is very sluggish. Why?
Requirements concerning the safety of substances are the main focus. The better the validation of an alternative method, the more robust the test. This is usually both complex and expensive. Data are often lacking or not accessible. Therefore the ECHA (European Chemicals Agency) is working to publish data from dossiers and completed studies bit by bit. We need to ask ourselves however whether or not the existing 'in vivo' tests that are considered to be 'gold standard' should be the benchmark for the new *in vitro* tests. For this reason the OECD is also checking how existing tests actually perform, which of them we actually need and which ones should be improved or abandoned. In this way animal testing can also be avoided. The problem with QSARs is that they are often poorly documented in registration dossiers. Furthermore, the user instructions are often so complicated that they are not practicable. QSARs and *in vitro* tests simply do not work without expert knowledge!

How can research contribute to overcome the hurdles?
When researchers develop new experimental approaches or non-testing methods such as QSARs, then they must be user-friendly for both industry and regulators. For this we need a much closer co-operation between research and users, whether this is through research networks or through the SETAC working group 'Non Animal Alternatives in Ecotoxicology' where UFZ experts are also represented. Particularly in non-testing methods, there is more potential. A very positive example of this is the EU-project OSIRIS coordinated by the UFZ. Among other things, regulatory acceptable and understandable QSAR-models for the acute fish test were developed within the project.
The interview was conducted by Doris Böhme.



UFZ researchers want to use mathematical models to close the knowledge gap between chemicals that are in the environment and their visible effects on people. (Photo: © Sam, © Sebastian Kaulitzki / Fotolia.com, montage: noonox media)

CALCULATIONS FOR HEALTH

Imagine that you are renovating your home: you are doing the decorating and fitting new carpets. The unpleasant smell that lingers in the air for days after makes you feel uneasy and so you decide to play it safe and take yourself and the family to stay with friends for a while. How long will these conditions last? When will you be able to return home again without damaging your health? In order to make some kind of assessment you would not only have to know which chemicals are lingering in your home and how harmful they are, but also how your body will react to and cope with them. In order to be able to answer such questions, Prof. Dr. Kai-Uwe Goss and his co-workers use a mathematical model. This helps to put them in a position where they can make forecasts about what happens to environmental chemicals such as solvents, pesticides or plasticisers once the body has absorbed them.

At least the researchers don't have to start from scratch, because similar models are already available in pharmaceutical research, where they are used to understand how medicines are distributed in the human body. Unfortunately such models cannot simply be transferred 1:1. They neglect processes that are very important to trace the whereabouts of harmful pollutants in the body – for instance respiration as a potential path of uptake. Furthermore, they are optimised for chemical characteristics that are typical for medicines. In this respect, characteristics can be very different, for instance the absorbency of harmful substances in the body can vary greatly compared to medicines. "For this very reason we take what we consider to be the best available model in pharmaceutical research and optimise it on the basis of our own scientific findings in terms of details that we consider to be important" explains Dr. Kai-Uwe Goss.
He regards his model as an important tool for finding the answers to different questions in environmental chemistry, among others: How effectively does the human body absorb different environmental chemicals? How long does it take them to spread to various organs and how do they get there? How high is the permeability of membranes for hazardous substances, for example in the stomach? Which chemicals accumulate in which organs and how are they egested or excreted? Eventually, researchers want to be able to make predictions about processes that determine concentration levels in the human body, which would be important prior knowledge for the work of toxicologists. They in turn would be able to conduct further research and come up with correlations with visible effects e.g. an allergy or symptoms of intoxication. "We can therefore use our model to close a knowledge gap between the chemicals that are found in the environment and the effects that are visible to humans", says Kai-Uwe Goss.

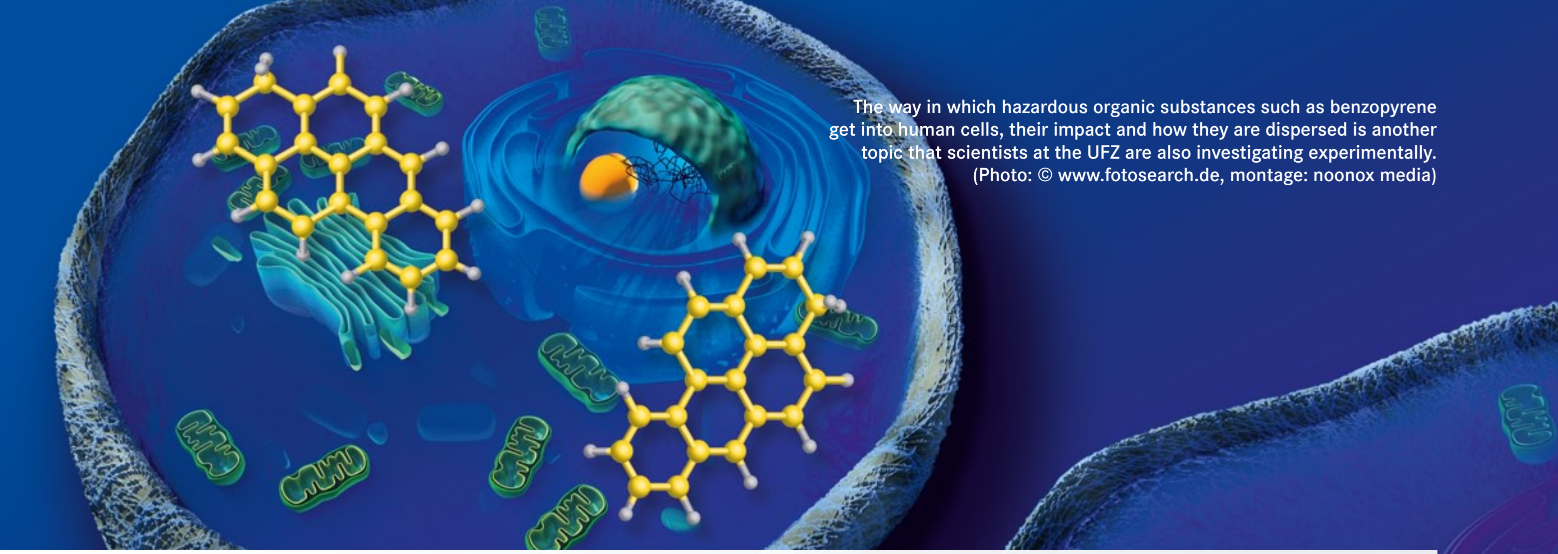
The practical relevance of this basic research is obvious, when we think back to the opening example of the freshly refurbished home. Above all however it is about providing accurate findings to authorities and companies in order to adjust regulations on health and safety issues and for the authorisation of chemicals. Far too often these are based on rough assessments as opposed to on accurate scientific findings. In those cases where humans are exposed to harmful substances at work for example, the optimal work and leisure time could be calculated to avoid unnecessary damage to health. Likewise a very directed detoxication could be prescribed for those people who have come into contact with toxic chemicals.

The researcher team used a rather unusual method to test the reliability of the mathematical model in its current development phase. They met after work to do an experiment on themselves, whereby they drank precisely measured quantities of an organic-chemical substance (in this case alcohol) at specifically defined time intervals in the form of wine and liquor. They then fed the model with their blood-alcohol levels and calculated as a function of parameters such as age, weight or size, the rise and fall of alcohol levels in the blood for each individual participant of the study. A simple experiment that was still able to demonstrate that the model can supply both reliable and accurate results. *Susanne Hufe*

UFZ Contact person:

Prof. Dr. Kai-Uwe Goss
Dept. Head of Analytical Environmental Chemistry

e-mail: **kai-uwe.goss@ufz.de**



The way in which hazardous organic substances such as benzopyrene get into human cells, their impact and how they are dispersed is another topic that scientists at the UFZ are also investigating experimentally. (Photo: © www.fotosearch.de, montage: noonox media)

SMALL AND BIG ALIKE

In contrast to environmental chemist Dr. Kai-Uwe Goss, who tries to understand the effect of organic chemicals in organisms using a theoretical mathematical model, the scientific approach of his UFZ colleague Dr. Martin von Bergen is of a clearly experimental nature. The focus of his research is the smallest living organisms: cells. According to his hypothesis, this is where answers can be found to questions about the effects of chemicals. “If we understand what is going on here, we can draw conclusions about the entire system”, biochemist Dr. Martin von Bergen comments on his Systems Biology-based research approach, who since 2008 has been part of the network coordinated by the UFZ within the Helmholtz Alliance on Systems Biology. He assumes that in order to be able to understand the molecular effects in cells the same factors are decisive that also apply to the entire organism: there are sources and sinks, kinetics of distribution, the interaction with surfaces as well as non-specific and specific mechanisms of catabolism.

The interdisciplinary team of scientists from the fields of biology, biochemistry, bio-informatics and modelling at the UFZ together with partners in Dresden, Zurich and Heidelberg are analysing the effects of the substance benzopyrene. This chemical also known as benzo(a)pyrene (BaP) is a hydrocarbon that is formed by the partial combustion of organic substances, e.g. in overcooked charcoal barbecued meat or in exhaust fumes from diesel engines and gasoline as well as in cigarette smoke. For this reason people outside of scientific circles are sometimes familiar with it. Although it is not highly toxic in itself, due to the intermediary products that are formed during enzymatic metabolism, benzopyrene is considered to be carcinogenic to humans and other organisms in the environment.

If so much is already known about benzopyrene, one might wonder why research is still being conducted on it? “We have focussed on concentrations which clearly show no direct toxic effects on the cellular level. We were surprised to find that the detection of alterations was much more sensitive on the molecular level”, says von Bergen, making it clear that until now there have been no findings about the effects of benzopyrene in subacute toxic concentrations.

In order to understand the way in which harmful substances such as benzopyrene get into cells, how they are distributed there and the impacts they have, scientists proceed in the following way: The uptake and distribution of the harmful substance within the cell are made visible by means of fluorescence microscopy. From modelling this data, conclusions can then be drawn about the number of ligands of the receptor in different cell components. The highly complex processes at work as a result of chemical contact in the cells are investigated on the gene, the protein level and in terms of the metabolic products with very high resolution and accuracy. From the high-dimensional data, the signalling pathways and reaction patterns in the cells are identified. Thereby the researchers can then generate a model that enables predictions for different concentration levels – and possibly also prognoses for other chemicals.

