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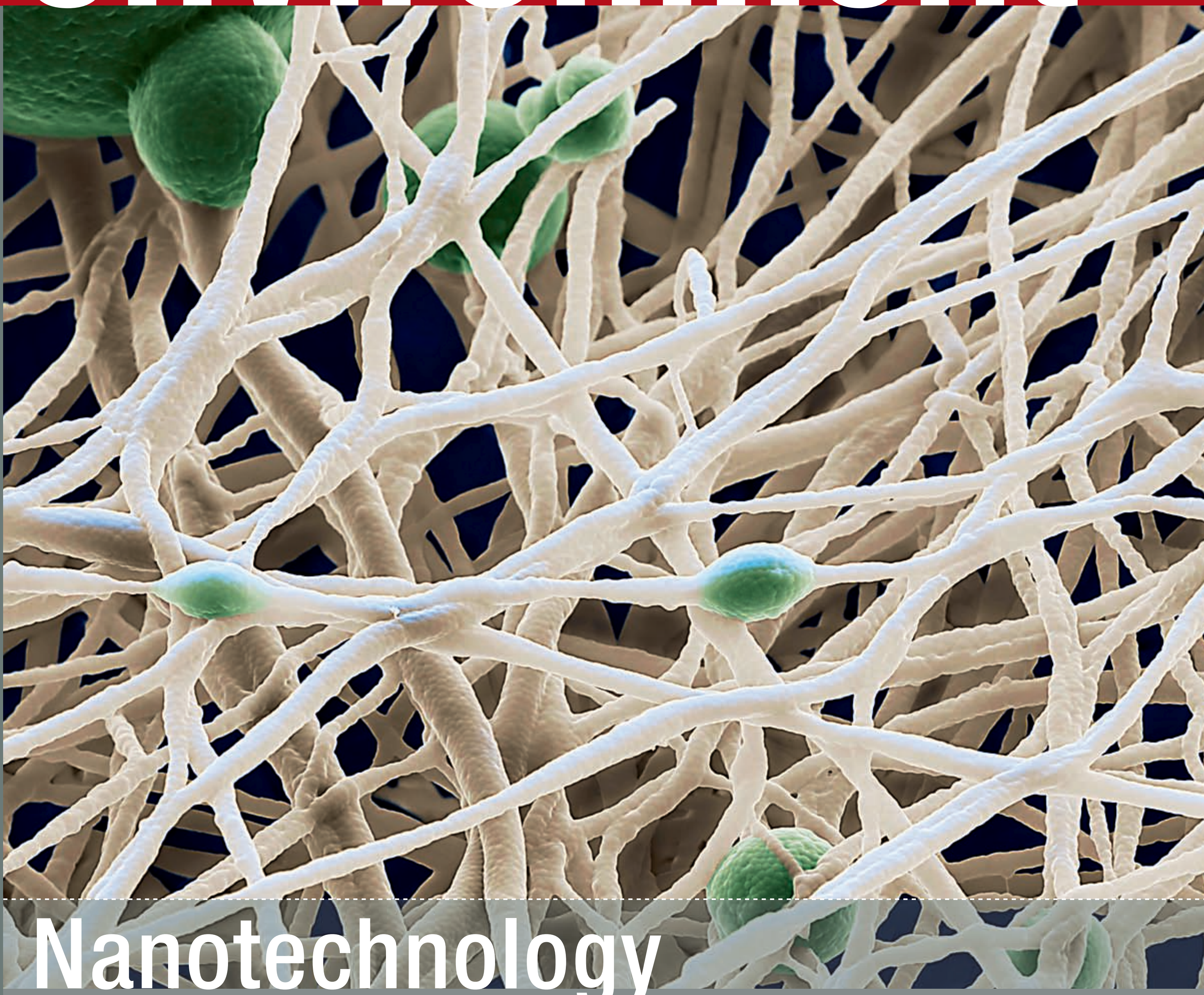
Natural resources in Switzerland

environment



Nanotechnology

Exploiting opportunities and remaining aware of risks > Minute particles with huge potential > Bright future for solar energy > Nanotechnology for clean drinking water > Still many unknowns > Nanomedicine in focus

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Nanofibres composed of a fine synthetic fibre are frequently used in composite materials with antistatic properties and integrated UV protection. Approximate 33 000-fold magnification under a scanning electron microscope.

Photo: Keystone / Science Photo Library

> Good to know

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In the area of nanotechnology, the federal government wants to establish a culture of caution in which all conceivable risks to health and the environment are minimised as far as possible.
Photo: Suva media service

Exploiting opportunities and remaining aware of risks

Nanotechnology offers Switzerland's economy and society a multitude of opportunities that need to be put to use in the interests of the country as a whole. Specialists at Swiss universities and many private-sector companies are working to unlock the secrets of this ultra-miniature world and are achieving technological developments that give us good grounds to be optimistic for the future, especially in the area of environmental protection. For example, they are researching and producing low-cost solar cells with a higher degree of efficiency, better batteries, extremely fine filters for water treatment, lighter materials and products with a lengthier useful life. Nanotechnology thus opens up many possibilities for using energy and resources less wastefully and for reducing environmental pollution.

Alongside the undisputed opportunities associated with nanotechnology, the production and manipulation of nanomaterials also entail risks that have not yet been exhaustively identified. It is therefore too early for comprehensive state regulations to be formulated. However, the federal government requires that all involved players must act in full awareness of the potential hazards. Our goal is to promote a precautionary risk culture in which all conceivable risks to health and the environment are minimised as far as possible. Conscientiously exercising the precautionary principle as called for by the Federal Environmental Protection Act, and practising operational responsibility will allow the potential risks to be identified at a sufficiently early stage, thus avoiding undesirable consequences and investment losses.

Switzerland is not acting alone in the areas of risk research, hazard assessment and risk management, but is co-ordinating its efforts with those of the international community, both at the UN level and within the Organisation for Economic Co-operation and Development (OECD). The resulting findings, advances and precautionary measures are also being placed at the disposal of developing countries and countries with economies in transition.

Bruno Oberle
Director of the FOEN

www.environment-switzerland.ch/mag2010-3-01

Minute particles with huge potential

Which nanomaterials are most common today, what are their specific properties and in which areas are they used? Here we provide an overview of eight of the most important materials used in nanotechnology.

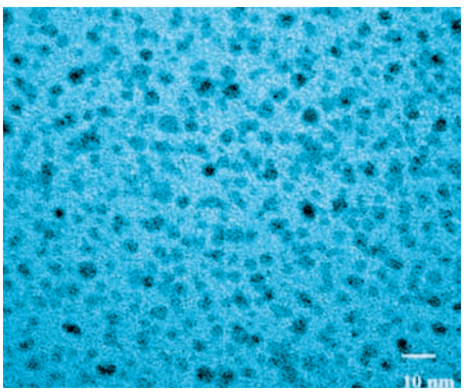
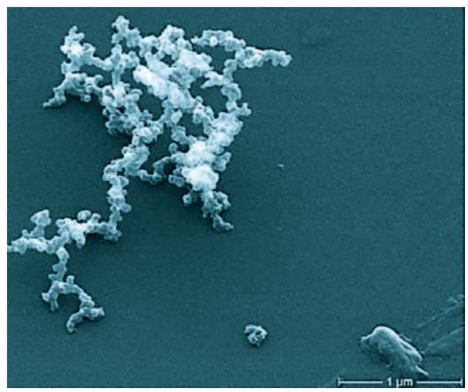


Photo: Empa



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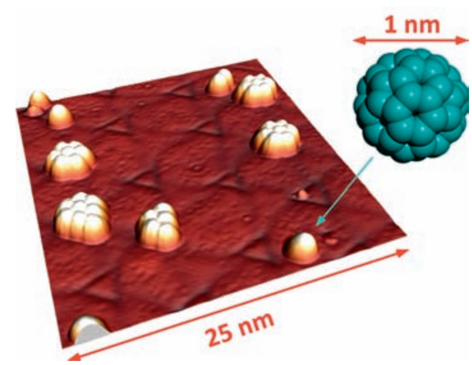


Photo: Empa

Nanosilver

The antibacterial effect of silver has been known for thousands of years, and today this property of silver is being used in the form of nanoparticles to an ever increasing extent. For example, nanosilver is used in medical products such as plasters and bandages in order to destroy harmful bacteria. Nanosilver coatings are also used in order to ensure that computer keys, door handles, painted surfaces, etc., are kept free of bacteria. Nanosilver is added to hygiene articles such as special soaps and detergents and is processed into textiles, e.g. socks, to prevent the unpleasant smells caused by the bacteria responsible for breaking down sweat. However, when these clothes are washed, some nanoparticles find their way into sewage treatment plants and bodies of water where their antibacterial effect is unwelcome.

Soot particles

Soot particles represent one of the first man-made nanomaterials. Soot produced industrially under controlled conditions is primarily used as an additive in rubber goods such as car tyres, but also as a black pigment for paints and lacquers, as an antistatic additive in plastics, and as a material for electrodes. However, large quantities of soot nanoparticles also escape into the environment under uncontrolled conditions, such as from incomplete combustion of fuels in furnaces, vehicle motors and machines. These fragmented particles consist of elementary carbon to which organic substances and metal compounds adhere. Fine and ultra-fine soot particles are harmful to human beings and animals because they can enter the lungs and circulation via the respiratory system, where they can give rise to chronic inflammation such as asthma, result in cardiovascular disease and, depending on their chemical composition, also cause cancer.

Buckminster fullerene

Like carbon nanotubes (see page 7), Buckminster fullerene (C60) is a pure carbon molecule. Its spherical structure consists of 60 carbon atoms and resembles a football. Due to high production costs, limited availability and largely unknown health risks, there are as yet not very many uses for these nanoparticles. However, researchers are examining a variety of potential applications, e.g. as semiconductors, superconductors, catalytic converters, lubricants, cancer medicaments and antioxidants in cosmetics and in the production of artificial diamonds and ultra-light synthetics. Research is also being conducted on metallofullerenes, in which metal atoms are encapsulated inside a fullerene (carbon) cage, with the hope of discovering unique electronic properties that could be used for data storage media in the nano range.

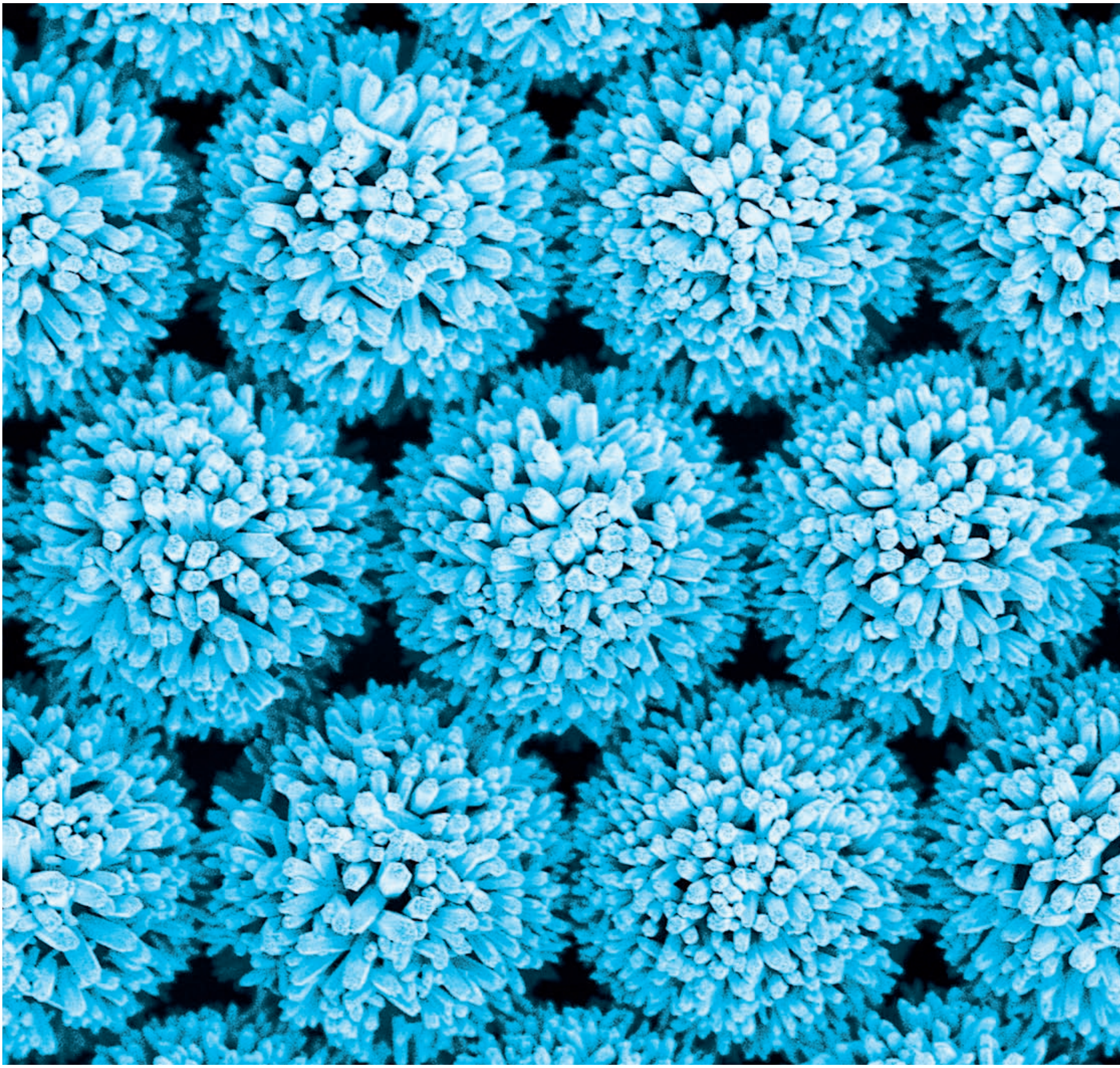
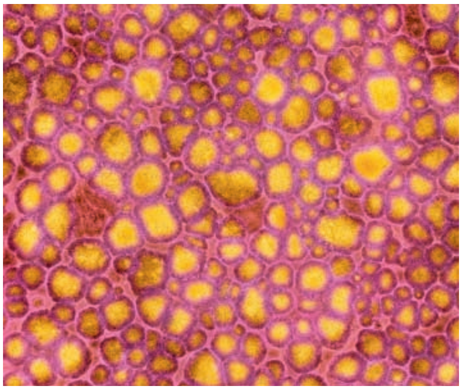