Martin von Bergen and his team of researchers perform these experiments preferentially using liver cells, because these are responsible for metabolising foreign substances in the body. “It is often these cells that determine whether the body is in danger or not”, states von Bergen. Past results confirm his hypothesis: even subacute concentrations of benzopyrene were found to damage cells.

Prospectively, the researcher team can look well beyond individual substances such as benzopyrene. From comprehensive data, scientists are developing models, which are to help test the effect of substances in cells more quickly and thereby come up with new methods in toxicological research for the recognition and protection against harmful chemicals.

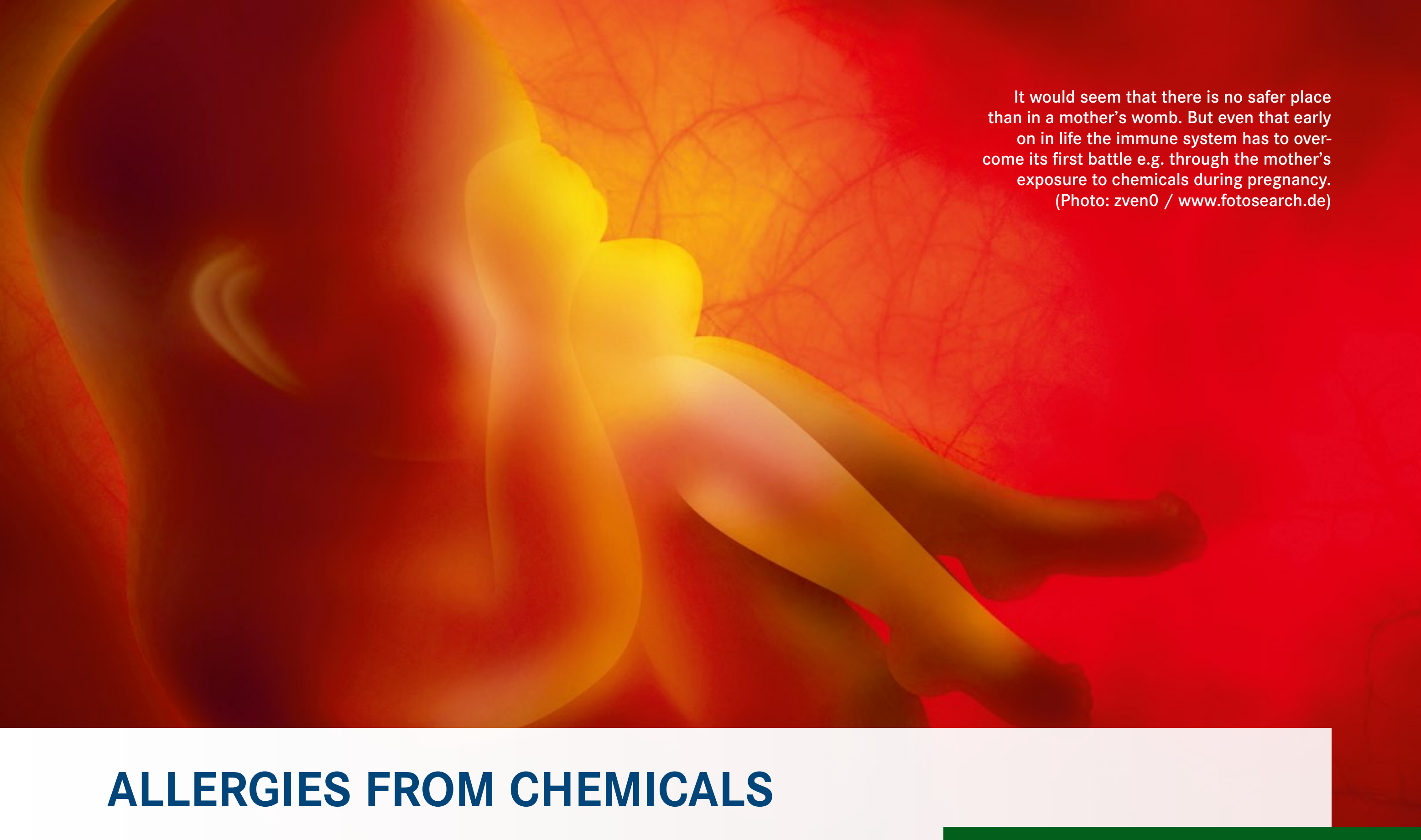
Bergen’s fundamental research results are (like those of his colleague Dr. Goss) supposed to flow into very practical regulations, threshold values or provisions, which until now have been oriented too much towards rough scientific findings.
In fact, if it was up to the two scientists, then one day there will also be a model that will combine the two scientific approaches (theoretical and experimental).

Susanne Hufe

UFZ Contact person:

- **Prof. Dr. Martin von Bergen**
  Dept. Head of Proteomics

Speaker of Dept. Metabolomics
e-mail: **martin.vonbergen@ufz.de**



It would seem that there is no safer place than in a mother's womb. But even that early on in life the immune system has to overcome its first battle e.g. through the mother's exposure to chemicals during pregnancy. (Photo: zven0 / www.fotosearch.de)

ALLERGIES FROM CHEMICALS

Allergies are the price that we have to pay for our western life-style. About 300 million people in the world suffer from allergies. Thereby the number of registered cases in Western Europe has doubled over the last two decades. Data from many studies give evidence for an impact of life-styles and environmental factors on allergy risk. In the past, the immune system of our children used to be trained by infections and a microbial-rich environment, but this training is lacking today due to hygiene measures with the consequence that the immune system is not being challenged. As a result, it may overreact against harmless substances such as grass pollen. In addition, pollutants such as chemicals released from paints, flooring, furniture, cleaning agents or cigarette smoke are also known to contribute to allergy development. And the earlier in life our immune system is exposed to such pollutants, the greater the impact on our health.

The first challenges already *in utero*

The mother's womb appears to be the safest place for an unborn foetus. In this soft, warm and cushioned environment all organs start to form and develop their functions, such as the immune system. But there are harmful factors that could already change the regular development of the body's defence system *in utero*. Even in completely healthy newborns, cells with an abnormal or destroyed function can be found in umbilical cord blood. In consequence, the irritated immune system is leaving its regular path of protecting the body from pathogens with the result of an overreaction to harmless substances: Atopic eczema, hay fever or bronchial asthma can develop as part of the atopic march which greatly disturbs the lives of those affected.

The immunologist Dr. Irina Lehmann and her team are particularly looking into the time during pregnancy, when the foetus' immune system starts to work according to unphysiological rules. The scientists are interested in the mechanisms behind these altered rules. Their goal is to recognize the irritation of the immune system before the first symptoms of an allergy occur and possibly even provide some opportunities to prevent the onset of a disease outcome. Indeed, once the immune system has started to attack harmless substances it will take longer therapies to delete this reaction from its immunological memory. To find out exactly what is going on in the maternal womb, the researchers need to answer a number of fundamental questions: Which factors affect the immune system before birth? Through which mechanisms is the mother's immune system connected to that of the embryo? How does the sensitivity of the immune system differ between children and adults?

To answer these questions, the scientists working together with Irina Lehmann soon realised that they need to cooperate with those affected (in this case pregnant women). Therefore they started the large prospective mother-child birth cohort study 'LiNA', together with a local children's hospital in 2006. In the context of this study, several hundred pregnant women and their newborn children were examined for their exposure to chemicals and other environmental factors. Furthermore, information on the occurrence of diseases later on in these childrens' lives are collected annually until they become adults.

The scientists and physicians involved were particularly interested in the results from the blood tests. Both the blood from pregnant women and later the cord blood of the newborn babies were analysed. Among others, they wanted to find out what happens to T lymphocytes – cells which control the function of all immune cells, when they are exposed to chemical stress. When T cells overreact after contact with allergens, signalling molecules are released that enforce the production of immunoglobulin E – the antibodies that lead to allergic reactions. This pathological reaction could still be compensated by regulatory T cells, which (under normal circumstances) can control other T cells and prevent an over-reaction. However if there are not enough of these regulatory T cells or if these do not work properly, the risk of getting allergies increases. “This is exactly what we observed in our study”, says Irina Lehmann. The UFZ researchers found smaller numbers of these crucial regulatory T cells in the cord blood of newborns, whose mothers smoked during pregnancy or who were exposed to chemicals. As a consequence, children with lower Treg numbers much more frequently developed an allergy later on.

One goal of the research team from Leipzig is to diagnose such critical changes very early on in life to be able to identify high-risk children. This could then for example justify special therapies. “We are also helping parents to influence their child’s environment, for example by avoiding critical exposure to chemicals during pregnancy or during early infancy”, says the scientist Dr. Lehmann. At the same time it is also necessary to make legislators aware about the fact that our immune system can already be damaged at such an early stage. It has to be considered that different threshold values for chemical exposures might be relevant for pregnant women and babies. Manufacturers of building materials and interior designs also need to take these criteria into account.

Inflammation within the respiratory system

The chemicals which most of us have been exposed to daily do not only damage the immune system of our children before birth. Inhaled volatile organic compounds (VOCs) emitted from adhesives, furniture or paints can also be harmful to our respiratory system, where they can cause inflammation.

Research conducted by the UFZ has determined the extent of these effects: The probability that a child will suffer from respiratory complaints when a home is refurbished in the first years of its life is quadrupled. Special *in vitro* models established in their laboratory helped the researchers to understand the effect of VOCs inside the lungs. These models consist of epithelial cells from the human lung (which can grow in incubators without any problems), a thin membrane upon which the epithelial cells grow and a feeding medium. The lung cells are exposed to air containing VOCs simulating the physiological conditions in the lung where epithelial cells come into contact with VOCs through the air. “We are then able to measure how the lung cells react and whether and in which direction normal processes are disrupted”, Irina Lehmann describes the experiment. “What we observed was the activation of epithelial cells under the influence of VOCs, consequently releasing signals of inflammation. Inside the lung, other immune cells are attracted by these signals and also activated so that the inflammatory reaction continues to spread.” The UFZ researchers found out that oxidative stress is the cause of these inflammatory reactions in the lung; they could show the formation of reactive oxygen molecules (also known as oxygen radicals) following VOC exposure. These damaging forms of oxygen play a crucial role in diverse illnesses as well as in aging processes.