Photo: Empa

Zinc oxide

Zinc oxide (ZnO) is the second most frequently used nanosubstance and, like titanium dioxide, it is a direct semiconductor. The electronics industry, for example, takes advantage of the very high transparency in the visible spectrum of conductive ZnO nanocoatings in the production of blue light-emitting diodes (LEDs), liquid crystal displays and thin-film solar cells. Because extremely thin zinc oxide coatings reflect and disperse sunlight, a great deal more light reaches the silicon layers of solar cells, thus increasing their efficiency. Since ZnO nanoparticles efficiently absorb ultraviolet radiation from the sun, they are also used for long-term protection of surfaces, e.g. in lacquers. Sun creams containing zinc oxide provide higher protection factors, since nanoparticles reflect the sun's rays like tiny mirrors, without penetrating healthy skin cells.



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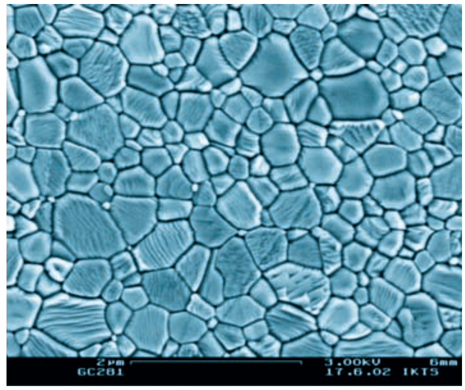


Photo: A. Krell, Fraunhofer IKTS Dresden

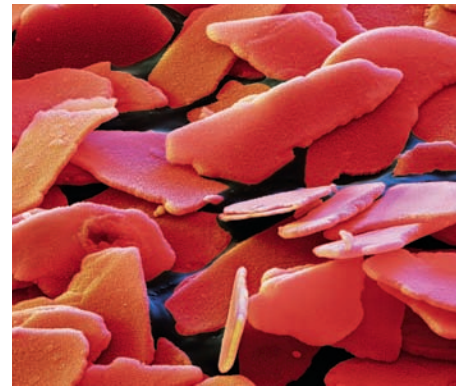


Photo: BASF

Liposomes

Liposomes are spherical arrangements of fat-like substances with surface-active molecules that are formed from one or more double layers. They can encapsulate compounds that are soluble in water or fat, such as sensitive proteins. In the field of medicine, efforts are being made to use nano-sized liposomes for the targeted delivery of encapsulated medicaments intended for specific parts of the body. If, for example, bioactive substances such as chemotherapeutic agents for the treatment of cancer were to only attack tumour cells, this would help reduce undesirable side effects. Furthermore, the liposome capsule offers camouflage against the immune system, which significantly prolongs the time for active substances to accumulate in the targeted region. Permeability can be controlled via an external stimulus such as an electromagnetic field. Liposomes are also used as carriers for vitamins, minerals, proteins and flavours in functional foods and cosmetics.

Aluminium oxide

When added to paints and lacquers, various aluminium oxides such as boehmite help make treated surfaces more resistant to scratches and abrasion. However, particles in the micrometre range make the coating duller, less transparent and less flexible. Aluminium oxide nanoparticles do not have these drawbacks, but still increase resistance to scratching, making them particularly suited for use in coatings for timber, furniture, industrial applications and motor vehicles. They also enhance the glossiness and colour intensity of printing paper. Aluminium oxides optimise the electrostatic properties of printing ink in copying technology. They are also used as thin interior coatings in the foodstuffs packaging industry, for example to reduce permeability to gases and flavours of PET beer bottles and foil-sealed packages, thus extending the product life. Other advantages include greater packaging strength and heat resistance.

Titanium dioxide

With an annual global production of several thousand tonnes, titanium dioxide (TiO_2) is by far the most frequently used metallic nanomaterial. This metal oxide, which also occurs naturally in soils, is used in particular for smoothing rough surfaces by coating their pores, for example in order to prevent penetration by pollutants. This application is especially interesting for buildings in which high levels of hygiene are required, e.g. hospitals, laboratories and food processing operations. TiO_2 nanoparticles also have photocatalytic properties and are therefore used in paints, lacquers and plasters for self-cleaning facades – soiling, odours and bacteria are degraded through the action of light. In cosmetics such as sun creams, these particles help protect the skin against harmful ultraviolet rays from the sun. TiO_2 is also used in the production of dye-sensitised solar cells, for the growth of artificial bones and as a component of catalytic converters for eliminating nitrogen from exhaust gases.

Compiled by Beat Jordi

www.environment-switzerland.ch/mag2010-3-02

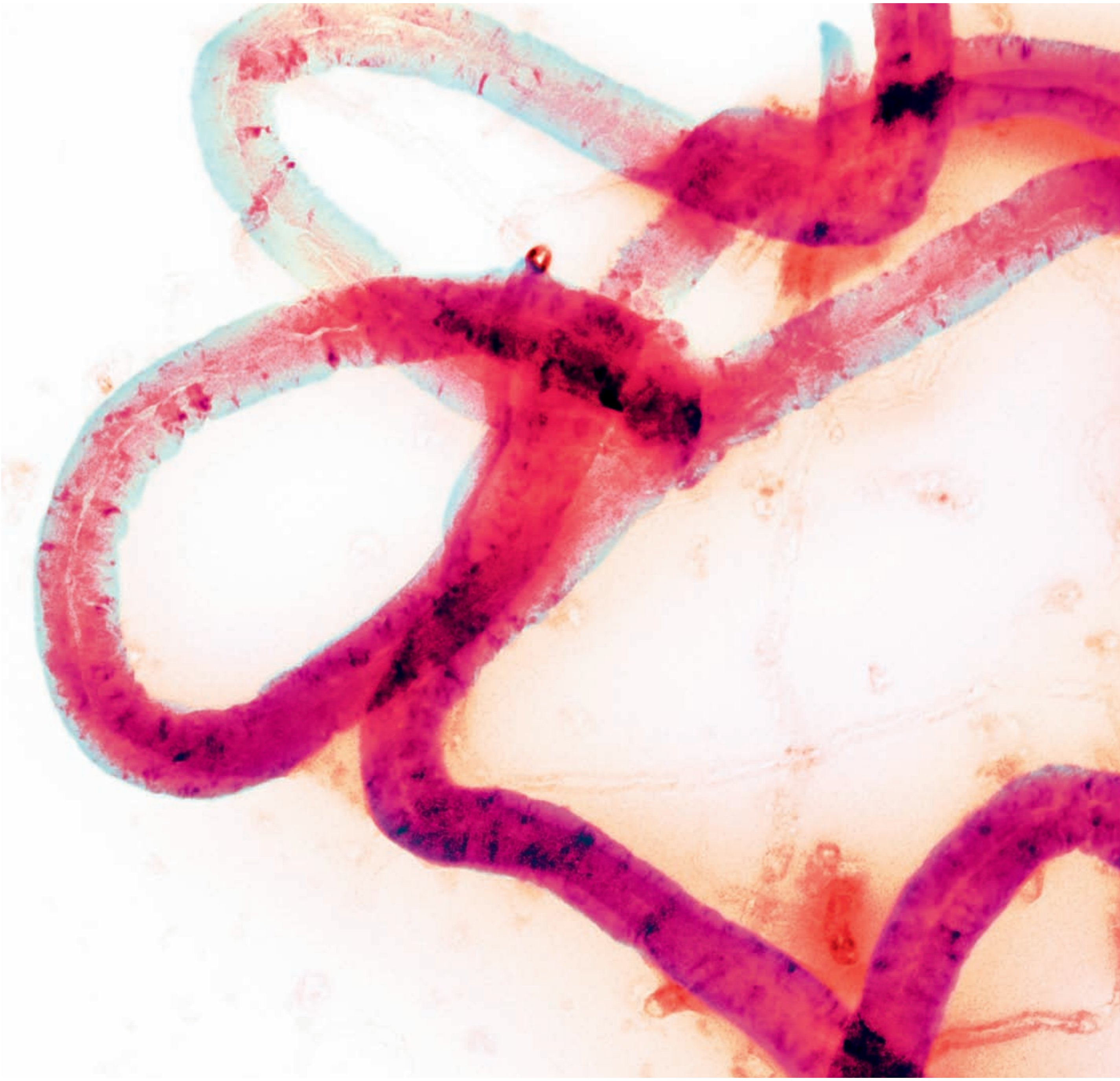


Photo: Keystone

Carbon nanotubes

Carbon nanotubes have a honeycombed structure similar to that of graphite, which can comprise several layers. They attain lengths of a few millimetres, are very elastic, extremely robust and have up to 50 times the tensile strength of steel. When used in combination with conventional plastics they improve their mechanical properties. They are used for producing light yet strong bicycle frames, hockey sticks, tennis rackets, etc. They are also suitable for producing very dark surfaces, which means they are of interest for manufacturing solar collectors with a high light-absorbing capacity and for screening out radio waves in a broad frequency range. Depending on their structure, nanotubes can function as insulators, semiconductors or as metallic conductors. The electronics industry intends to make greater use of these functions in new types of transistors, storage systems, diodes, displays, etc. Carbon nanotubes are widely used as a means of enhancing the performance of lithium batteries. In addition, they are used as probes in scanning tunnelling microscopes to improve performance and image resolution.

"Switzerland has carried out pioneer work"

"In the use of nanotechnology, Switzerland has struck a good balance between courageously leading the way and carefully assessing the associated risks," explains Georg Karlaganis, chemical engineer and former division head at FOEN, who now works for the UN. In an interview with *environment*, he talks about the technological revolution of the 21st century.

environment: **Georg Karlaganis, when was the last time you came into contact with a nanoproduct?**
Georg Karlaganis: At home I have a tie that repels spills thanks to nanotechnology. I can eat spaghetti or salad with a French dressing and not have to worry about my tie! But seriously, I usually don't know when I'm using nanotechnology products, and that is actually a problem. It's estimated that approximately 600 companies process or use nanomaterials in Switzerland, but since there is neither a registration nor a declaration requirement, neither the authorities nor consumers know which companies and which products are involved.

Are you concerned about that?
If a car contains nanoparticles I see no reason to be concerned, since the particles are integrated into the material and are resistant to abrasion. And if the car is made by a German manufacturer, I have no concerns regarding the health of the employees involved in its production. But the situation is different in the case of beverages in packaging that uses nanoparticle coatings. In view of the still existing gaps in our knowledge, I think it's better not to consume such products because the health risks have not been adequately researched.