After knowing what causes the damage to the cells lining the lung, the researchers started combating this process. They used antioxidants – chemicals that can neutralize the reactive oxygen molecules that have formed within the cell due to chemical exposure. With these antioxidants (that are already available as medicine), the lung cells in the experiment could be protected against the harmful effects of VOCs.

Approximately ten years ago Irina Lehmann’s team started this series of experiments. “With our results we were able to prove that VOCs can actually cause allergies and inflammatory reactions in the lung and we were also able to identify the underlying processes going on at the cellular level. Based on these findings we could outline new potential strategies to treat or even prevent the reactions caused by chemicals within the lung.” Antioxidants seem to be one solution in this respect. They can also be ingested by the body in the form of food e.g. as fruit juices or vegetables. The extent, to which nutrition rich in antioxidants can protect us against the damaging influences of environmental impacts, is one of the exciting questions that UFZ researchers want to answer in the future. *Marlis Heinz*

LINA – LIFE-STYLE AND ENVIRONMENTAL FACTORS AND THEIR INFLUENCE ON THE NEWBORN’S ALLERGY RISK

Photo: Kristin Weiße, UFZ

UFZ Partner: Children’s hospital at the Municipal hospital “St. Georg” in Leipzig, University of Leipzig (Clinical Immunology and Dermatology)

No. of participants in the study:
622 pregnant women and their 629 newborn children

Recruiting period of the pregnant women:
2006 to 2008

End of study: 2024 to 2026

Exposures investigated: cigarette smoke, chemicals in the home (VOCs), mould, traffic, noise, stress

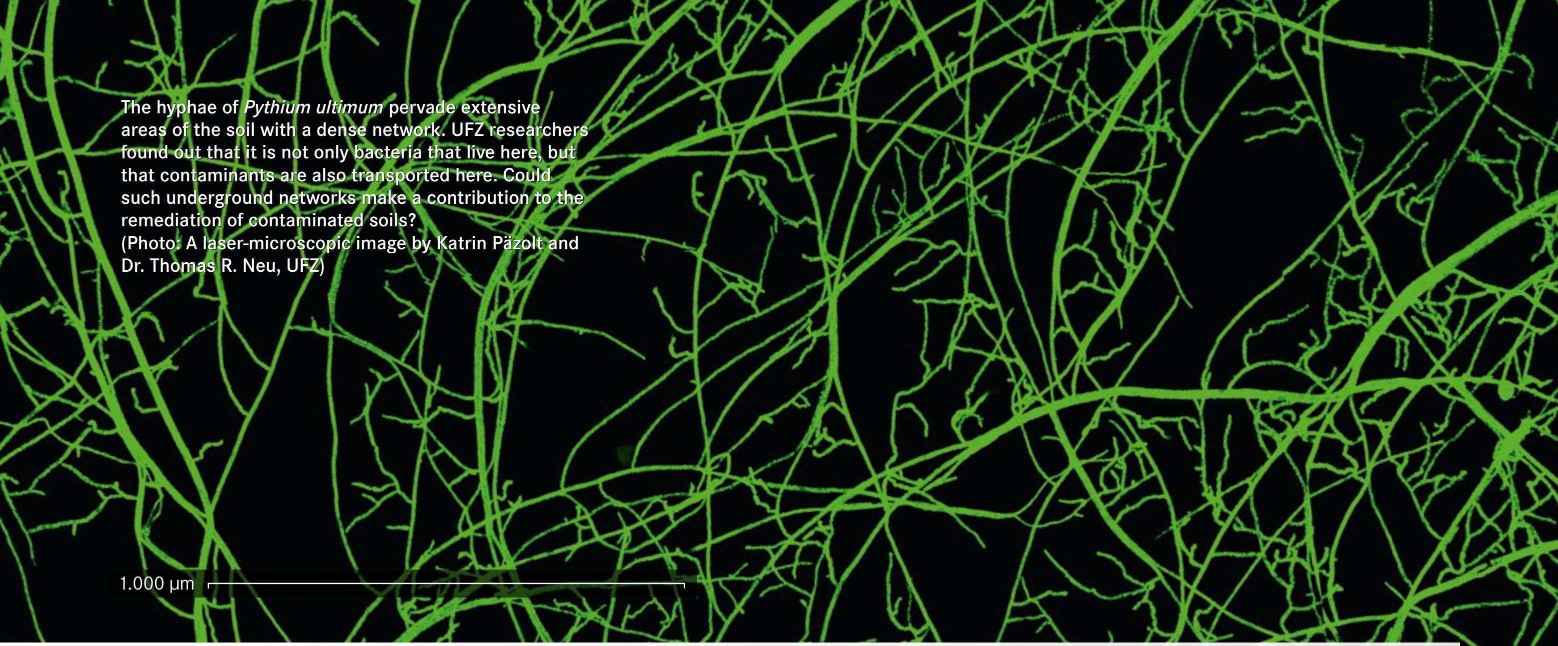
Methods:

- Blood tests were conducted to investigate the influence of environmental factors on the immune system of pregnant women and their newborn babies as well as their allergy status later on – starting from the 34th week of pregnancy and in the umbilical cord blood of newborn babies.
- The health status of the children will be recorded until they are 18 years old. They will be examined once a year at the children’s hospital of the Municipal hospital “St. Georg” in Leipzig and parents will annually answer a questionnaire about the illnesses of the children.

UFZ Contact person:

Dr. Irina Lehmann
Dept. Head of Environmental Immunology

e-mail: **irina.lehmann@ufz.de**



The hyphae of *Pythium ultimum* pervade extensive areas of the soil with a dense network. UFZ researchers found out that it is not only bacteria that live here, but that contaminants are also transported here. Could such underground networks make a contribution to the remediation of contaminated soils?
(Photo: A laser-microscopic image by Katrin Päzolt and Dr. Thomas R. Neu, UFZ)

COMBINING EXPERIMENTS AND MODELS

Microorganisms play a crucial role in the remediation of contaminated soils. Substances that we perceive as contaminants, serve as a source of substrate for bacteria. Thus, bacteria help to break down contaminants and act as ecosystem service providers. However, this does not work everywhere and every time – the right conditions in the soil have to be available and bacteria need to be able to access their substrates. Even the tiniest air-filled pore that is only a few micrometers in diameter can become an insurmountable obstacle. "In their motion bacteria are bound to liquid films", explains environmental microbiologist and chemist Dr. Lukas Y. Wick. "Even if the source of substrate (in this case the contaminant) appears to be extremely close: when there is no direct access they will starve."

But, emergency helpers are not far away: In a dense network fungi branch out with their filamentous structures (so-called hyphae) creating fungal threads through large areas of soil. These hyphae are covered in a layer of physiological liquid, allowing bacteria to rapidly travel along them, as if on a 'fungal highway'. In this way the bacteria can reach those soil areas that provide suitable living conditions for them. Because fungal hyphae are able to grow through air-filled pores, they build bridges through impenetrable areas for the bacteria. Moreover, the fungi may not only transport bacteria to the contaminants, but also transport the contaminants themselves: like some kind of 'fungal pipeline' they pump the contaminants within their cell plasma through the soil and hence make them available to other bacteria.

The infrastructure would appear to be optimal. However, not all microorganisms do degrade contaminants, the environmental conditions are not always ideal and not all bacteria can cope with fungi that sometimes also discharge antibiotics. "We are looking for particularly effective bacteria-fungi combinations with the goal of being able to stimulate them in the future by creating the ideal conditions for their interaction in practice", explains Lukas Y. Wick.

In search of the most suitable combination for this microbial contaminant degradation strategy, he closely collaborates with Dr. Thomas Banitz, who is a mathematician and looks at the system from a different perspective. He sees the soil processes from the eyes of an ecological modeller. Different ideas and interpretations can therefore result from exactly the same observations. With the help of computer models, the UFZ researchers can simulate numerous scenarios. For example, they are able to vary the given environmental conditions, like the supply of water or oxygen, the concentration and the distribution of contaminants or also the competition of different types of bacteria. Furthermore, they are investigating which role these conditions play for different pairs of bacteria and fungi, how the conditions interact with each other and which influence they will eventually have on contaminant degradation. Thus, they are able to determine the soil conditions under which substantially improved degradation rates can be expected, as well as the physical, chemical and ecological key factors for achieving these improvements.

The two researcher teams use a combination of computer models and laboratory experiments to investigate the interactions of bacteria and fungi in contaminant degradation. The experimental results are integrated into ecological models and the insights gained from the models serve as a basis for the design of new experiments. Dr. Wick: "We have an extremely effective and profitable synergy from integrating these two very different disciplines. The ecological processes taking place on the large scale are possibly also taking place on a small scale: in the microbiological domains of the soil. By combining experiments and models we hope to trace the real processes in the soil and thus to be able to better support contaminant degradation in the future."

Nicole Silbermann

UFZ Contact persons:

Dr. Lukas Y. Wick
Dept. Environmental Microbiology
e-mail: **lukas.wick@ufz.de**

Dr. Thomas Banitz
Dept. Ecological Modelling
e-mail: **thomas.banitz@ufz.de**


(Photo: Tobias Hametner)

ISOTOPES TO MEASURE *IN-SITU* CONTAMINANT DEGRADATION

Soils and aquifers contaminated by organic pollutants require economically-feasible remediation concepts. In-situ remediation, the so-called *Monitored Natural Attenuation* (MNA) makes use of natural degradation processes for cleaning up pollution. The planning of MNA remediation concepts requires an accurate assessment of natural degradation processes and the prediction of their sustainability over longer time periods typical for MNA strategies. Some pollutant-degrading microorganisms for example require a certain concentration of oxygen or other so-called electron acceptors to mineralise the pollutant. For this reason humans sometimes intervene to create the optimal conditions for bacteria and thus to instigate or improve the natural processes that clean up or attenuate pollution *(Enhanced Natural Attenuation, ENA)*.

But how can we find out whether or not these processes are actually taking place? "A method that uses simple chemical analysis is not sufficient in this respect. As a result of abiotic processes such as accumulation, evaporation or dilution, the concentration of pollutants in the soil can be reduced, even though natural degradation might not have actually taken place", says geochemist Dr. Hans-Hermann Richnow from the UFZ. So-called isotope monitoring can be used however to provide compelling evidence of such degradation processes and even to quantify them. Isotopes are variations of the same chemical element that differ only in their number of neutrons. The carbon isotope ^{12}C for example has a total of six neutrons and is thus somewhat lighter than the carbon isotope ^{13}C with seven neutrons. Both carbon isotopes occur naturally, however ^{12}C is much more common accounting for 98.9 percent of carbon isotopes compared to ^{13}C with only 1.1 percent. Carbon isotope ratios are used as a basis for isotope monitoring as a reference value for estimating pollutant degradation.

If this method is to be used to quantify pollutant degradation, it is important to know at which rate the microorganism degrades the isotopically-lighter compared to the isotopically-heavier contaminant species. In principle, pollutants consist of light (^{12}C) and heavy (^{13}C) isotopes, the ratio of which changes upon biodegradation. During biological degradation therefore heavy ^{13}C isotopes start to concentrate in the remaining pool of pollutants and there is an enrichment in the non-degraded contaminant fraction. In other words, the ratio between the two isotopes shifts. From this shift, which can be measured using mass spectrometers, one is able to deduce how far the degradation process has progressed and whether intervention is necessary. Compared to other methods of analysis, isotope monitoring has one major advantage: The isotope ratio of a pollutant can be exclusively determined by microbial degradation and is hardly affected by other processes. "There is no other method of analysis that can provide such compelling evidence or even quantification of the degradation processes in the black box of soil", says Hans-Hermann Richnow.

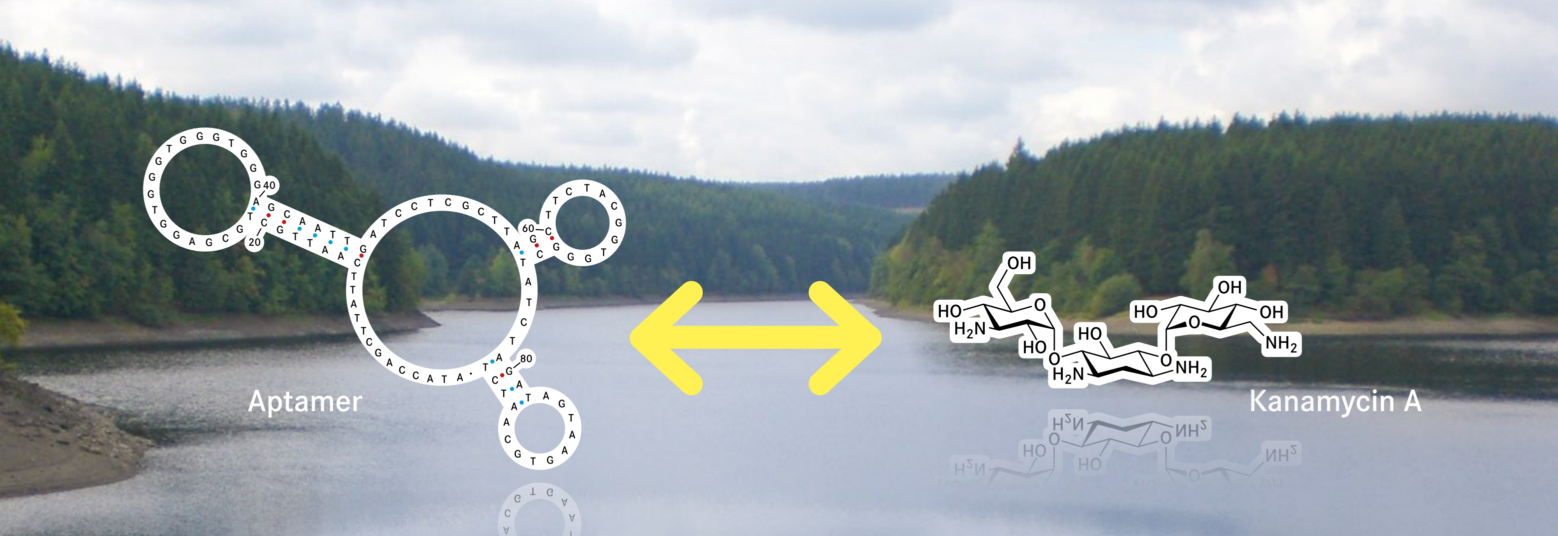
Together with his colleague Prof. Rainer Meckenstock of the Helmholtz-Center in Munich, Dr. Richnow founded the company Isodetect GmbH in 2005 that uses isotope monitoring to assess contamination cases in the environment. In the future the procedure is also to be applied to monitor the degradation of pesticides and pharmaceuticals. Isotope monitoring is not only a recognized procedure in Germany, but also recommended in the USA by the *Environmental Protection Agency* (EPA).

Dr. Richnow and Dr. Meckenstock are pioneers in this field. They have developed a new field of research over the past 15 years – from its philosophy to its practical application: At the end of the 1990's Dr. Richnow worked as a junior scientist on experiments with stable isotopes as markers and came across discrepancies in the chemical fate of these substances. In this context the principle of isotope fractionation during photosynthesis occurred to him, where for the production of sugar molecules, plants preferably resort to carbon dioxide (CO_2) with the lighter ^{12}C isotopes, which they are able to utilise by exerting less energy than with the heavier ^{13}C isotopes. "I put one and one together and thought that the same principle could also be applied to degradation processes", says Richnow. Soon afterwards he conducted his first experiments on isotope fractionation with pollutants together with Rainer Meckenstock. As a result there are now numerous groups of researchers around the world who are currently working in this field. *Nicole Silbermann*

UFZ Contact person:

PD Dr. Hans-Hermann Richnow
Dept. Head of Isotope Biogeochemistry

e-mail: **hans.richnow@ufz.de**



Aptamers are the heart of biosensors, which are being developed at the UFZ for the detection of antibiotics such as kanamycin A in the environment. (Photo: Beate Strehlitz, montage: Fuenfwerken Design AG)

FINDING AND BINDING THE FITTING PIECES

Every year millions of people all over the world die from illnesses that they have contracted from contaminated water. The situation is particularly grave in water-poor countries, but even in our country news about drinking water like for instance in the state of Thuringia polluted with *E. coli* bacteria or deaths from unexplained infections in hospitals can be very alarming for the population. In order to find out, which harmful substances are responsible, very time-intensive and costly laboratory tests are usually necessary. Time and money – two imperative factors, which Dr. Beate Strehlitz has to keep in mind while conducting her research: Her working group is developing simple, quick and low-cost biosensors that are able to safely measure whether drinking water or other foods are palatable or not.

Biosensors are measuring systems that convert a biological identification reaction between the target molecule to be measured, e.g. the pollutant, and an appropriate biological receptor into an electronically measurable signal. The principle is not new. Biosensors are already very well established for determining diabetics' blood sugar levels or for measuring the lactate values in the blood of sportsmen. While enzymes or antibodies are normally at the heart of these kind of sensors, more stable receptors are required for environmental pollutants such as pathogen microorganisms or for the residues resulting from drugs and antibiotics used on animals raised for meat. Aptamers, which can very literally be translated as "fitting pieces" (from the Latin aptus – fit, and the Greek meros – piece) might be the answer. These are single-strand DNA or RNA nucleic acids, which because of their specific three-dimensional structure are able to bind to a specific target molecule. As sure as a key fits a lock, the 3D-structure of the aptamers fit to specific connection points of entire cells, bacterial poisons, proteins or small molecules consisting of just a few atoms. "What we do is look for the suitable aptamers for the defined target molecules – it's a bit like molecular matchmaking, but with an unmanageable database", explains Beate Strehlitz jokingly. The analogy of "looking for a needle in a haystack" springs to mind where by means of a purposeful evolutionary *in vitro* procedure the best binding pairs are selected and enriched from a huge pool of 1015 different nucleic acid molecules. Once developed, the aptamers can then be produced by means of chemical synthesis. Sequence modifications to incorporate defined properties such as stability, immobilization and detectability can also be made. Beate Strehlitz and her team want to achieve more than just aptamers however. Their goal is a kind of aptamer toolbox, which provides methods on developing aptamers, user-specific aptamers as well as sensor- and assay principles i.e. practicable devices particularly for applications in environmental analytics.

Currently the research group is working on aptamers for pharmaceuticals and pathogens as environmental pollutants. A selected aptamer for the aminoglycoside antibiotic kanamycin A that is mainly used on animals raised for meat has already been patented. Furthermore, aptamers are under development, which can be used as biological recognition elements to detect ofloxacin and ciprofloxacin – antibiotics that are often prescribed for urinary infections.

The aptamers will not only be used to detect pharmaceuticals but also to remove them from wastewater. In sewage works pharmaceuticals are often only poorly degraded, and thus get into the environment and ultimately the human body through drinking water and food. In small quantities they are considered as harmless to humans. However the long-term effects on human health are still not known. What we do know however is that antibiotics in the environment can cause bacterial resistance. The imminent danger is when humans come into contact with resistant bacteria e.g. through infected food or in hospital. In such cases antibiotic aptamers could be life-saving recognition elements, with which dangerous pharmaceutical residues can be detected and enriched so as to remove them. So that it does not come to that, UFZ researchers recommend limiting the use of antibiotics, which would at least reduce the amount of them getting into the environment. *Gundula Lasch*

UFZ Contact person:
Dr.-Ing. Beate Strehlitz
Dept. Center for Environmental Biotechnology (UBZ)
e-mail: **beate.strehlitz@ufz.de**

When certain genetically-modified bacteria come into contact with arsenic, they light up. The luminosity of the bacteria provides information about the arsenic concentration in water. (Photo: André Künzelmann, UFZ)

SAVING LIVES WITH THE GLOWWORM PRINCIPLE

"Around 50 researcher groups from all over the world found this problem a hard nut to crack" says environmental microbiologist Prof. Hauke Harms. "We simply kept hacking away at it for the longest – but also because the Helmholtz community was backing us up. As a result we are the first ones to have made it to the application stage with bioreporters". These comprise a biological test procedure, with which one can easily and quickly detect highly toxic arsenic in the groundwater.