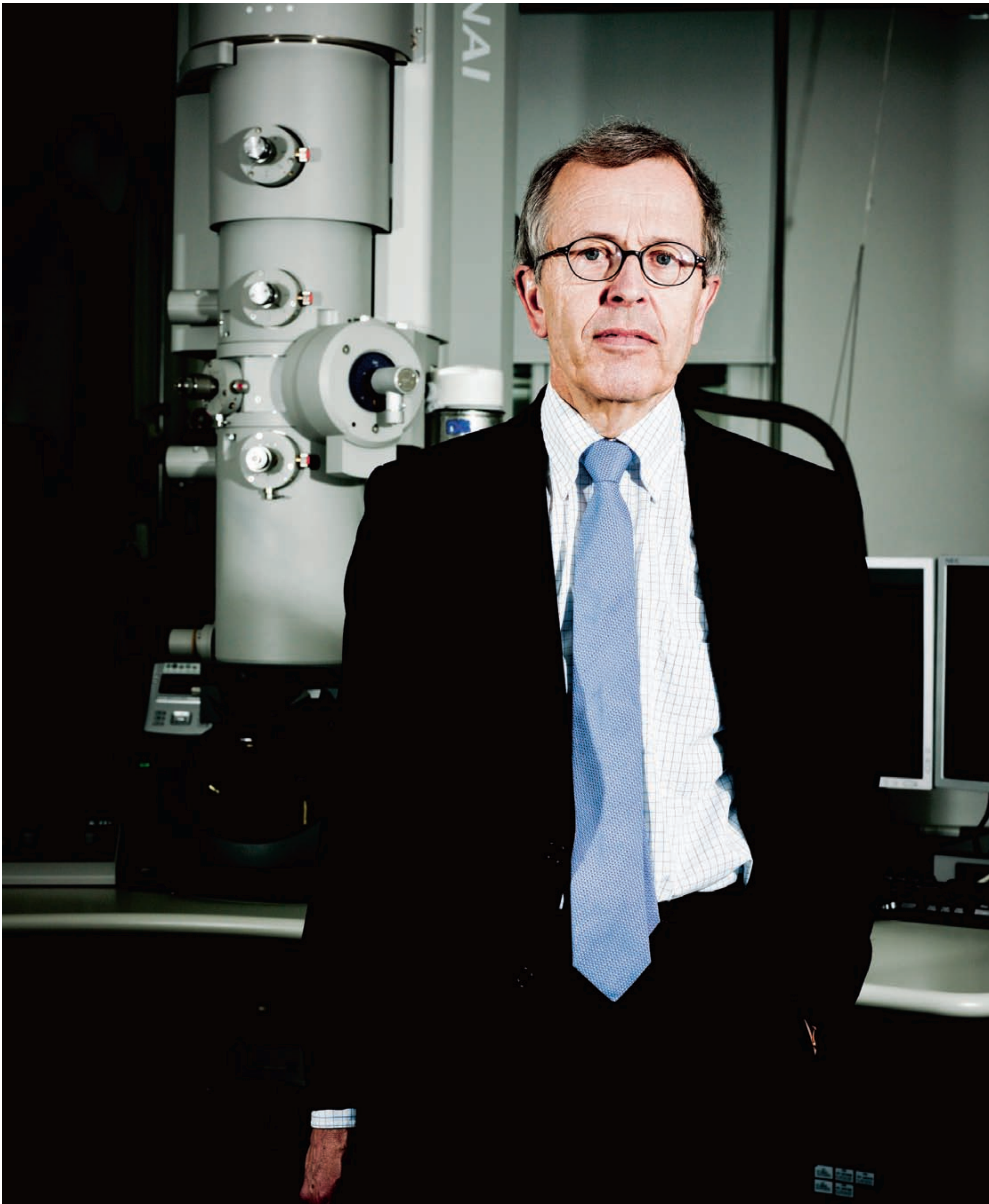
Nanotechnology has been described as the technological revolution of the 21st century, and high expectations have been placed on it. Let's first focus on the basics: how small are nanoparticles really?
Imagine the difference in size between an apple and our planet. That's equivalent to the difference in size between a nanoparticle and an apple.

What's the difference between natural and synthetic nanoparticles?
Natural nanoparticles are found in soils and in sediment formations in lakes. When we speak of nanotechnology, we are primarily referring to synthetically produced nanoparticles or manufactured nanomaterials. Such particles also occur in polluted air, for example as the result of exhaust emissions from diesel motors, but this has nothing to do with nanotechnology.

How are nanoparticles produced?
The source materials are zinc or titanium oxide in powder form, for example. Major companies in the chemicals sector reduce these materials to nanoparticle size using a complex high-tech process or by injecting corresponding solutions into a flame. They are then passed on to small and medium-sized companies for further processing.

Compared with their volume, nanoparticles have a large surface, which makes them highly reactive and alters the physical properties of the source material. What does this mean in practical terms?
The same material may have a different colour, depending on the particle size. Nanoparticles can also take on different colours under varying light conditions. If such a material is used for auto body painting, the colour of the car will change according to the weather and light conditions. Iron is an interesting example: if iron is stored in large, solid pieces, flammability is not a problem, but when it's in powder form the situation is radically different. Nano-iron reacts so vigorously to the oxygen in the air that it can only be stored in an anoxic environment, e.g. under nitrogen or inert gas. There are also

Georg Karlaganis in front of a tomographic electron microscope at the University of Bern, Institute of Anatomy.
Georg Karlaganis studied chemistry at the Federal Institute of Technology, Zurich, and completed his doctorate at the Institute of Molecular Biology and Biophysics. He was guest researcher at the Department of Physiological Chemistry, Karolinska Institute in Stockholm, and in 1985 went on to lecture in chemical analysis in clinical pharmacology at the University of Bern. He was head of the FOEN Substances, Soil and Biotechnology Division from 1987 until his retirement at the end of 2009. Now aged 65, he has been working for the United Nations Institute for Training and Research (UNITAR) in Geneva since his retirement from the FOEN. He is married and father of three adult children.
Photo: Stefan Bohrer



some interesting examples in the area of nanobiotechnology: if nanoparticles are coated with certain proteins, their properties are altered still further. Combined with antibodies, they can be used in medicaments in which the particles directly target pathogens.

Is the medical industry placing high expectations on nanotechnology?

The potential is considerable, but as yet no therapies have been developed. However, research projects are in progress, e.g. concerning the treatment of tumours or better diagnosis through imaging processes such as nuclear magnetic resonance spectroscopy, which makes organs or certain parts of the body better visible. But it will be at least another 10 years before such medicaments for treating cancer will be available on the market.

In which areas are applications the most advanced?

Carbon nanotubes – cylindrical carbon molecules – make materials lighter and tougher. They are already being used to produce bicycle frames and tennis rackets. The metal surfaces of cars can be made tougher and more scratch-resistant thanks to nanocoatings. In the construction industry, nanosilver is mixed into paints for buildings. This produces a protective antimicrobial coating that prevents the formation of algae, mould, moss and lichens on damp walls. A similar principle is applied in the textile industry: nanosilver particles woven into fabrics destroy micro-organisms, so that sweaty socks or t-shirts don't smell so strongly. And nanotechnology is also used in the area of corrosion prevention.

Minute gaps on surfaces are coated with nanoparticles so that dirt, for example, can no longer settle there permanently.

Yes. This effect is also practical for house owners because a protective nanocoating on the exterior of buildings lets blemishes such as graffiti be easily washed off. This principle can also be applied in hospitals to improve hygiene, as well as for ski goggles and bathroom mirrors, which then no longer steam up, and for making garments water-resistant.

And why do nano sun creams provide better protection against ultraviolet rays?

The titanium dioxide that is mixed into sun creams absorbs and disperses UV rays. Unlike macroscopic particles, nanoparticles appear transparent and thus do not form a white film on the skin.

Nanomaterials are apparently also leading to developments in environmental technology.

Yes. For example, building insulation can be improved through the use of nano silica aerogel, and batteries and solar cells can be made more efficient. Lighter wind turbines can be constructed, which results in higher electricity production. Expectations are also high in the area of international development co-operation, where nanotechnology has potential uses in sewage treatment and drinking water purification. This is of particular appeal to countries in Africa.

Nanotechnology can be used in a very broad variety of ways. The National Science Foundation in the USA estimates a global potential of around 1 billion US dollars by 2015. Is this a realistic prediction?

Economic interests in nanotechnology are certainly very high. This also applies to banks, which are investing in young companies developing such products. It is almost impossible to estimate how many of these firms will survive, since it is difficult to assess the true added value potential. The extremely heterogeneous areas of application are the main problem here. At the European Patent Office there is no nanotechnology section where all nanotechnology-related patents can be registered; so they are spread over a broad variety of different areas.

In view of the major economic potential of nanotechnology, is there a danger that health and environmental risks could be ignored?

Yes, of course. However, the industrial sector has become sensitised following recent negative experiences with new technologies, e.g. genetic engineering. For example, the US agriculture group Monsanto is encountering enormous scepticism concerning its genetically modified plants, particularly in Europe. Not long ago, the *Neue Zürcher Zeitung* very pointedly described

> **"I may be interested in a car that can't be scratched, or in an artificial hip that doesn't have to be replaced every 10 years, but I'm a lot more cautious when it comes to foodstuffs."**
>
> Georg Karlaganis

the feelings of the population in an article entitled "Nano, yes – but not too close". And I agree: I may be interested in a car that can't be scratched, or in an artificial hip that doesn't have to be replaced every 10 years, but I'm a lot more cautious when it comes to foodstuffs.

But for consumers it's difficult to be cautious, since they don't know what they're consuming because there's no declaration requirement.

This is true. But I also know that the greatest danger is associated with nanoparticles that enter the body via the lungs. The membrane between the lungs and the circulatory system is very thin, and this lets nanoparticles enter the bloodstream and thus be carried to all parts of the body. By contrast, our skin protects us quite effectively. Very little is known at present about the effects in the intestinal tract after ingesting food. A close watch also needs to be kept on employees in small and medium-sized companies who process nanomaterials. They are often insufficiently qualified or are unaware they are handling nanoparticles. I remember the example of a factory in Asia in which nanomaterials lay on the floor like flour – and the employees were barefoot.

What's being done to quickly improve the status of knowledge we need in order to draw up effective safety measures?

The Federal Council has announced a national research programme (NRP 64) focusing on the opportunities and risks of nanomaterials. The aim here is to create a foundation of scientific knowledge within the next 5 years that will enable recommendations and suitable measures to be drawn up relating to the production, use and disposal of nanomaterials. The sum of 12 million Swiss francs has been budgeted for this purpose.

Is that sufficient?

It's not as if we don't already have regulations and legal provisions that apply to nanotechnology. The duty of care applies here too: manufacturers have to meet the same obligations with respect to nanotechnology as they do in other areas. And common sense is a factor that should always play a role: someone who owns a bicycle reinforced with nanoparticles should certainly not saw up the frame before disposing of it. In 2008 the Federal Council presented an action plan that precisely describes the next steps. A comprehensive public debate is planned in order to sensitise the population. In an international context, a definition of the size of nanoparticles needs to be prepared so that the authorities can use it as the basis for specifying thresholds and regulations. Switzerland has also developed a model that can be used for readily assessing the risks to health and the environment based on the current status of scientific knowledge. In addition, the principle of self-regulation already applies to companies today. For example, an importer who wants to sell washing machines made in Japan that add nanosilver to the wash is obliged to monitor the resulting environmental impacts. Larger companies meet this obligation since they have the necessary specialists at their disposal.

How do you envisage a future with nanotechnology?

With its comprehensive action plan, Switzerland has carried out international pioneering work, and we must maintain this lead. Here we have struck a good balance between courageously leading the way and carefully assessing the associated risks. Maintaining this position will require continued major efforts in the future.

Interview: Peter Bader

www.environment-switzerland.ch/mag2010-3-03

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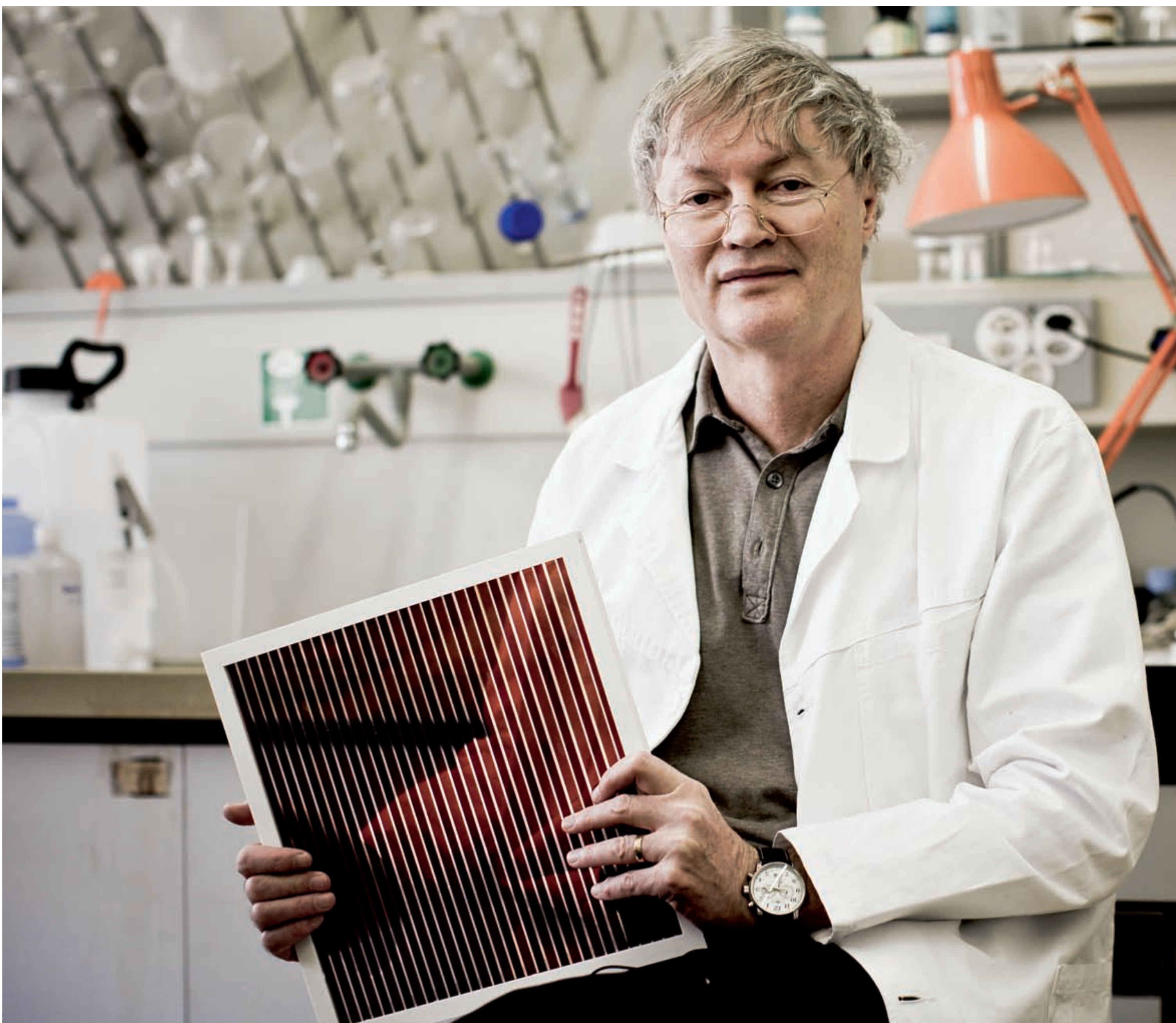
Bright future for solar

Thanks to nanotechnology, it is possible to produce more efficient solar cells that permit a higher energy yield at lower material costs. Two departments of the Swiss Federal Institute of Technology in Lausanne (EPFL) are among the leading research centres in this field worldwide.



energy

The interior walls of the Institute of Microtechnoloy (IMT) in Neuchâtel are covered with solar panels of different sizes and colours. They are mounted on fixed or mobile attachments and are made of a variety of materials. Display cases feature the energy systems that are being researched by the Photovoltaics and Thin Film Electronics Laboratory (PV LAB) here at the IMT. Naturally, the roof of the building is equipped with silicon cells that supply the research centre with electricity.

The PV LAB, which has been attached to the EPFL since 2009, conducts basic research and develops photovoltaic technologies for concrete applications. “Our goal is to offer renewable alternatives to the less than satisfactory conventional energy sources,” explains Director Christophe Ballif. “We want to make it possible to produce low-cost, high-quality electricity from solar energy, reduce the grey energy required for the production of source materials, and minimise the use of toxic substances.”

Increased efficiency of silicon cells. Converting the virtually limitless supply of sunlight into electricity is in itself a good thing. But the ecological balance of solar power can be made even better by reducing consumption of the materials involved, increasing energy efficiency and thus lowering the market prices for photovoltaic systems. Here, nanotechnology can make a valuable contribution thanks to its versatility. In Neuchâtel, researchers are specialising in silicon-based applications and transparent conductive oxides. Amorphous silicon, the atoms of which are completely unorganised, can be used for producing flexible thin-film solar cells.

Under the leadership of Christophe Ballif’s predecessor, Professor Arvind Shah, the PV LAB discovered that micro- or nanocrystalline silicon is also suitable for photovoltaics. It consists of minute crystals with a diameter of less than a millionth of a metre. Using a combination of amorphous and microcrystalline silicon cells, the usable light spectrum can be expanded, which results in increased efficiency. Amorphous silicon absorbs blue and green sunlight, while microcrystalline silicon absorbs red and infrared rays. Based on this technology, Oerlikon Solar has been manufacturing production systems for “micromorph” solar modules since 2007.

The PV LAB is now working on a further development of the solar cell that combines amorphous and single crystal silicon in order to increase efficiency levels by 20 per cent and more. Although production is slightly more costly, IMT hopes to be able to market its tech-

Professor Michael Grätzel (EPFL Lausanne) with a module of the dye-sensitised solar cell – his own invention – which is based on a principle of energy extraction that emulates photosynthesis in plants. For this invention he was awarded the 2010 Millennium Technology Prize (0.8 million euros).

nology together with the German company Roth & Rau. This world-renowned supplier of coating systems and complete production lines for solar cells opened a technology centre in Neuchâtel in 2008.

Tests under extreme conditions. "The challenge is to produce materials with a degree of precision in the nanometre range that are suitable for surface applications of several square metres," explains Christophe Ballif. In his laboratory, numerous specialists work at futuristic-looking machines that allow them to apply extremely thin layers of materials and produce and even encapsulate photovoltaic cells. The main focus is on improving energy efficiency and the materials used, optimising all the layers, mastering the interfaces and developing new structures and processes. For these purposes, the PV LAB produces samples measuring a few square centimetres and thoroughly tests their reliability in a simulator.

"We subject the solar cells to a series of demanding tests in order to ensure that they function faultlessly even under extreme conditions", says Christophe Ballif, "because manufacturers have to be able to guarantee a service life of 25 years for their modules."

Broad range of practical applications. The solar cells developed in Neuchâtel are intended for installation on roofs and facades, in power plants and in solar parks in open fields, deserts, etc. The thin-film modules can also be used in clocks and watches, and variations of the devices can be used in flat LCD screens, optical fibres, radiation sensors and in special detectors for electrons and x-rays. In order to ensure the rapid dissemination of its innovative technologies, the PV LAB has entered into partnerships with a number of industrial and start-up companies, including Oerlikon Solar, Flexcell (in Yverdon, canton of Vaud), and Roth & Rau Switzerland. It is also participating in the development and selection of solar panels for Bertrand Piccard's light aircraft, Solar Impulse.

"We believe that through nanotechnology we can make major advances towards achieving a sustainable energy supply," says Hans Hosbach, head of the FOEN Waste Management, Chemicals and Biotechnology Division. "In some sunnier southern countries, the production of solar power is already competitive. In Switzerland, the faster we succeed at increasing the efficiency of solar cells and minimising the materials they consume, the sooner the cost of solar power will fall into line with the cost of power from non-renewable sources." This also applies to the development of light but strong materials for wind turbines. Grave environmental problems such as global air pollution stemming from power plants run on coal and oil, the pollution of the atmosphere by greenhouse gases, and the disposal of radioactive waste from nuclear power plants could thereby be at least partially alleviated.

Emulation of photosynthesis. In this respect, great hope is placed in the effort to emulate photosynthesis and in Michael Grätzel, inventor of the dye-sensitised solar cell which bears his name. His research team at the Laboratory of Photonics and Interfaces (LPI) at the EPFL is working on the direct extraction of hydrogen from water and the development of high-performance lithium batteries, and is researching solar cells that can convert the energy contained in sunlight into electricity with the aid of a natural dye.

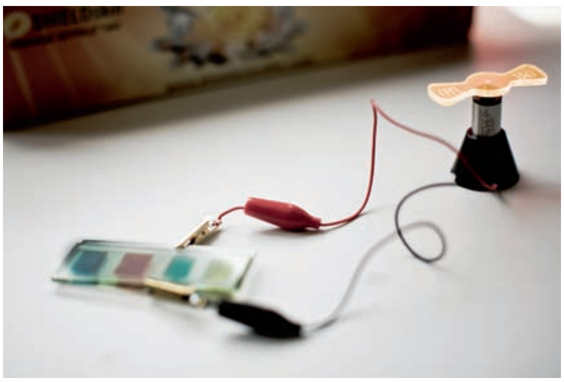
"By emulating nature – or to be more precise, the process of photosynthesis in green plants – we have succeeded in developing a solar cell that absorbs light efficiently," explains Michael Grätzel. Light is collected by a special molecular layer applied to a thin, very coarse oxide film made of semiconducting nanocrystals. In this way a maximum proportion of the visible light can be converted into electricity. Thanks to low production costs, a broad range of applications and the environmental compatibility of these cells, they are considered a highly promising solution for the large-scale production of solar power. The first patent for solar cells of this type was already registered in 1988.

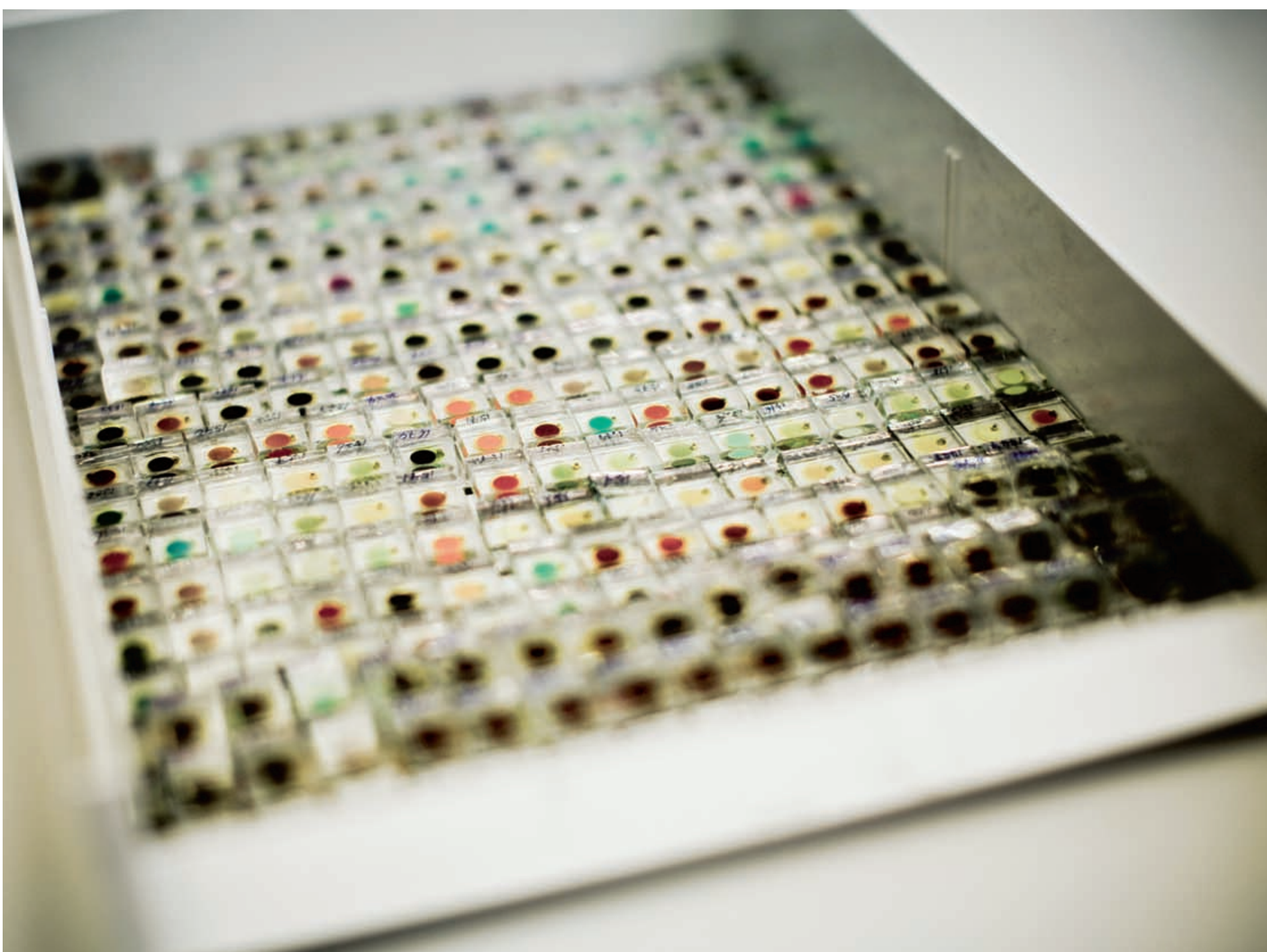
Technology with major growth potential. Science has made a great deal of progress since the early days of the dye-sensitised cell. "We are currently working on new nanostructures and dyes with huge potential for simplification and increased productivity," Michael Grätzel enthusiastically points out. For example, nanoparticles can be

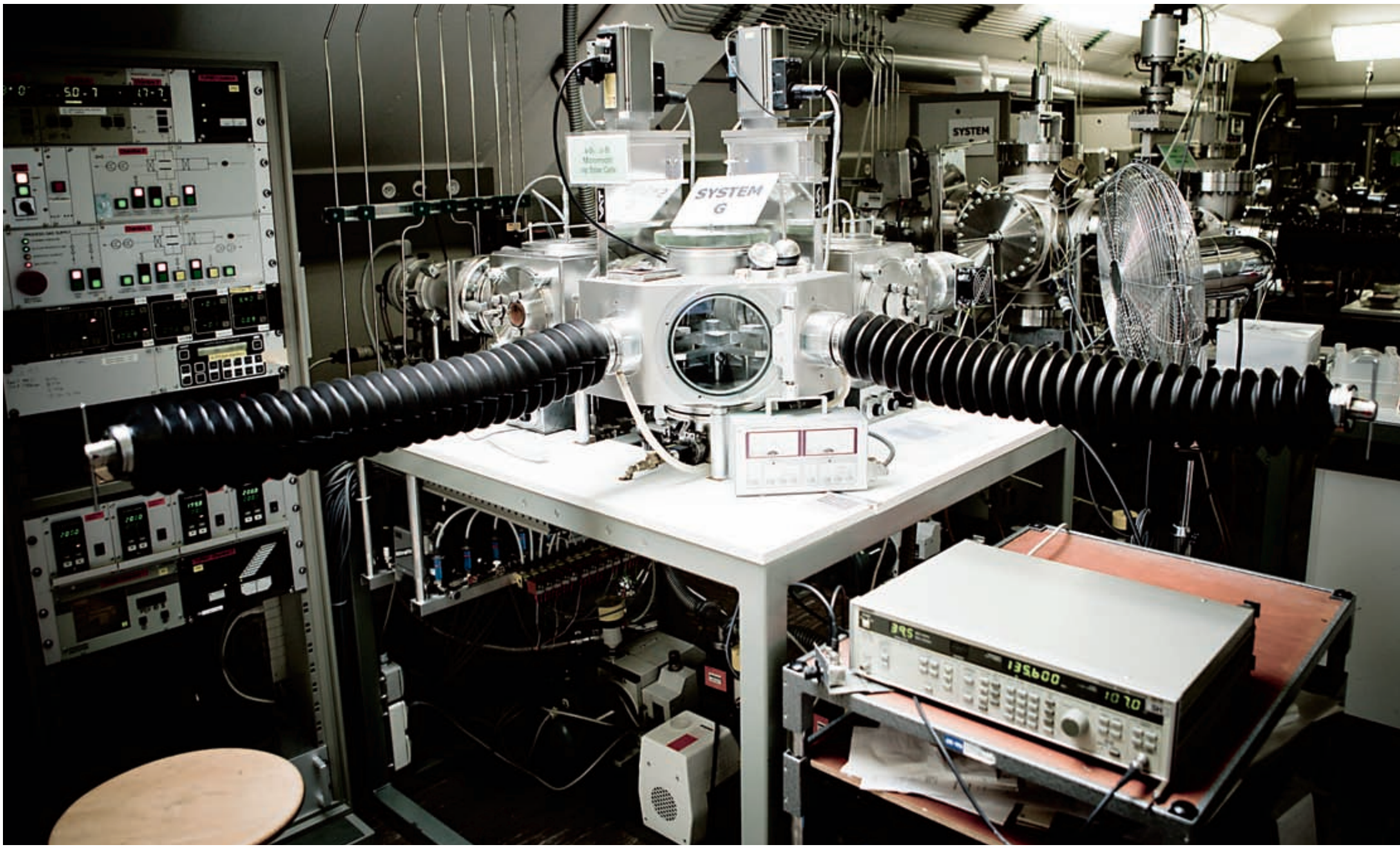
"The challenge is to produce materials with a degree of precision in the nanometre range that are suitable for surface applications of several square metres."