The main actors in this method are genetically-modified bacteria that light up when they come into contact with arsenic. Hence, the name of the biosensor – ARSOlux. The scientists use *E. coli* bacteria, because these are able to fight toxic substances. They switch on a defence mechanism, which keeps pumping out the substance that penetrates into the cell. This switch is coupled with a source of light. As soon as the genetically-modified bacteria come into contact with arsenic they produce light: A true test tube spectacle. The "luminometer" – a measuring device that is the size of a desk telephone, measures the light intensity of the bacteria, converting it into arsenic quantities. The method can be compared to the glowworm principle or bioluminescence in nature. The subtlety is that the researchers two different systems have brought together: a defence system and a signal system. A single person is able to carry out 160 tests per day – from collecting samples to analysing them. "So far this is unbeatable" says scientist Prof. Dr. Harms.

Since 1995 Hauke Harms has been investigating the reaction of bacteria to pollutants. Back in those days he worked at the Swiss University of Lausanne together with microbiologist Prof. Jan Roelof van der Meer. The two researchers were of the same mind that genetically-modified bacteria should not be able to get into the environment. Therefore the question about the necessity for such an invention had to be asked. "It soon became clear to us that only a very serious problem would justify the application of organisms that had been genetically-modified in such a way", recalls Hauke Harms. The researchers were confronted with this serious problem in the year 2000: Arsenic in the groundwater, which in most cases had got there through naturally-existing geological conditions or from mining activities. In those areas where there is no drinking water supply system and water is simply taken unfiltered from the ground, humans became ill – typically with severe skin lesions, kidney and liver disorders or even cancer. According to estimates of the WHO approx. 150 million people around the world consume arsenic-contaminated water, in particular in countries such as Bangladesh, Nepal, India, Vietnam or Mongolia.

In 2004 Hauke Harms came to the UFZ in Leipzig where he worked to put the test into practice, meaning that: ARSOlux needed to get out of the laboratory and into the "focal arsenic areas" of the world. This also meant that both international and local authorizing bodies as well as the organisers of testing campaigns in the countries concerned had to be convinced by the sensor. It was a venture that was new ground for everybody involved and proved to be an extraordinarily lengthy process that was not always compatible with the funding available from the typical run-time of a scientific project. "There is usually a great interest from the countries concerned", adds ARSOlux team leader Sonja Hahn-Tomer, "but it is often difficult to get a hundred percent commitment, because in most of the countries concerned arsenic poisoning is not ranked first on the agenda, but is topped by famine and environmental catastrophes". Besides which, the genetically-modified bacteria are often regarded with distrust. "Test it in your own country first" was the argument that we often heard. In fact, this is what happened in 2011 with a measuring campaign in the state of Saxonia, where scientists wanted to build confidence in the product. There is no potential danger from the bacteria used in the biotest, stresses Harms. "The *E. coli* K12 used are harmless laboratory bacteria that would hardly survive in nature." In 2010 the ARSOlux research received a very special reward. The German-Swiss researcher team received the Erwin Schrödinger award of EUR 50,000 for outstanding interdisciplinary research. *Annegret Faber*

UFZ Contact person:

- **Prof. Dr. Hauke Harms**
  Dept. Head of Environmental Microbiology

e-mail: **hauke.harms@ufz.de**

Collect and destroy – that is the task of Carbo-Iron, a substance as fine as coal dust, which was developed at the UFZ for groundwater treatment. (Photo: André Künzelmann, UFZ)

TINY GIANTS

Prof. Dr. Frank-Dieter Kopinke reaches for a vial in his laboratory and puts a pinch of black powder from it onto his visitor's finger. A substance as fine as coal dust sticks to the skin like soot, rather unspectacularly and dirty. For Kopinke however this substance holds a kind of magic formula in the battle against water contaminated by chemicals. Carbo-Iron is what his research group have named this substance, which they developed here at the UFZ in the group of Dr. Katrin Mackenzie, bringing them to the forefront of technological development in this field.

He chooses his words carefully to describe the substance most appropriately, because a single particle of this classical nano-technology application is so small that it is difficult to describe it in common units of size. "As small as bacteria", says Kopinke finally. Carbo-Iron is made up of carbon and iron: cheap and environmentally-friendly basic materials. In the laboratory there is a rotary kiln, in which the iron salts can be reduced to metallic iron. The scientists produce iron nano-particles on carbon micro-particles, which gives the substance its chemical reactivity. Micro-particles are the final product with an enormous internal surface area. "It is hard to imagine", Mackenzie says about the dimensions, "but if you unfolded the flimsy inner walls of ten grams of this particle, they would actually cover an area that is the size of a football pitch." It is on this large surface that the pollutants are collected from the water. The carbon accomplishes this task, whereas the metallic iron in the pores is responsible for destroying chlorinated pollutants. 'Collect and destroy': is the formula that can be used to describe the UFZ's innovation. Besides, Carbo-Iron is so light that the particles can easily be transported in the sandy aquifer. This mobility increases its effectiveness.

Kopinke regards the conventional methods used for groundwater treatment as unsatisfactory. The classical "Pump and Treat" system, i.e. the pumping and then treating of water is often not very economical, because of the long time period involved that can sometimes take years or even decades. Even the more modern methods (so-called *in situ* procedures) have their disadvantages, even if they do attack the pollutants directly in the environment without using chemical reactors. For example Advanced Oxidation Processes (AOPs) destroy the pollutants through oxidation by means of a strong oxidizing agent. "You can break down almost any chemical with this kind of process, but it is a very big club to be using", says Kopinke. According to Kopinke when *in situ* Chemical Oxidation (ISCO) is implemented, one is not able to control the reaction conditions, unlike with a chemical reactor. Consequently, unwanted by-products are often formed. "Although the procedure is *en vogue*, it has a questionable charm", says Kopinke, "because post-treatment, authorities normally test whether the target pollutant has been eliminated but not whether new ones have emerged."

The specifications for a new procedure were therefore clear: It should be target-specific and economic and not create new problems in solving old ones. "We have developed a procedure that is more resemblant of scattering bread crumbs than dropping a bomb", says Kopinke stressing perhaps the most crucial characteristic of Carbo-Iron: 'Environmental safety'. Carbo-Iron can remain in the groundwater reservoir after it has collected and destroyed chemical pollutants. It is completely harmless and poses no environmental risk. In fact, the components of Carbo-Iron also occur in nature (that is – almost), because the properties of activated carbon resemble the soot that is created for instance in forest fires.

The scientists working together with Frank-Dieter Kopinke have developed an efficient reagent without any harmful side effects. Because they produce Carbo-Iron themselves in the laboratory, the first field test using Carbo-Iron could recently be conducted in a contaminated groundwater reservoir. We will soon find out whether Carbo-Iron particles will become the tiny giants in water purification. Currently, industry is in the process of turning this innovation into 'state of the art'.

Michael Kraske

UFZ Contact person:

Prof. Dr. Frank-Dieter Kopinke
Dept. Head of Environmental Engineering

e-mail: **frank-dieter.kopinke@ufz.de**

Filter beds at the UFZ's test site Leuna. With the robust eco-tech process, groundwater is rid of benzene and MTBE that are normally mixed to premium fuel. (Photo: André Künzelmann, UFZ)

ECO-TECH IS HIGH-TECH

Dr. Manfred van Afferden is stood in front of a large gravel bed that is the size of a tennis court and squints up at the sun. Directly next to this bed is a second similar-looking bed that is planted with willows. "Their entwined penetrating roots enable better oxygenation", he explains as he looks over at the chemical park. What he sees, could not be more antithetical. There, set out on 1,300 hectares of land are smoking chimneys, industrial buildings and cooling towers: an ensemble that is more reminiscent of a garden allotment estate.

Something that comes very inconspicuously from there, is able to very efficiently solve a problem that has been a burning issue for Sachsen-Anhalt for a long time. The groundwater below the chemical industry site of Leuna is very contaminated and requires urgent treatment. Here, methyl tert-butyl ether (MTBE) and benzene are found in high concentrations in the groundwater – a relic from the GDR's oil industry as well as from even earlier times. For many years MTBE has been mixed to premium fuel as a replacement for organic lead compounds to increase its octane rating and thus the knock resistance of the engine. Up to 5,000 micrograms of chemicals that make drinking water unsafe were recorded in one litre of Leuna's groundwater. It doesn't look much better either for the carcinogenic benzene, where the threshold value for drinking water was exceeded by 15,000 times.

"Over recent years we have developed a new process for such contamination that copies the degradation processes in nature", says environmental biotechnologist Dr. van Afferden. The researchers can fetch the contaminated groundwater from depths of four to six meters up to the surface, where it is then trickled through special distribution systems inside the gravel beds. Some of the bacteria naturally occurring in the groundwater use benzene and MTBE as nutrition. Once at the surface, they become active and start to utilise the toxic substances. To be more precise, the two-stage eco-tech process works as follows: The first basin is a vertical filter, which is predominantly filled with coarse-grained expanded clay substances. Here it is above all iron that is precipitated, which would otherwise lead to the blocking of pipes, pumps and sensitive appliances. Furthermore, the plant is designed in such a way so that it does not allow limescale to settle – a great advantage compared to conventional chemical plants, where limescale deposits can incur very high operating and maintenance costs. In the second step of the process the groundwater passes through a filter, which is filled with a fine-grained substance and provides a large surface for micro-organisms to settle. An impressive 15,000 micrograms of benzene per litre are finally reduced here over only a few days to one microgram and 5,000 micrograms of MTBE to under ten micrograms per litre. These are concentrations that are below the threshold values that apply to safe drinking water.