Christophe Ballif

Dye-sensitised solar cells produce electricity even in poor light conditions, e.g. in building interiors. In order to enhance their efficiency, specialists at the EPFL are developing solar cells in their laboratory using different dyes. The electricity yield is measured using a small ventilator. At top right, a researcher is preparing pastes with nanocrystalline particles of titanium dioxide for screen printing.







The laboratory for photovoltaics in Neuchâtel has been focusing on increasing the efficiency of silicon solar cells, and is currently developing flexible thin-film solar modules with the aid of nanotechnology. Above, and on page 17 (bottom left): A reactor operated by an engineer in the laboratory's cleanroom serves the purpose of extracting high-grade silicon for the production of thin-film cells. Page 17, right: Preparations for efficiency measurements with a large sun simulator.

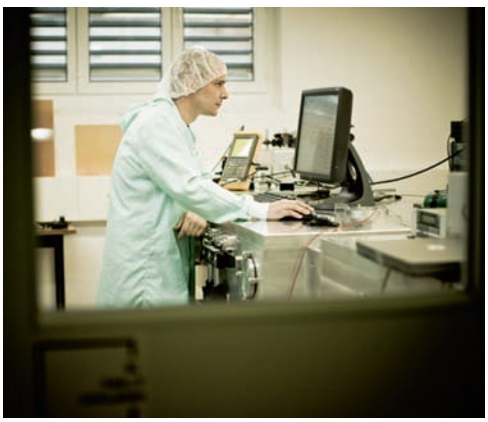
All photos: Stefan Bohrer

arranged into spherically formed groups that capture light more efficiently. Thanks to this grouping of nanoparticles, it is thus possible to produce more electricity. LPI not only produces dye-sensitised solar cells, it also tests their efficiency and spectral sensitivity, i.e. the proportion of the light spectrum that can be used by the cells.

An analysis by South Korean market research company Displaybank estimates that global industrial production of such cells could increase electricity production from 5 megawatts in 2009 to 246 megawatts by 2013. The range of uses includes solar panels for roofs and facades, electricity-producing window panes, street lighting, power supply for portable electronic devices such as MP3 players, backpacks, tents, water purification appliances, radios, refrigerators, lamps, electric vehicles and energy self-sufficient bio-toilets. However, the efficiency of dye-sensitised solar cells still limits their use. They are more efficient than amorphous silicon cells, but still significantly less efficient than monocrystal silicon cells. "But the materials, as well as the dyes and nanostructures, still have considerable potential for improvement," Michael Grätzel assures us.

There are already numerous flexible products on the market for supplying electronic devices with electricity that are based on dye-sensitised cell technology, for example the products of UK company G24 Innovations, which uses the patented inventions of the EPFL under licence. As a spokesman of the company explains, "Such applications are ideally suited for certain regions such as Africa or India, where there is no electricity grid but plenty of sunlight." Progress is also being made in the construction sector. For example, Solaronix (Aubonne, canton of Vaud) and Greatcell (Lutry, canton of Vaud) sell electricity-producing window panes and facade elements. "These companies are creating jobs in the region while doing something to protect the environment," notes Michael Grätzel. "Our work is clearly resulting in benefits for mankind in that it is paving the way for new forms of electricity supply."

PEC House and NanoPEC projects. Together with the EPFL Energy Centre (CEN), LPI is also working on the development of a photoelectrochemical (PEC) solar cell that is able to break water down into hydrogen and oxygen on the electrode surface. A project called PEC House is



"For example, nanoparticles can be arranged into spherically formed groups that capture light more efficiently."

Michael Grätzel

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striving to optimise this process by developing more efficient and more robust, corrosion-resistant materials, thereby enabling low-cost production. The project is being sponsored by the Swiss Federal Office of Energy, and the Swiss Federal Laboratories for Materials Science and Technology (Empa) are supporting it by providing know-how. PEC House recently entered into a partnership with Toyota.

The CEN and LPI are also jointly leading a project called NanoPEC as part of the 7th European research programme, "FP7". The project's aim is to develop a new generation of systems for converting solar energy that efficiently split water molecules into hydrogen and oxygen. Hydrogen produced with solar energy has considerable potential as a sustainable fuel for use in fuel cells for the production of heat and electricity. NanoPEC will primarily research new semiconductors that are suitable for the photoelectrolysis of water and will develop innovative solutions for their nanostructuring. Research commenced in January 2009 and will last three years.

Cornélia Mühlberger de Preux

www.environment-switzerland.ch/mag2010-3-04

A CHANCE FOR THE ENVIRONMENT: TREATMENT OF WATER

Nanopores for clean drinking water

Nanotechnology has been used for some time in the preparation of drinking water with membrane filters, and its potential is enormous. There are no environmental risks as long as nanopores, not nanoparticles, are used.

The Valais mountain village of Zermatt consumes more than 6000 cubic metres of drinking water a day when all hotels and apartments are fully booked in the peak holiday period – twice as much as in off-peak periods. The water from the area's 85 sources is then no longer sufficient. An additional source was found near the Findel Glacier, 2280 metres above sea level: the Gand springs. The water is perfectly hygienic, but it contains too much sulphate, which gives it an unpleasant taste, and the high calcium content clogs up boilers, washing machines and hot water pipes.

The Gand springs have nevertheless been providing clean drinking water with calcium and sulphate levels in compliance with the relevant regulations since 2006, when the "Wichje" reverse osmosis plant was put into operation. The

Water supply nanofiltration facility in Zermatt (Valais): In the pipes, the source water is passed through the microscopic pores of the membranes (cf. page 19).

Photo: Reinhard Perren, Zermatt Water Supply facility feeds 72 cubic metres of water per hour into the network.

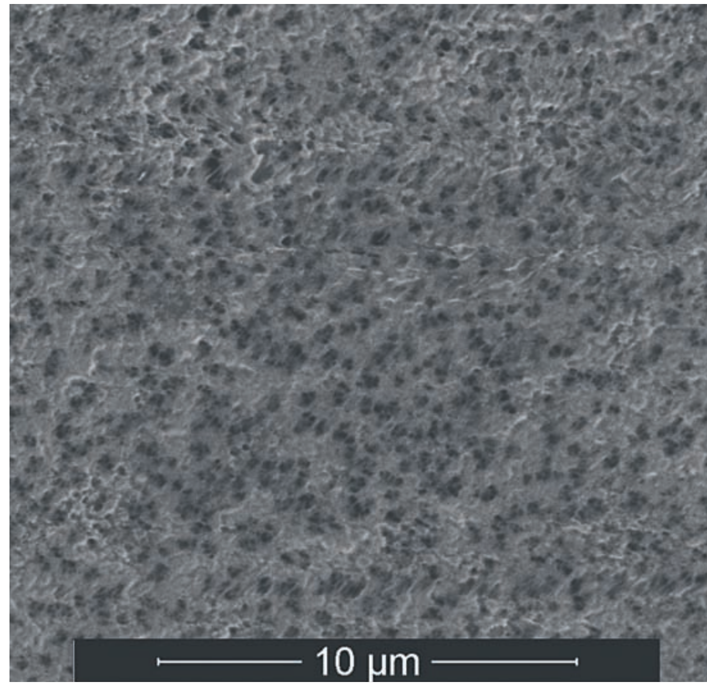
Membrane technology in the nano range. In the process of reverse osmosis, water is passed through a membrane which has pores that are less than 1 nanometre (nm) in diameter and can thus filter out the calcium and sulphate ions. For nanofiltration, separation is effected with a membrane pore diameter of 1 to 2 nm. If the pores are between 2 and 60 nm, the process is referred to as ultrafiltration (see table). The distinctions are slightly confusing in that nanotechnology processes – which by definition involve structures below 100 nm – are used in all cases.

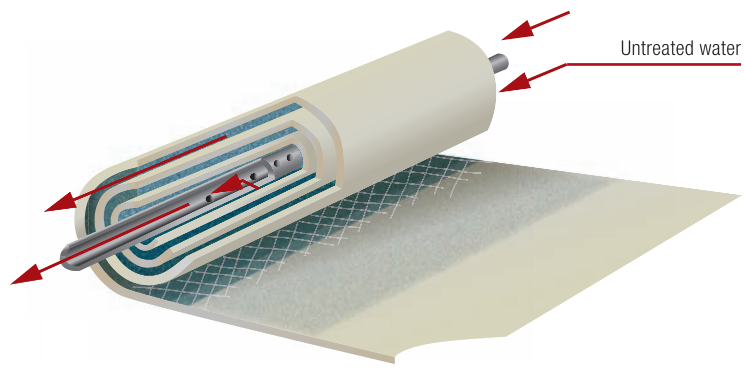
MEMBRANE FILTRATION PROCESSES

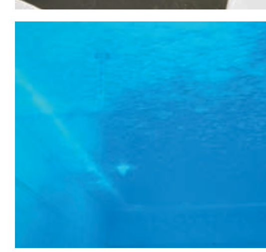
Separation process	Pore size (nanometre = nm)	Filtered materials
Microfiltration	> 60 nm	Particles
Ultrafiltration	2–60 nm	Bacteria, viruses
Nanofiltration	1–2 nm	Viruses, calcium, molecules
Reverse osmosis	< 1 nm	Molecules, ions

"Nanotechnology existed in the water treatment industry long before this term was coined," says Wouter Pronk, head of the Membrane Technology Section at Eawag (water research institute of the two Federal Institutes of Technology). The most modern, but by no means the only, ultrafiltration facility for water treatment in Switzerland is located in Männedorf (canton of Zurich), and since 2005 it has been supplying the 26 000 inhabitants of three lakeside towns with clean drinking water from the lake. The filter removes all particles and bacteria from the water.

One-fifth of the public drinking water used in Switzerland is extracted from lakes. Compared with conventional purification processes, membrane technology permits low-cost water treatment with fewer chemicals, less energy consumption and smaller space requirements. The water from karst sources, which is also not entirely free from micro-organisms, can be processed into drinking water with the aid of membrane technology. "By contrast, groundwater from loose rock formations, the most important of which are found in major river valleys in the Alps and Central Plateau, can usually be used as drinking water without any special processing," explains Benjamin Meylan from the FOEN Groundwater Protection Section. "The water is purified naturally underground, if the applicable groundwater protection measures are complied with."







Top: Microscope image of a polyvinylidene fluoride membrane for water treatment. The scanning electron microscope used for the image permits enlargements to millions of times the original size.
Photo: Brian Sinnet, Eawag

The illustration in the centre shows the interior of a tube-shaped drinking water filter with the rolled-up membrane layers (cf. illustration on page 18).
Bottom: The two images from a water treatment plant in Conthey (Valais) depict the effect of treatment: the often murky water from two karst sources is clarified using ultrafiltration.
Photos: Membratec SA / Ruth Schürmann

Opportunities for developing countries. The potential for the use of membrane technology is especially high in developing countries, where around 1.5 billion people do not have access to clean water today. In many places, polluted water flows into bodies of water that are used as a drinking water supply downstream. For such cases, Eawag is currently developing and testing low-cost membrane filtering processes that are simple to use. A device called "LifeStraw Family" developed by a Swiss company is already available, and contains an integrated ultrafiltration membrane that eliminates all pathogenic germs.

The options for treating water using nanotechnologies are as widely varied as the demands placed on them: everything that is undesirable in drinking water – dirt, bacteria, viruses, organic compounds, pesticides, heavy metals, radionuclides, nitrate, phosphate, calcium, sulphate, etc. – can be removed using existing processes.