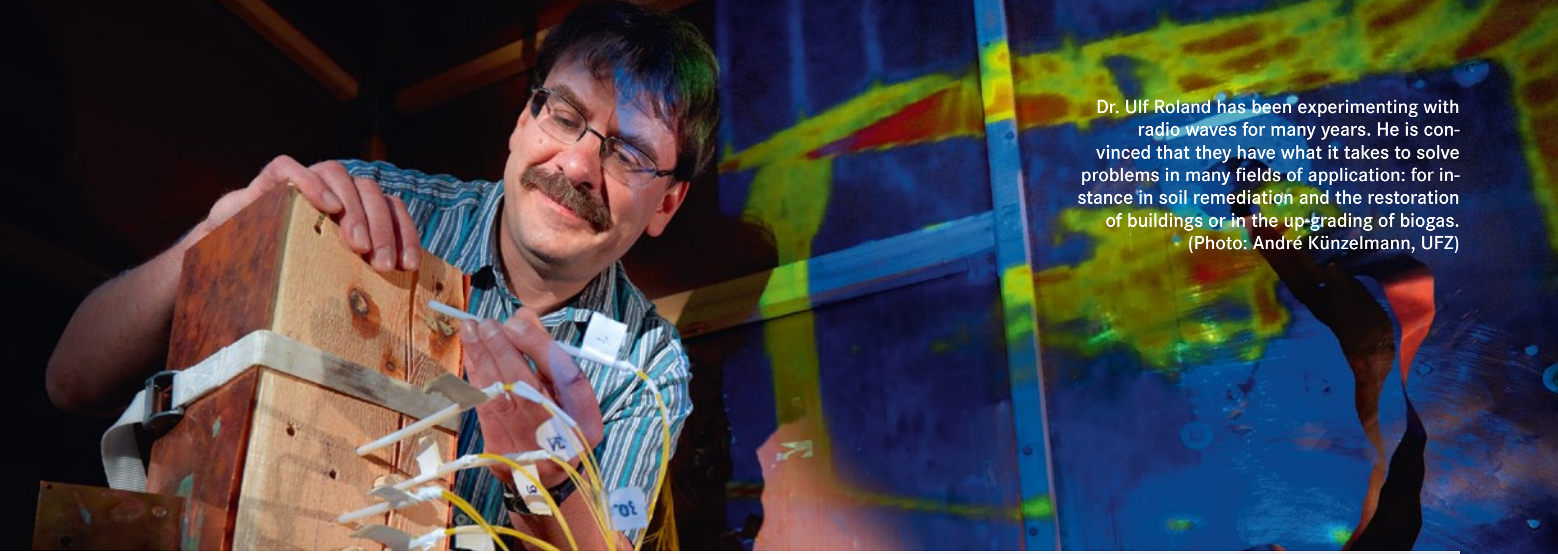
On the road to practical implementation however there were other hurdles that had to be overcome e.g. the procedural setting for winter temperatures. So that microbial degradation is not restrained by sub-zero temperatures, it should never be colder than 5 °C inside the filter. The solution is not an external heating like one might expect. Through a special operating control of the facility, the groundwater that is constantly kept "warm" at 8-10 °C is continuously pumped through the filters in such large quantities that even with outdoor temperatures of -20 °C, a cooling down below the critical threshold value can still be avoided. An integrated "discharged air filter", in which microorganism communities are the main actors, also prevents volatile pollutants from being emitted.

The company 'BAUER Umwelt' received the contract to build a pilot facility in Leuna. "Compared to the conventional high-tech plants this one here is very robust, requires little maintenance and is therefore much more economical. It even looks quite decent" says BAUER project manager Dr. Uwe Schlenker. If the plant proves its worth, additional filter beds will be built alongside of it. Today it is already further proof of the link between UFZ research and technological developments with active implementation on a technological scale. What is more: it represents an important milestone after many years of co-operation with the Regional Authority for Cleaning Contaminated Sites of the State of Saxony-Anhalt (LAF), without whose collaboration, the development of this process would not have been possible. *Annegret Faber*

UFZ Contact person:

- **Dr. Roland A. Müller,**
  Dr. Manfred van Afferden
  Dept. Center for Environmental Biotechnology (UBZ)

e-mail: **manfred.afferden@ufz.de**



Dr. Ulf Roland has been experimenting with radio waves for many years. He is convinced that they have what it takes to solve problems in many fields of application: for instance in soil remediation and the restoration of buildings or in the up-grading of biogas. (Photo: André Künzelmann, UFZ)

THE PERFECT WAVE

The remediation of soils contaminated with chemicals is still a complex issue. The easiest solution is just as expensive as it is demanding on resources: to excavate the soil with its hazardous substances and then dispose of it. It is a far more sophisticated approach to leave the soil at the site and to remove the contaminants during an *in situ* remediation without excavation. Conventional methods have been pushed to their limits however, because they are often not effective or universally applicable enough. This motivated physicist Dr. Ulf Roland some years ago to think about the alternatives. He realised that there was a pent-up demand, in particular for processes that could be used to specifically influence the soil temperature, as this is responsible for a whole range of physical-chemical parameters, which are essential for removing pollutants and for the effectiveness of microbiological degradation processes.

But which approach should he take? Heat injection lances, water vapour, electricity – everything had already been tried out and sometimes with only moderate success. Finally, he and his Leipzig colleagues were given the idea from the work of American scientists, who had been conducting research on shale oil extraction, to try out a special form of electromagnetic waves: radio waves. These work in the same way as a "kitchen microwave", but can penetrate much deeper into the substance due to their longer wavelength. Ulf Roland got to work in his research group carrying out experiments with radio waves and was able to prove in the laboratory that they bring together so many positive characteristics that could be perfectly suitable for the remediation of contaminated soils. Indeed, radio waves very effectively target the places that are to be warmed up and are therefore very energy-saving and economical. Unlike the microwave they work in practically all types of soils – whether dry or moist, sandy or silty. In addition, radio waves can warm up large volumes evenly, down to several meters in depth and over a wide temperature range from below 0 °C to above 400 °C. These characteristics open up a whole range of options for soil remediation. In this way for example, microbial degradation can be thermally supported (irrespective of the season) with an optimal 30 °C to 40 °C. Pollutants can be thermally desorbed at temperatures of up to 200 °C and sucked up afterwards by soil vapours. By contrast, at temperatures over 400 °C chemical reactions can be initiated that lead to the degradation of contaminants. The process has already found its way into practical implementation – even internationally. In Copenhagen for example it was tested on the premises of a dry-cleaning company, in order to eliminate chlorinated hydrocarbons. In London, highly-contaminated areas of an industrial site were remediated and in the British town of Manston, a fuel station with a mineral oil spill was cleaned up.

With the marketability of the process for soil remediation, research in this particular field has been completed – but not for the fields beyond it. "Radio waves have what it takes to solve problems in many fields of application", Ulf Roland is convinced, "and there is still a great need for research to be conducted". An enormous market is waiting to be tapped for example in the restoration of buildings: radio waves can be used for drying but also removing wood preservation agents or for the residues from fuel oil or for a chemical-free control of wood pests or dry rot. Besides they could enable different technological processes in industry to be designed more economically and more effectively for example in the heating of so-called packed beds. These are vessels used in chemical plants, through which air is cleaned and which so far have either been disposed of or regenerated energy-intensively. Radio waves could also be useful in the treatment of raw biogas, whereby water and carbon dioxide are removed in order to achieve a good quality equivalent to natural gas.

For Ulf Roland and his UFZ colleagues, a whole spectrum of opportunities has presented itself for the implementation of radio waves in environmental technology, which they are now already following up in the laboratory, in the pilot plant stations, or in applications together with partners in industry. The fact that they have been able to do this successfully can clearly be seen from the Kurt-Schwabe Award 2012, which they recently received from the Saxonian Academy of Sciences in Leipzig for their outstanding scientific and technical achievements. *Susanne Hufe*

UFZ Contact person:

- **Dr. Ulf Roland**
  Dept. Environmental Engineering

e-mail: **ulf.roland@ufz.de**

POINT OF VIEW: SUSTAINABLE USE OF RESOURCES MUST INCLUDE THE UNDERGROUND!

Photo: André Künzelmann, UFZ

Prof. Dr. Holger Weiß is head of the Department Groundwater Remediation at the UFZ. He studied geology at the Technical University of Clausthal and completed his PhD in the field of sedimentology, tectonics and the metamorphosis of iron ore deposits in Minas Gerais (Brazil).
His main focus of research is currently on the remediation of contaminated soils and groundwater as well as the use of underground storage for substances and energy.

e-mail: holger.weiss@ufz.de

The decision about an energy turnaround in Germany starting with giving up the use of nuclear energy and increasingly switching from fossil fuels to renewable energy sources represents an enormous challenge for both research and society. It is an obvious fact that the use of renewable energy sources does not meet the sustainability requirement per se, but rather urgently requires a scientific analysis of the impacts on the living and the inanimate environment in advance.

Discussions on the sustainable use of resources have so far concentrated on those aspects of the environment that people are more conscious about i.e. water, soil, air, and sometimes landscapes and the climate. This is also reflected in the respective legislation as these environmental compartments are deemed worthy of protection under extensive laws and statutory instruments. However, as soon as one delves beyond these (not only in the figurative sense) into the depths of the geological underground, one realises that information about the impacts of its use and any comparative regulations of such are simply lacking.

The geological underground has already been used for a long time to extract minerals, mineral oil and natural gas, to generate energy directly or to store substances either temporarily or permanently. As a direct consequence of the energy turnaround, competing claims among interest groups for using the underground will increase to such an extent, making it imperative to carry out impact assessments not only from a natural science and technological perspective but also from a socio-economic perspective. Even beyond all aspects of public perception, participation and acceptance, it must be stated that there are substantial gaps in our knowledge about the impacts of an intensified underground use on geological systems and ecosystems as well as deficits in regulating these developments.