Elimination of micro-impurities and salts. This opens up options for solving one of the main problems relating to water protection: in existing sewage treatment plants, micro-impurities such as residues of medicaments and hormone-like substances that affect the reproduction of fish and other aquatic life forms are not adequately eliminated. But with membrane technology, at least some of these can be filtered out. In Wouter Pronk's view, membranes are the method of choice for treating waste water from specific sources like hospitals and nursing homes, where the waste water contains high levels of such substances.

Desalination of sea water is another area with enormous potential. Experts estimate that the global market for desalination plants will grow from 3 billion US dollars per annum to 70 billion by 2020. With the aid of reverse osmosis, desalination requires far less energy than conventional methods. Scientists are unaware of any direct environmental risks associated with membrane technology – as long as only nanopores are used, not nanoparticles.

However, nanoparticles are now also playing a role in water treatment, because they have a large specific surface making them suitable as adsorption material that can efficiently remove organic as well as inorganic substances such as nitrate from water. Researchers have developed an adsorption agent based on a carbon nanotube that is capable of eliminating arsenic. Nanomaterials are also suitable as catalytic converters in water treatment.

Nano-iron for groundwater remediation. Certain nanoparticles can also react chemically with pollutants and thus destroy them. This occurs when groundwater that has been polluted with chlorinated hydrocarbons is decontaminated with nano-iron. The pollutants react chemically with the iron, which turns them into harmless substances. Until now, normal iron swarf has been used that was placed in the underground in the form of a permeable barrier allowing the groundwater to pass through it. Higher reactivity and lower outlay can be expected if nano-iron particles are pumped into groundwater through bore holes. The particles are coated with organic substances so that they do not adsorb on surfaces. In this way they remain mobile and are distributed more evenly in the groundwater. Initial tests have shown that this method could also prove to be successful in practice.

Unlike membranes, the use of nanoparticles in water treatment is still in its infancy. The signs are promising, but little is known about the risks that arise when nanoparticles are released into the environment. As noted in a report on water supply in 2025, which was prepared by Eawag on behalf of the FOEN and published in 2009, it remains to be seen how environmentally compatible nanomaterials are when used in water treatment.

Treating contaminated water using nano-iron is also a relatively costly process. "Thorough underground studies are a prerequisite for success in such in-situ processes," explains Bernhard Hammer, head of the FOEN Contaminated Sites Section, "otherwise it could be difficult to place the reaction agents at precisely the location of the pollutants that need to be removed."

Hansjakob Baumgartner

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"Nanotechnology existed in the water treatment industry long before this term was coined."

Wouter Pronk, Eawag

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Still many unknowns

Throughout the world there are already more than 800 nanoproducts on the market. During and after use they can release nanoparticles into the environment, most of which end up in bodies of water. Swiss researchers therefore want to find out whether these compounds build up in flora and fauna, and what their effects are.

What effects do nanocompounds have on the environment – for example, when the antimicrobial nanosilver added to hiking socks is washed out and ends up in sewage? And what happens when soil-resistant paints containing titanium oxide begin to wear off from a building's facade? On behalf of the FOEN, Bernd Nowack from the Swiss Federal Laboratories for Materials Science and Technology (Empa) is looking for answers to these questions. His team of specialists modelled the substance flows for five kinds of nanoparticles and calculated the levels that remain in the air, water, sewage sludge, sediments and soils.

Nanoparticles in sewage sludge or in combustible waste are of little concern, since in Switzerland these residues are incinerated and the nanoparticles are thereby either destroyed or trapped in exhaust gas filters. Nanocompounds that enter surface bodies of water, however, are more problematic. The Empa study showed that silver and zinc oxide react relatively quickly with other substances in water and no longer act as nanoparticles, but it also found that nano titanium dioxide can build up in sediment. "In-depth risk studies are needed on this substance", says Bernd Nowack, "because to date no one has researched its actual behaviour in the environment." One particular aspect – namely, how nanoparticles find their way into the environment – is to be studied in a European project called "Nanohouse".

Numerous questions relating to nanoparticles that are released into the environment remain unanswered. For example, in industrial applications the surface of these highly reactive particles is coated in order to prevent clumping. But we do not know what happens to this protective coating in waste water. Existing studies are insufficient to estimate either theoretical levels on the basis of substance flows or the actual levels in the biosphere. As Bernd Nowack points out, "In nature we do not have laboratory conditions."

Uncertain long-term effects. Kristin Schirmer, head of the Department of Environmental Toxicology at Eawag water research institute, is studying how nanoparticles are washed out into the environment and eventually assimilated into living organisms. Summarising her initial findings she explains: "Nanoparticles can enter cells even if they occur in a medium in clumped form." Previously, it was believed that such clumps of particles remained in the water and were therefore of little concern. Kristin Schirmer also examined what happens with nanoparticles when they enter the cells of humans or vertebrates such as fish. "So far we have not found any evidence of particles in the cell nucleus," was her cautious and provisional finding. However, it is possible that only very few of these minute particles reach the nucleus and it has not yet been possible to detect them. If nanoparticles were to be found in the cell nucleus, it would be bad news: due to the large surface area of nanoparticles and other characteristics, they can potentially release reactive molecules. Because of their proximity to DNA as the carrier of genetic information, these "free radicals" can damage the cell's genetic material and in the worst case even cause cancer.

"But even nanoparticles regarded as non-reactive, and those that settle outside the cell nucleus, are not necessarily harmless," says Ernst Furrer, a chemist from the FOEN Industrial Chemicals Section. "For example, they may remain in the organism for a long time and could give rise to chronic inflammation." As Eawag studies have shown, particles can end up in the lysosome, the cell organ where enzymes break down cellular waste. It is conceivable that nanoparticles remain there, with uncertain consequences for the cell. But it is also possible that they are transported close to the cell surface and are then excreted and thus eliminated from the organism.

Danger of accumulation. Another area of Eawag's environmental toxicology research concerns the influence of silver nanoparticles on algae. We know that silver ions can break away from nanoparticles and hamper photosynthesis in algae. But studies have shown that the nanoparticles themselves also interfere with the energy intake of plants. "Nanoparticles thus have a greater toxic effect than pure silver ions," notes Kristin Schirmer. One possible explanation for this is that the nanoparticles are ingested by the algae and form a silver deposit from which toxic ions are then continuously released.

Nanoparticles occur in waste water in fairly steady amounts rather than in sudden large quantities, and this increases the risk of accumulation in flora and fauna. This could be the case for non-polar (i.e. fat-soluble) nanoparticles, for instance, which may build up in animal fat. However, no related studies have been carried out to date. Even if nanocompounds accumulate in parts of cells such as lysosomes and are neither excreted nor broken down, accumulation still occurs: based on algae and water fleas (for which algae are the prime food source), Eawag is currently examining whether these two forms of accumulation lead to a build-up of nanoparticles in the food chain.

Co-operation at the OECD level. Until now, environmental toxicologists at Eawag have been working with silver, gold and tungsten carbide cobalt nanoparticles. They are now also focusing on cerium particles. These compounds play an important role in the textile and toolmaking industries, and in the development of catalytic converters. But it's a challenge for science to keep pace with economic development. "We cannot be sure whether we are really studying the substances that are most important for assessing environmental risks", admits Kristin Schirmer, "because we only know about part of the nano market." In her view, it would make sense if manufacturers were to clarify risks together with research institutes in the development stage. "But unfortunately we haven't got that far yet." The objective of Eawag's studies is to derive general rules about nanostructures and their environmental risks.

The objective of Eawag's studies is to derive general rules about nanostructures and their environmental risks.

It is impossible to carry out a comprehensive risk assessment for every new nanocompound. In view of this, in a project of the OECD (Organisation for Economic Co-operation and Development), Eawag is participating in environmental toxicology tests of the most important nanoparticles in use today. The aim is to define standard testing methods for nanomaterials.

Specific regulations do not yet exist. The Federal Environmental Protection Act imposes a duty of care and an obligation of self-regulation before nanomaterials are brought onto the market. Furthermore the requirements of the safety data sheet must be observed. Researchers want to advise the industry on how to design safer nanoproducts and which substances it would be better to avoid. "Firmly anchoring particles in a material matrix would help keep them from washing out," notes Kristin Schirmer.

Rapid technological development. How are the findings to be integrated into acts and ordinances? On behalf of the FOEN, Empa has made the first calculations of nanoparticle concentrations that could be problematic for the environment. Its calculations were based on eco-toxicological studies (predicted environmental concentration, predicted no-effect concentration and a safety factor of 1000). Bernd Nowack (Empa) justifies this caution in that there are gaps in the data concerning the physically restructured substances. The more nanocompounds there are in circulation, the greater the need for research. But as Bernd Nowack emphasises, Swiss research organisations also want to take account of the unique dynamics of the new technology: "Our task is to constantly examine what's been done so far and compare our findings with those made abroad."

Pieter Poldervaart

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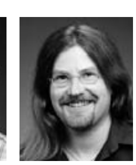

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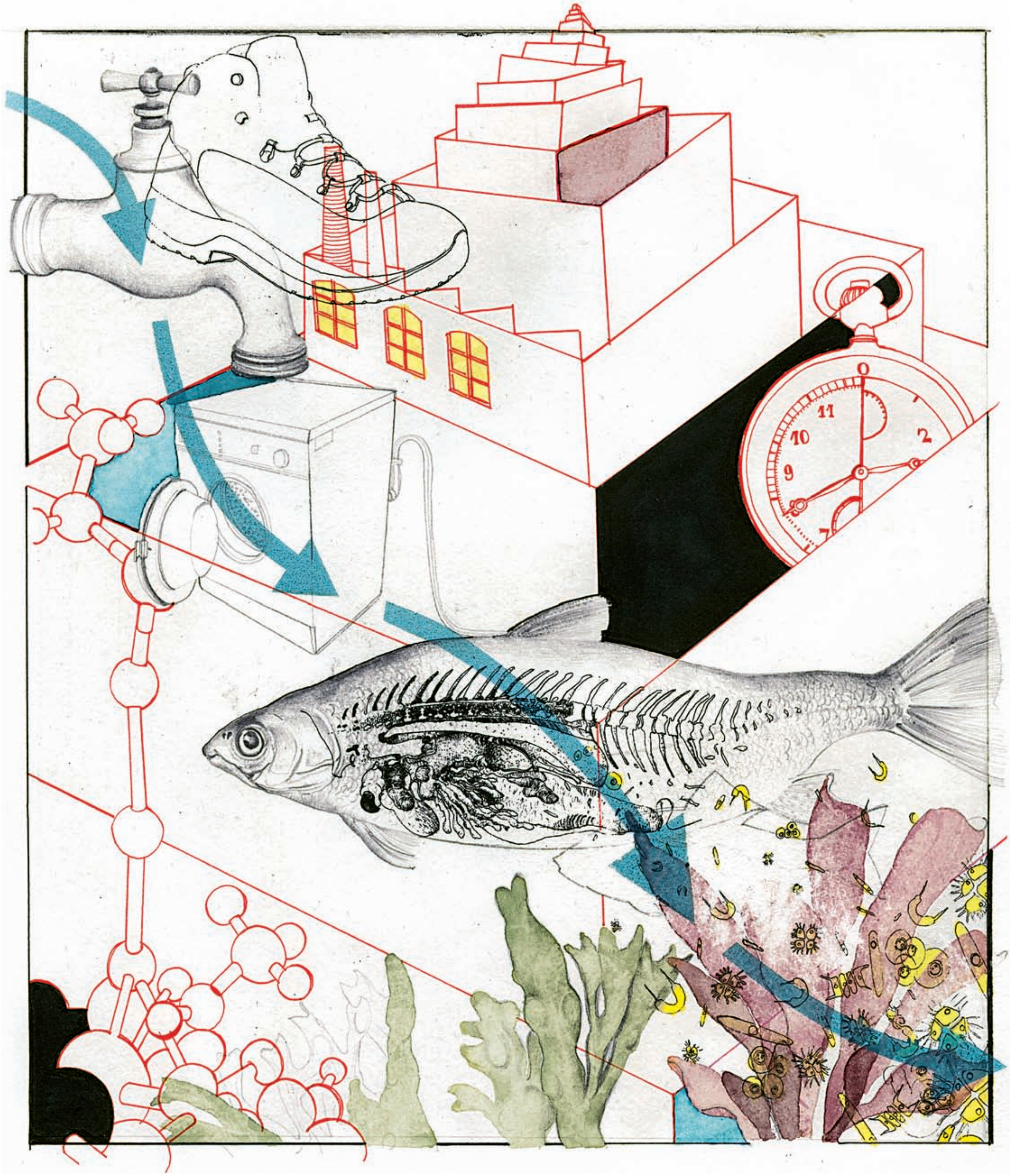


Nanoparticles enter the environment, particularly surface bodies of water, in a diffuse manner. Their effects on water organisms such as fish are still largely unknown. A representation of this problematic by illustrator Lorenz Meier (Zurich).

HEALTH RISKS

Nanoparticles can penetrate brain tissue

Synthetic nanoparticles can penetrate tissue and cells, and spread throughout the body – even to the brain. Professor Peter Gehr of the University of Bern, an internationally renowned tissue specialist, is astonished that potential health risks are barely acknowledged outside the scientific world and government agencies.