Currently, it is the booming exploration of the non-conventional natural gas reserves ("shale gas") that have particularly led to some rather heated discussions. Here, cracks are made in rock in order to create sufficient gas pathways, which is carried out by implementing suitable liquids under high pressures (a process known as "fracking").
These liquids contain a number of chemicals that are considered to be rather problematic under aspects of water protection. There are inherent risks to groundwater reserves worthy of protection as a result of potential hydraulic bypasses between the deep natural gas horizons or as a result of technical defects with drillings. This does not only refer to the use of these fluids, but also to their disposal. In spite of preliminary scientific analyses and assessments of environmental compatibility and safety, a comprehensive (material) risk assessment of these combined substances is still pending. The intentional implementation of combinations of hazardous substances in the environment as is the case with fracking, makes it evident that a framework is urgently required to protect groundwater from the dangers of the underground.

The geological underground is not only stressed however by the prospecting and exploitation of shale gas: the necessity for the storage of intermittently-produced energy (i.e. from wind/ solar power) will occur in the form of substance storage. Compressed air, hydrogen, synthetic gas, methane, all of these will have to be increasingly (temporarily) stored in underground caverns.

The (necessary) use of underground repositories for nuclear waste storage is another area in which a lack of social consensus and a lacking legal framework hinder much needed R&D activities. In this respect one is reminded of the failure of the CCS legislation.

Finally, geological reservoirs are being used to a rapidly increasing extent to directly produce energy or to store energy produced from renewable sources. A lack of scientific insights and (also) the legal authorisation restrictions normally based on these currently limit the feasible temperature range for the thermal utilisation of groundwater to below 10 °C and therefore to a range that is not very effective from an energy perspective.

The geological underground has tremendous potential for use. It is therefore imperative to recognize and to weigh up the risks that are inevitably connected with competing claims among interest groups – not only in terms of their technological feasibility. Spatial planning must finally encompass the third dimension: the geological underground. It is only in this way, by balancing all competing claims among interest groups and by considering protection entitlements that a truly sustainable use of our resources will be possible.

Dr. Christoph Ewen is the owner-manager of “team ewen”, a company founded in Darmstadt in 2003, which specializes in conflict and process management in the public arena. Its references range from the organization of round tables to the moderation, mediation and leading of dialogue processes on the most diverse topics in industry and nature protection as well as town and country planning. Together with the company Hammerbacher GmbH Osnabrück, “team ewen” facilitated the information and dialogue process on fracking from March 2011 to April 2012. (Photo: Jürgen Mai)

“THE PUBLIC DEBATE NEEDS CREDIBLE STATEMENTS FROM EXPERTS”

Full of vehemence, the citizens of our country are demanding a stronger say in social and politically relevant projects as can be seen from the violent protests and discussions concerning railway projects, biogas plants, wind parks, power lines or geothermal energy. How do you explain this wave of public outrage?
I can’t make any empirically founded statement about it but only describe my own perception: I personally feel that it is a combination of uncertainty (what will it imply for me, for my surroundings, for my health?) and emancipation (I won’t let it happen right under my nose!). Interestingly, the polls show that those citizens who are not directly affected by a particular issue have a lot of empathy for those who are affected and who object to such facilities – even when these are meaningful or necessary for the public at large. It has also got something to do with satiety: The economy is running alright, electricity is available and the landscape is already fully utilised – why do we need more?

You have specialized in solving such conflicts in the public arena. How?
I try to avoid the word “solving”, because we do not actually solve conflicts, but rather support the decision-making processes that are inherent in our democracy. We do this by attempting to steer destructive forms of conflicts into more constructive ones. We try to make dialogues possible again, where the discussion thread has been torn or lost completely and by helping to develop a neutral position (“third party”) from which a rationalization of debates becomes possible. One prerequisite for this is that complex circumstances are understood and can be structured. Not everything that project critics come up with holds water. Some points can indeed be objectified i.e.: How strong are the vibrations from geothermal energy? How loud are wind turbines? It really comes down to switching from the arbitrary statements that are ‘for’ and ‘against’ in the public debate to credible statements from experts.

Just how sustainable are the results and how binding are they for the conflicting parties and for official decisions?
One must really differentiate between the results obtained from dialogue (for instance the round table recommendation to the Werra or to the airport mediation in Frankfurt) and long-term social developments. Not every dialogue process ends with a result and even if there are results, they rarely become mandatory. The regulatory authorities are not allowed to adopt the results from informal negotiation groups, but there is a *de facto* virtue, which is more effective, the greater the above described rationalization effect works on the public discourse.

Which role does science play in all of this and how has it changed over recent years?
Since the 1960s a process of creeping secularisation of science can be observed. There are expert opinions and second opinions, there are bought experts and so-called experts. In addition, the proportion of people with academic training has increased substantially – it is no longer difficult to find someone with a degree in the proximity of a disputed facility, who is able to interpret results and appraise expert reports. Interestingly enough there is nevertheless still the desire to find out the objective scientific truth. I often see how confused and helpless people seem when they experience a conflict of opinions among scientists. Considering the obligatory set of rules and criteria for scientists to follow about what is a scientifically correct approach to factual questions, one would expect different experts to come up with similar answers. My experience is to get consultants and specialists with a second opinion to formulate a common appraisal and to prevent these two from meeting in public against each other – then you will contribute to a more constructive handling of the conflict.

If we take a current example where a set of UFZ experts were involved – the discourse about the safety and environmental compatibility of fracking technology for natural gas production. How did the one-year dialogue go that has just ended?
At the beginning ExxonMobil wanted to scientifically invalidate the allegations against fracking. As process facilitator, I together with my colleague Ruth Hammerbacher advised ExxonMobil and got them to change their approach. It changed from “invalidation” to a common scientific search. It was important for us not to involve those scientists that normally work in the oil and gas

industry, but to look for a circle of experts who were impartial about the subject matter and yet intrigued by it. We then worked on three levels: The neutral circle of experts started an intensive interdisciplinary cognitive process. For many of the experts it was unusual how often we called them together and what intensive discussions we had between the specialist disciplines. However by the time that we all travelled to the USA together at the end of the project to take a look at fracking in practice and were able to exchange opinions with relevant stakeholders, the experts acknowledged just how much they appreciated this nevertheless very time-consuming way of working. On a second level we called together a circle of stakeholders from the municipalities, water companies and associations (the authorities participated as guest observers). The neutral circle of experts put its approaches and intermediate results up to debate and received many valuable suggestions and constructive criticism. Finally, the third level was the public, whose questions we collected and worked on and opened up for discussion via a website and meetings (www.dialog-erdgasundfrac.de).

The interesting thing is that through this intensive communication within the circle of experts, with stakeholders and the public, the focus was gradually extended. We appointed more experts to carry out appraisals over the course of the work on issues such as wastewater and matter flow, on land consumption and on the climate.

FRACKING

Induced hydraulic fracturing - commonly known as "fracking" refers to the technique used to make cracks deep underground to facilitate the release of gases or liquids in reservoir rock formations for extraction. Fracking has been used in Germany for approx. 50 years to enable a more 'economic' extraction of oil and natural gas. The current debate on fracking broke out above all because of the intention to use the technology for the extraction of coal bed gas and shale gas in unconventional reservoirs, in which the gas is fixed in the rock in such a way that it cannot be released to the bore hole without external impacts.

Step by step we worked out that it was not so much the fracking itself, but rather the large-scale implementation of this technology that poses the real problem. In the end we presented the results at a two-day conference in Berlin where we were able to discuss the findings with internationally-renowned reviewers. After that another revision loop followed in order to consider their comments, and then the results were presented in the region – together with a clear recommendation from the experts. In short the recommendation was: an analysis of the risks does not make it possible to generally prohibit fracking. However there are numerous indications of serious dangers and therefore one should proceed carefully: Demonstration projects should enable any open questions to be answered and local risk assessments to be made. Furthermore, the entire process should be accompanied by an intensive dialogue and a further development of the legal basic conditions.

A crucial aspect for the effectiveness of this process was to gain the cooperation of ExxonMobil. Without the absolute openness of the company regarding many of our questions, we wouldn't have got very far. The company also committed itself from the very onset that it would apply the recommendations – the chairman of the board affirmed this again at the end of the process. From observation I can honestly say that the information and dialogue process on fracking technology has led to considerable changes in the enterprise. Although we had been looked upon with reservation at first by some departments of the enterprise, I now have the feeling that the enterprise has understood how important it is to do some things differently. This requires transparency, the willingness to enter into dialogue (also with critics), and the willingness to include scientists other than those from the mining universities.

Did the fact that ExxonMobil was the contractor have a negative impact on the credibility of the results?
First and foremost one has to look at the history of this case: Natural gas extraction in Lower Saxony had a high acceptance among the locals in the past. Mining authorities and enterprises of the oil and gas industry had uncomplicated dealings with one another. That all changed, when new regions came under focus for exploration with fracking technology, where until now no oil or gas industry or any other environmentally-intensive industry had previously been active. While the public stance was sorting itself out, ExxonMobil "tackled the problem head on" and placed its hopes on transparency and dialogue. The neutral circle of experts received funding from ExxonMobil in order to conduct a risk assessment of fracking.

Even if it didn't reach the really critical stakeholders, who still sense 'greenwashing', the circle of experts gained a lot of credibility in the professional world and with many professional stakeholders. As far as I am concerned the reasons for this can be found at several levels: First it is down to the selection of experts. None of the experts had ever worked in the oil and gas industry and some of them are rather well-known for their positions in industry. Take Prof. Alexander Roßnagel for example who was a legal facilitator of the federal government in the nuclear phase-out or Dr. Hans-Joachim Uth as former hazardous incident expert of the Federal Environmental Agency or Uwe Fritsche as an employee of the Ecological Institute. Secondly, there is the peer review process with internationally renowned scientists, which is very uncommon in this kind of contract research. Then there is also the construct, which guarantees that ExxonMobil provides the funding, while the scientific head Prof. Dietrich Borchardt from the UFZ is responsible for allocating the funds.

Despite the recommendation of the expert commission to test the procedure in a pilot project, it was rejected by the federal county governments of Lower Saxony and North-Rhine/Westphalia. Does this mean that dialogue has failed?
The federal county state of North-Rhine/Westphalia still rejects fracking on the whole, whereas the federal county state of Lower Saxony rather favours natural gas as before. As addressed above, such dialogues do not normally change the positions of the stakeholders, but they do lead to greater reflection and the willingness to take the arguments from the opposite side more seriously. The consultants, who are now assessing the risks of fracking on behalf of the Federal Ministry of the Environment and the county of North-Rhine/Westphalia, will now have to deal with the risk assessment from the circle of experts, by which time Exxon will have already implemented the first recommendations. From a medium-term point of view this will defuse the conflict and make solutions possible.

The interview was held by Susanne Hufe

INTERESTING FACTS ABOUT THE CHEMICAL INDUSTRY AND CHEMICALS

CHEMICAL ELEMENTS

There are 94 naturally-occurring chemical elements and 20 artificially-produced ones. Each element has a specific weight and special characteristic properties.

There are 57 elements in the human body. The element oxygen accounts for the largest proportion of the total weight of humans with approx. 60 percent.

CHEMISTRY

Chemistry is a natural science that investigates the structure, the characteristic properties and the conversion of substances (elements and compounds). It started off as a pure natural science in the 17th and 18th centuries. Antoine de Lavoisier (1743-1794) is known as the father of modern chemistry. Through measurements, observations and experiments he founded modern chemistry and among other things he introduced the chemical nomenclature as a systematic method for naming substances.

THE CHEMICAL INDUSTRY


Photo: © Tom Bayer / Fotolia.com

Accounting for more than 10 percent of Germany's total turnover in the processing trade, the chemical industry ranks fourth after the automobile-, mechanical engineering and electronics industry. Germany belongs to one of the leading export nations for chemicals in the world with more than 50 percent of its chemical products being exported. Approx. 500,000 people are currently employed in about 2,000 chemical companies in Germany. The most important products are both inorganic- and organic chemicals, fertilizers, plastics, varnishes, pharmaceuticals and pesticides as well as adhesives and dyes, textiles, paper, photo-chemical products, cosmetics, preservatives and explosives. Electric mobility has been a growth engine of the chemical industry, for which large batteries, catalysers, electrolytes, innovative lightweight but strong plastics and carbon fibres are needed, as well as solar energy and photovoltaic energy. *(sources: Verband der Chemischen Industrie e. V. and Manager Magazin online)*

GLOSSARY OF CHEMICALS IN THE ENVIRONMENT

Chlorine. This element with the atomic number 17 makes it to number 1 at the top of the hit list of pollutants. Many carbon-containing (and thus organic) products of chlorine chemistry are highly toxic and not very degradable. In nature there are also numerous organic chlorine compounds, where they are useful for killing microbes or act as semiochemicals for plants.

DDT – Dichlordiphenyltrichlorethane. This widely effective insecticide is both a contact and stomach poison and has been prohibited in Germany since 1974.

CFC's – Chlorofluorocarbons. CFC's were celebrated in the 1920's and 1930's as completely non-toxic compounds. They replaced flammable cooling agents in air conditioning systems and refrigerators, and were used in solvents and cleaning agents as well as for propellant gases, for foamed insulating materials and spray cans. It was only 50 years later on that their drawback was revealed: CFC's contribute to the destruction of the ozone layer in the stratosphere. Consequently they were outlawed and prohibited at the beginning of the 1990's.

Metabolism. This is the entirety of all chemical processes in an organism, which ensure that substances are converted in the process of uptake and transport and ultimately transferred to the environment as metabolic end-products.

PAH – Polynuclear aromatic hydrocarbons. These partially carcinogenic substances that accumulate in fatty tissue occur in soot and tar. They are also formed when fat is burnt e.g. with barbecued meat.

Pathogens – microorganisms and substances that cause diseases. When humans are affected one speaks of human pathogens, whereas when plants are affected one refers to phytopathogens.

PBT's – Persistent, bioaccumulative and toxic substances. PBT's are considered to be particularly dangerous chemicals due to the fact that they break down very slowly in organisms or in the environment (they are persistent), that they accumulate in the food chain (they are bioaccumulative) and that they are dangerous (toxic).

THE AUTHORITIES

UBA – The Federal Environment Agency. The UBA is Germany's central federal authority on environmental matters. Its most important statutory mandates are providing scientific support to the Federal Government (among others the Federal Ministries for Environment; Health; Research), implementing environmental laws (e.g. emissions trading, authorisation of chemicals, pharmaceuticals, and plant protection agents) as well as informing the public about environmental protection.

ECHA – European Chemicals Agency. The ECHA is an authority of the European Union with 500 employees and its headquarters in Helsinki in Finland. It is the central nerve center for REACH, which regulates the technical, scientific and administrative aspects for the registration, assessment and authorisation of chemicals.

CHEMICALS

More than **60 million** chemicals are known world-wide.

In 1930 ca. **1 million tons** of chemicals were produced, whereas today it is well over **400 million tons**.

In Europe about **100,000** synthetically produced **substances** are traded and in use, of which there are almost **2,500 chemicals** in quantities of more than **1,000 tons** per year.

Photo: © bluedesign / Fotolia.com

EU DIRECTIVES ON THE PROSPECTIVE AND ENVIRONMENTAL QUALITY ORIENTED REGULATION OF CHEMICALS (SELECTED EXAMPLES)

REACH – Registration, Evaluation, Authorisation and Restriction of Chemicals.
According to REACH from 1st June 2008 producers and importers that produce or import more than one ton of a chemical per year, must register these with the ECHA and provide information about any potential adverse effects. For those chemicals that were on the market before 1981, transition periods apply. Otherwise the rule applies "no data no market" – without prior registration, a new chemical may not be marketed.

CLP – Classification, Labelling, Packaging. With this regulation a new system was introduced throughout Europe in 2009 for the classification, labelling and packaging of substances and mixtures.

The Biocidal Products Directive. With this legislation that entered into force in 1998 biocidal products are assessed and authorised. This ensures a high level of protection for both human health and the environment. Since 2003 it has been mandatory to authorise all biocidal products. The directive was amended in 2009.

Directive on the sustainable use of pesticides.
In 2009 the European Union adopted a new framework directive on pesticides. The new authorisation regulation prohibits the use of particularly hazardous active substances in plant protection products.

WFD – The European Water Framework Directive.
With the European Water Framework Directive that entered into force in December 2000 a uniform legal framework was created for an integrated water protection policy within the European Union with the goal of aligning water policies more strongly to a sustainable and environmentally compatible water usage. In 2006 the **Groundwater Framework** was adopted as a requirement of the WFD. It specifies additional measures to protect groundwater against pollution in order to work against the deterioration of the condition of all groundwater bodies.

Pesticides – chemicals that are used in agriculture to combat undesired organisms. These can be subdivided further depending on their target organisms e.g. into bactericides, fungicides, insecticides, herbicides, etc. In the non-agrarian sector they are referred to as biocides.

POPs – Persistent Organic Pollutants. They have an extremely long lifetime and are very persistent. Since 2001 there has been an internationally valid, legal fundament for a world-wide ban on the production and use of twelve POPs (the dirty dozen). There are nine pesticides among the dirty dozen (including DDT), two industrial chemicals – among others polychlorinated biphenyls (PCBs) and two chemicals that are produced unintentionally in combustion processes (dioxin and furan).

PVC – Polyvinyl chloride. This plastic is very disputed, because although it can be produced inexpensively and it has a very wide application, there are problems with its disposal. In fire accidents, it is not only carbon dioxide and water that are produced, but also hydrogen chloride (HCl) and highly toxic dioxins. Furthermore, old PVC often contains cadmium or lead compounds as stabilizers or PCB (polychlorinated biphenyls) as plasticisers.

Toxin – poison of a biological nature. Mould fungi for example produce mycotoxins (fungal mould toxins). An illness caused by mycotoxins is called mycotoxicosis.

Xenobiotics. Man-made, unnatural chemical compounds.

RESEARCH FOR THE ENVIRONMENT

As an international competence center for environmental sciences, the **Helmholtz Centre for Environmental Research – UFZ** investigates complex human-environment interactions under the influence of global change. In close cooperation with decision-makers and representatives of civil society, scientists at the UFZ come up with system solutions to improve the management of complex ecosystems and to tackle environmental issues.

The Helmholtz researchers work on the management of water resources and the impacts of land use change on biodiversity and ecosystem services. They develop remediation strategies and monitoring- and exploration techniques for contaminated ground and surface waters, soils and sediments. They investigate the behaviour and effect of chemicals in the environment and on our health and work on models that predict environmental changes as well as on adaptation strategies to climate change.

Solving these tasks not only requires a solid scientific foundation, but also calls for environmental research that is traditionally dominated by the natural sciences to be increasingly more linked to the human sciences, social sciences and law.

Environmental research should be guided by environmental issues and learn to deal with complex issues, uncertainty and matters that are closely related to practice. This calls for an exchange of knowledge, understanding and compromise, the bringing together of different competences and specialisations and an involvement of decision-makers and stakeholders from the economy, politics and the public – in other words a very high level of integration.

The goal is to chart a path forward that keeps the balance between economic and societal development on the one hand and the long-term protection of our natural resources on the other.

The UFZ is a member of the Helmholtz Association and has approx. 1,100 employees at its locations in Leipzig, Halle and Magdeburg. It has an annual budget of around 100 million Euros (state funding and third-party funding). 90 percent of the state funding comes from the federal government, while 5 percent comes from the State of Saxony and 5 percent comes from the State of Saxony-Anhalt. **www.ufz.de**

THE HELMHOLTZ ASSOCIATION

The **Helmholtz Association** contributes to finding solutions for large and pressing issues in society, science and the economy through excellence in the following 6 areas of research: energy, earth and the environment, health, key technologies, structure of matter, transport and aerospace. With over 31,000 employees in 17 research centres and with an annual budget of approx. 3.3 billion Euros the Helmholtz Association is the largest scientific organisation in Germany. Work is conducted in the tradition of the renowned biologist Hermann von Helmholtz (1821-1894). **www.helmholtz.de**

UFZ premises in Leipzig, Permoserstraße 15

UFZ premises in Halle, Theodor-Lieser-Straße 4

UFZ premises in Magdeburg, Brückstraße 3a

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Public Relations Department
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phone: +49 (0) 341 / 235-1269 · fax: +49 (0) 341 / 235-1468
e-mail: info@ufz.de · web: www.ufz.de

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