Photo: Stefan Bohrer

Peter Gehr is Professor of Histology (the study of tissue) and Anatomy at the University of Bern. He is internationally renowned as a researcher, for example for his studies on the behaviour of nanoparticles in the lungs and on their interaction with cells. He is head of the national research programme NRP 64, which is examining the opportunities and risks of nanomaterials and will be initiated in December 2010.

environment: **Is the Swiss population concerned about the effects of nanoparticles on human health?**

Peter Gehr: No, people either have no idea about nanoparticles or do not regard them as a problem. The potential risks are also of little interest at the political level.

Why this lack of concern?

There is a great deal of fascination with nanotechnology and nanoparticles, and exciting new applications have already been developed. For example, very tough and extremely light materials can be produced using carbon nanotubes. Bicycle frames, for instance, can now be made several kilograms lighter.

But there have also been alarming reports, for example about female Chinese workers suffering from severe lung damage due to high concentrations of nanoparticles at the workplace.

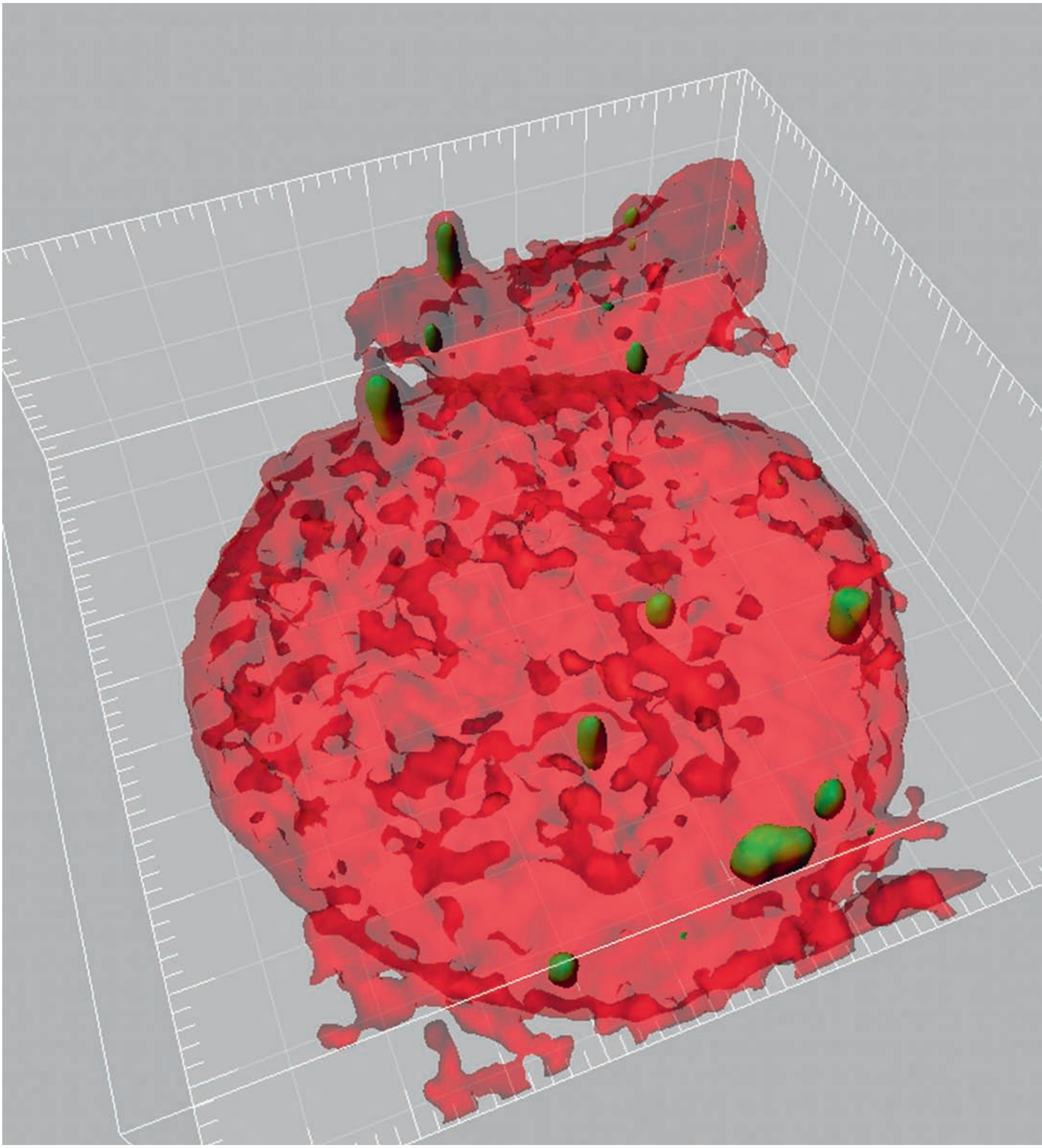
The study that reported this has in the meantime been found to have major shortcomings. When the media focused on this issue in December 2009, I thought this might result in a change of attitude. I believed that we nano researchers would now have to justify our actions because people would be worried and upset. But the press articles failed to trigger any notable discussions, and the subject was forgotten again within a few days. People are simply not reacting to the possibly harmful aspects of synthetic nanoparticles right now.

As a researcher, are you too reticent about your concerns?

No, on the contrary. I am constantly explaining the potential risks – in talks with politicians, in public lectures and in panel discussions. If nanoparticles are not solidly bound to another material, there is a risk that we could inhale them. They can then enter the bloodstream and spread throughout the entire body. As yet we do not know what the consequences of this are for our health. The mere fact that particles penetrate into the body is a problem, but this is barely acknowledged outside the realms of science and government agencies.

Presumably, people are also concerned about the contradictory assessments of the opportunities and risks of this technology.

I, too, became highly concerned about a year ago: tests on animals show that nanoparticles can penetrate tissue and cells, and spread via the bloodstream throughout the body – even to the brain. However, we do not yet know precisely how this happens. Researchers recently began addressing the phenomenon that nanoparticles which come into contact with our body become coated with a protein layer. This occurs already when the particles come into contact with the surface-reactive film lining the interior of our lungs. We still know very little about this coating process. It is not clear how it actually occurs, whether the protein layer is altered upon penetrating the cell, and how it affects cell function. In my view, this is where the greatest uncertainty lies with respect to health risks associated with nanoparticles.



Nanoparticles can penetrate into tissue and cells, and spread throughout the body via the bloodstream. This enlarged image of red blood cells, which was produced at the University of Bern, Institute of Anatomy, using a laser scanning microscope, shows green nanoparticles that have penetrated the cells.

Photo: Barbara Rothen-Rutishauser, Institute of Anatomy, University of Bern

What is your opinion of studies that suggest that carbon nanotubes are as hazardous as asbestos?

It is well known that asbestos fibres can lead to cancerous changes to the outer layer of lung tissue. Tests have been carried out with animals using synthetic nanoparticles, i.e. carbon nanotubes of a size and structure similar to asbestos fibres. Experiments in the abdominal cavity of mice have revealed that, following the introduction of these particles, tumorous growths occurred that are regarded as precursors of cancer. By contrast, carbon nanotubes of a different form and size did not cause any such changes.

Is this result reassuring or are there grounds for concern?

I have fundamental concerns about carbon nanotubes, regardless of their form. The idea of having to breathe in nanometre or micrometre tubes is worrying. In fact, such scenarios are not so far-fetched. At a recent nanotechnology congress in Japan, tyres were presented that were made more resistant thanks to carbon nanotubes. If all cars were to be fitted with such tyres, we would indeed have a problem, since rubber and the embodied nanoparticles are subject to abrasion and weathering, and are thus released into the air. And such a situation is by no means unrealistic.

The air we breathe is already polluted by particulate matter. Do these particles have a different effect on our health than industrially manufactured nanoparticles?

No – because the main problem of particles entering our body is their size. Size is much more important than the form or type of the material they are made from, as our research at the Institute of Anatomy has been able to demonstrate. PM10 particles, which contain numerous nanoparticles, are subject to the same physical mechanism when they are inhaled: upon deposition on the internal surface of the lung they become coated and are displaced by surface forces towards the lung tissue.

So particulate matter is just as hazardous as synthetic nanoparticles in this respect?

Yes, the effects are practically the same!

How problematic is it when nanoparticles are detected in the brain?

In my laboratory we were able to demonstrate with the aid of ultra-modern microscopes that nanoparticles can traverse the air-blood tissue barrier in the lungs. And similarly, they can pass the blood-brain barrier and penetrate into brain tissue, as colleagues have demonstrated in tests on animals based on radioactive substances. Although the quantities are extremely small, we are nonetheless talking about countless thousands of nanoparticles that reach the brain in this way.

Could this result in severe damage?

I am familiar with the work of a colleague who grew up in Mexico City and went on to work at leading centres for environmental research in the USA. She examined the brains of people who died from Alzheimer's disease, and compared these with the brain tissue of a young man who had lived all his life next to a busy road in Mexico City, and was killed in an accident. I will never forget how similar the images of these brains were. In both cases there were indications of the same inflammations of the brain – referred to as beta-amyloid plaques – that are regarded as precursors of Alzheimer's disease. So theoretically one could conclude that air pollution causes Alzheimer's disease.

Has this been established?

No, it's still a hypothesis. But some researchers are now seriously asking themselves whether environmental pollution could be a cause of Alzheimer's. If this were the case, it would almost certainly be due to inhalation of particles that enter the bloodstream and cross the blood-brain barrier.

Interview: Kaspar Meuli

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"I have fundamental concerns about carbon nanotubes, regardless of their form."

Peter Gehr, University of Bern

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Workplace safety is first priority

The enormous market potential of nanotechnology is attracting more and more companies into the field. But producing and processing these tiny particles entails risks. Bühler Partec, which has been producing nanoparticles since 2007 in Uzwil in eastern Switzerland, consequently places the highest priority on workplace safety.

The liquid Hans-Henning Homann is swirling in a small bottle looks like a suspension made of yeast. "This is how we deliver our finished products to our clients," explains the head of nanoproduction at Bühler Partec in Uzwil (canton of St. Gallen). But this viscous substance is certainly not intended for baking purposes! It is called "Oxilink" and is the company's own development. "These are the very smallest particles that can be mechanically ground." They are 10 000 times smaller than the source product – tiny grains of zinc oxide powder that resemble flour.

This material provides excellent protection against UV rays and can be used in many ways when made as fine-grained as possible. The particles have to be smaller than 1 millionth of a metre, i.e. 1 nanometre. They are then invisible and can be added to sun creams, enamels or plastic foils for use in agriculture. The effect is astounding. In distilled water containing nanoparticles, a laser beam remains visible since its light is reflected by the minute particles. This makes nanoparticles attractive for a broad variety of applications.

Scarcity of scientific findings. The size of these particles is also a cause for concern, however. As scientific studies have shown, when air-borne nanoparticles are inhaled, they make their way through the respiratory tract into the deepest parts of the lungs, where they can pass into the bloodstream. Protective measures are therefore essential, especially at the workplace. The rapid technological developments over the past few years represent a major challenge for health and environmental authorities. No relevant safety regulations exist yet for workplaces where nanoparticles are processed. One of the main reasons for this is that the corresponding risk research has not yielded definitive findings. Nonetheless, a recent study was able to eliminate the suspicion that nanoparticles could be absorbed via the skin and transported as far as the brain. For Hans-Henning Homann, the status of knowledge is the be-all and end-all in the manufacturing industry. "Three years ago, when we started production here, the number of publications was around 300. Today the number is over 600, which clearly indicates there is a major interest in scientific findings."

A recipe for production. For the Bühler group, which has an annual turnover of 1.7 billion Swiss francs, Bühler Partec (annual revenue, 1 million Swiss francs) is still of minor importance. But the economic potential is enormous, and it is still easy to keep an eye on competitors. This explains why the group modified its philosophy and decided to market a product itself, even though it had previously focused solely on constructing plants it would not be operating itself, says press officer Corina Atzli.

The technical process is the same as that for grinding cocoa beans or grains. Astonishing as it may sound, nanoparticles are the result of many hours of processing in a mill equipped with ultra-hard grinding stones. "This is as finely ground as it gets," says Homann. "We're almost down to atom size!" The production process for this viscous substance is described step by step in a comprehensive document, and leaves Hansueli Näf – one of two employees handling production – with very little leeway. Both the quantities and the processing times have to be observed precisely. It takes about a day to produce the dispersion from the raw material, which is delivered in

Bühler Partec (Uzwil, canton of St. Gallen) grinds raw materials such as zinc oxide into nanopowder that is used as the source material for the production of nanodispersions. For their protection, employees wear a mask, as well as protective glasses and overalls, for each processing step.

All photos: Stefan Bohrer

Employees of Bühler Partec wear gloves to protect them against dessication due to contact with the powder. The nanoproducts, which are produced in sealed systems, are only made available in dispersion form (left), never in powder form. To remove samples from the grinder, the necessary safety equipment comprises gloves, protective glasses, overalls and protective shoes.

sacks. In dispersed form, it is considerably less problematic to handle than a powder, and clients can simply mix the required quantity of the liquid into their product. With a daily production capacity of around 300 kilograms, the company produces around 100 tonnes per annum.

Comparable to a chemicals company. For Hans-Henning Homann, workplace safety is of the utmost priority, starting with the installations. The production hall is white and brightly lit, which gives it a clinical feel. Neither people nor material can enter or leave it unsupervised. But anyone who expects extreme security measures would be mistaken. "Essentially, similar rules apply here as would apply at a chemicals company," says Homann, who was employed by a major chemicals group in Basel for many years. Employees wear special shoes, work jackets and

Anything that could contain nanoparticles is stored in special safety containers and disposed of as hazardous waste.

protective glasses, and, if they come directly into contact with nanomaterials, they also have to wear latex gloves. The most hazardous task is loading the raw material into the mill. For this purpose, Hansueli Näf wears an overall and breathing mask. A special device developed by the company measures the particle count on site. "We operate at a level that is 70 times lower than that recommended in the relevant international standard," says Hans-Henning Homann. And how do they protect the environment? "Waste water is transferred to our internal treatment system, where it is tested and purified in two stages." Anything that could contain nanoparticles is stored in special safety containers and disposed of as hazardous waste.

Certified risk management. The basis of these measures is the certified risk management system of Bühler Partec. The "Cenarios" system is being used for the first time for this purpose. It was specially developed in co-operation with German service provider "TÜV Süd" and consulting company "Innovationsgesellschaft St. Gallen" for companies working in the field of nanotechnology. The system includes a standardised catalogue of requirements for certification. In 2007, Bühler Partec was the first company in the world to have its own risk management system examined and certified by "TÜV Süd" on the basis of these requirements, and follow-up examinations were subsequently carried out at intervals of several months. "In the meantime, our system has been perfected to a point where examinations are now only required every three years," notes Hans-Henning Homann. In addition to the ongoing evaluation of scientific findings, the company also constantly monitors all products and processes. Each product is also subjected to a risk assessment.

Urs Fitze

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Still no threshold for nanoparticles

According to a representative survey conducted in Switzerland in 2007, around 1300 people work directly with nanoparticle applications, primarily in the chemicals, electrotechnology and automobile parts industries. But nanoparticles are much more frequently encountered as secondary products, for example during welding or other thermal cutting processes. According to SUVA (Swiss National Accident Insurance Fund), based on the studies that have been carried out to date in connection with toxicology and health and safety at the workplace, a maximum level for nanoparticles cannot yet be specified. However, guidelines are to be introduced in 2011.

The relevant legal provisions governing the circulation of substances and preparations also apply to nanomaterials. This means their properties have to be assessed, and buyers of hazardous substances have to be informed about all the necessary safety and protection measures. An actual declaration requirement does not yet exist for nanoparticles. At the workplace, the employer is of course obliged to take all the measures that are required based on the properties of the hazardous substances in question.

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Handling uncertainties with care

The potentially harmful effects of synthetic nanomaterials on health and the environment have only been researched to a limited extent to date. How are the authorities approaching these uncertainties? The FOEN is defining principles for major accident prevention and safe waste disposal.

Processed aluminium is essentially a harmless metal, but when it is in the form of nanoparticles, the particles can ignite when they come into contact with air, and can thus trigger a fire or explosion. This means that such nanomaterials have to be classified as self-igniting substances, for which a quantity threshold of 20 000 kilograms applies in Switzerland. All companies that store larger quantities are subject to the provisions of the Federal Ordinance on Protection against Major Accidents, which is intended to protect people and the environment against serious damage due to extraordinary occurrences that can result from the operation of installations and systems. If, for example, an explosion on a company's premises could in the worst case result in the death of more than 10 people outside the premises, the company concerned is required to make a detailed assessment of the potential risks and submit it to the authorities for examination.

Study on major accident risks. As supervisory authority for the enforcement of the above ordinance, the FOEN constantly monitors developments relating to chemical risks. "In this capacity we also have to assess whether new criteria for specifying quantity thresholds need to be added to the ordinance in view of the fire and explosion properties of synthetic nanomaterials," explains Martin Merkofer, a chemist at the FOEN Prevention of Major Accidents and Earthquake Mitigation Section.

As part of its action plan, the Federal Council asked a safety institute to conduct a corresponding study of the existing literature. The focus was on nanoparticles of aluminium and carbon which have already been studied. It found that the minimum ignition energy of nanosubstances may differ from conventional metal particles. The latter can also ignite upon contact with air. However, carbon or aluminium nanoparticles do not behave very differently in terms of explosive properties from particles of the same materials that are not classified as nanoparticles based on size. "We do not yet have sufficient basic data for a definitive assessment, but the findings obtained to date do not indicate that special regulations relating to fire and explosion properties of nanomaterials need to be added to the Ordinance on Protection against Major Accidents," concludes Martin Merkofer. The provisions of the ordinance apply to potentially inflammable substances as well as to oxidisable nanoparticles. Furthermore, storage facilities for self-igniting substances must comply with the requirements of the fire prevention guidelines of the Association of Cantonal Fire Insurers (VKF).

More studies to follow. Based on existing studies, the FOEN assumes that most of the roughly 600 companies in Switzerland that work with nanomaterials today do not use oxidisable particles, or only use low quantities. But with the spread of nanotechnology, the types and quantities of particles will change. "At present the major accident risk involving fires or explosions is moderate, but we will have to monitor future developments very closely," says Martin Merkofer.

The study does not report on the effects of a possible release of nanoparticles on health or the environment, because the necessary scientific fundamentals relating to toxicology and eco-toxicology are still being compiled at the international level. As soon as sufficient data are available, the FOEN intends to examine these areas, which are of considerable significance for major accident prevention.

Correct disposal of nanowaste. Nanomaterials represent potential hazards not only at the beginning of the production chain, but also at the waste disposal stage. “There is a risk that particles that are harmful to health or the environment could be released in an uncontrolled manner due to the incorrect handling of nanowaste,” explains André Hauser (FOEN Waste Recovery and Treatment Section). In order to sensitise producers, processing personnel and the waste disposal sector to this problem, a workgroup created by the FOEN formulated a set of guidelines for the safe and environmentally compatible disposal of nanowaste. This document explains to industrial and commercial companies how to handle, pass on and dispose of residue of pure nanoparticles and objects contaminated with nanoparticles.

also have to be implemented. These include technical, organisational and staff-related measures such as wearing protective clothing with a hood, as well as protective masks and sealed protective glasses. And in order to reduce the external risk potential, companies should ensure that, wherever possible, any residue to be passed on for disposal is not delivered in powder form. A consignment note for hazardous waste ensures that operators of waste disposal facilities receive all necessary information.

Nanomaterials classified as hazardous waste must never be placed in household or commercial waste, fed into sewage or mixed with other types of hazardous waste. Disposal in waste incineration plants is not recommended, because too little is known to date about the behaviour of high concentrations of free nanoparticles in the furnace and the exhaust gas purification system. To fill the existing gaps in knowledge, an FOEN research project aims to demonstrate how nanowaste can be disposed of or recycled in a practicable manner without risks to health and the environment. In the meantime, the guidelines

Nanomaterials represent potential hazards not only at the beginning of the production chain, but also at the waste disposal stage.

It recommends that, where possible, waste nanomaterials should be further processed at the production site so that they lose their nanostructure. For example, metallic particles can be dissolved in suitable acids, and when oxides are sintered at high temperatures, larger particles are formed that are no longer in the nano range.

Objective: lowest possible level of emissions. The guidelines classify waste containing free particles as hazardous waste if it is not possible to rule out negative impacts on health, safety and the environment due to the nanostructure of the particles, or if the potential consequences are unknown. A model prepared by the Swiss Federal Office of Public Health and the FOEN helps companies quickly identify potential risks associated with nanomaterials during production, processing and disposal. “Residue with high risk potential or unknown effects must be handled at every stage in such a manner as to ensure that exposure of employees, release of nanomaterials in the form of dust or aerosols, and other emissions into the environment are kept as low as possible,” says André Hauser. Other measures, including the recommendations of the Swiss National Accident Insurance Fund (SUVA) for the protection of employees,

recommend using the respective known disposal processes for hazardous waste, such as high-temperature incineration in special facilities. The effectiveness of methods that would seem suitable based on technical considerations should be demonstrated through prior tests.

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At Bühler Partec, production waste such as solvents resulting from the cleansing of systems for producing nanomaterials is collected in metal containers and later removed by an external waste disposal company. In Uzwil (canton of St. Gallen), a special collection system is used for nanomaterials that is separate from the sewage system. This means that, in the event of a defect, any escaping substances do not enter the sewage system, but are collected in containers and properly disposed of as hazardous waste.

All photos: Stefan Bohrer

Cross-border exchange of know-how

At the international level, Switzerland is committed to ensuring that developing and emerging economies also have the chance to benefit from the potentials of nanotechnology. At the same time, by promoting a worldwide exchange of technological know-how Switzerland wants to encourage a responsible approach to dealing with the potential risks of this new technology.

"Defining national strategies for the responsible use of synthetic nanomaterials is decisive for the success of this technology and for the exploitation of its potentials in the interests of sustainable development," explains chemist Georg Karlaganis. As head of the FOEN Substances, Soil and Biotechnology Division he focused intensively on this topic for many years. Since his retirement from the FOEN, it is primarily the United Nations Institute for Training and Research UNITAR that now benefits from his comprehensive know-how in the area of nanotechnology.

One of the main objectives of UNITAR, which is domiciled at the International Environment House near Geneva, is to provide training and education for administration and government personnel in developing countries. Since autumn 2009, UNITAR has been organising regional awareness-raising workshops throughout the world together with the OECD (Organisation for Economic Co-operation and Development) in order to explain the chances and risks associated with nanomaterials to representatives of developing countries. "Interest in these workshops is enormous, since the environmental and health authorities being addressed are often only vaguely aware of the related problems," notes Georg Karlaganis. His message at these workshops is that insufficient know-how, a lack of measuring and testing procedures and gaps in legislation could give rise to unperceived risks to health and the environment. "To ensure that such risks do not hamper beneficial innovation, a carefully conceived risk management concept is required worldwide – in order to preclude double standards and major discrepancies between the regulations of industrialised and developing nations."

Commitment to a global chemicals and waste management strategy. Switzerland has co-financed an initial series of nanotechnology workshops in all UN regions, including the Middle East, and is now participating in a second information campaign. "We want to create an understanding for the challenges at the national level, and demonstrate how a suitable strategy can be developed," says Gabi Eigenmann (FOEN International Affairs Division). Within this framework, selected pilot countries will also receive support in the development of national programmes. "At the same time, the aim is to introduce the global objectives being targeted for the sustainable use of nanotechnology."

The associated activities are part of Switzerland's commitment to an efficient, coherent and co-ordinated chemicals and waste management policy at the international level. One of the goals is to establish uniform prerequisites and legal bases for well-functioning risk management of chemicals in order to prevent undesirable risks from being passed on to disadvantaged regions.

Switzerland as pacemaker. At the second International Conference on Chemicals Management

Switzerland is actively involved in educating government officials in developing countries and countries with economies in transition throughout the world about risk management in the area of nanotechnology. Here we see former FOEN division head Georg Karlaganis (second from right) at a workshop in Abidjan (Ivory Coast) organised by UNITAR and the OECD for African nations.

Photo: UNITAR

(ICCM2), which was held in Geneva in May 2009, the FOEN assumed a leading role, together with the USA, in drawing worldwide attention to the topic of nanotechnology and further developing the policy framework of the Strategic Approach to International Chemicals Management (SAICM). A resolution that was drawn up with significant input from Switzerland and adopted at the ICCM2 emphasises the special responsibility industrialised nations have towards developing and emerging states, which need professional and financial support so they can acquire the necessary know-how, benefit from the potentials of nanomaterials and minimise the associated risks. The resolution also underscores the responsibility for the safety of employees, and recommends the promotion of risk research as well as legal, voluntary and co-operative measures in order to promote the safe use of this developing technology.

Co-ordinated risk research. In view of the existing knowledge gaps and the diversity of synthetic nanomaterials, there is clearly a strong need for international co-operation in the area of risk research. "Specifying the decision-making criteria for dealing with accidents involving such chemicals would exceed the resources of any one country," explains Martin Merkofer (FOEN Prevention of Major Accidents and Earthquake Mitigation Section). Switzerland is therefore actively campaigning within the OECD for cross-border co-operation, and has been entrusted with the management of a project it proposed itself to conduct a joint study of the related accident risks.

Within the ISO (International Organization for Standardization), Switzerland is also involved in the development of uniform terminology for nanomaterials, standards for protection of employees, and co-ordinated measurement methods and testing guidelines.

Mutual exchanges of experience and know-how also support a network of environmental and public health authorities in Germany, Austria and Liechtenstein that was initiated by Switzerland. These four countries jointly organise periodical information meetings focusing on major issues relating to nanotechnology, such as safety data sheets, PR activities and the possibility of insuring potential risks. In this way, Switzerland is able to quickly obtain information about important developments within the EU.

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Nanomedicine in focus

All the main processes in the human metabolism take place in the nano dimension. Those who understand them and can deliberately influence them hold the key to solving many medical problems. However, from an ethical point of view, the advantages and disadvantages of newly developed nanosubstances and procedures have to be weighed up from an overall perspective.

It is often difficult to distinguish nanotechnology applications from other technological processes. In many cases, they do not break new ground, but merely improve conventional products. In the field of medicine, nanocoatings can help the body more effectively assimilate prostheses – such as artificial hip joints made of steel or tooth implants made of titanium – and render them more robust.

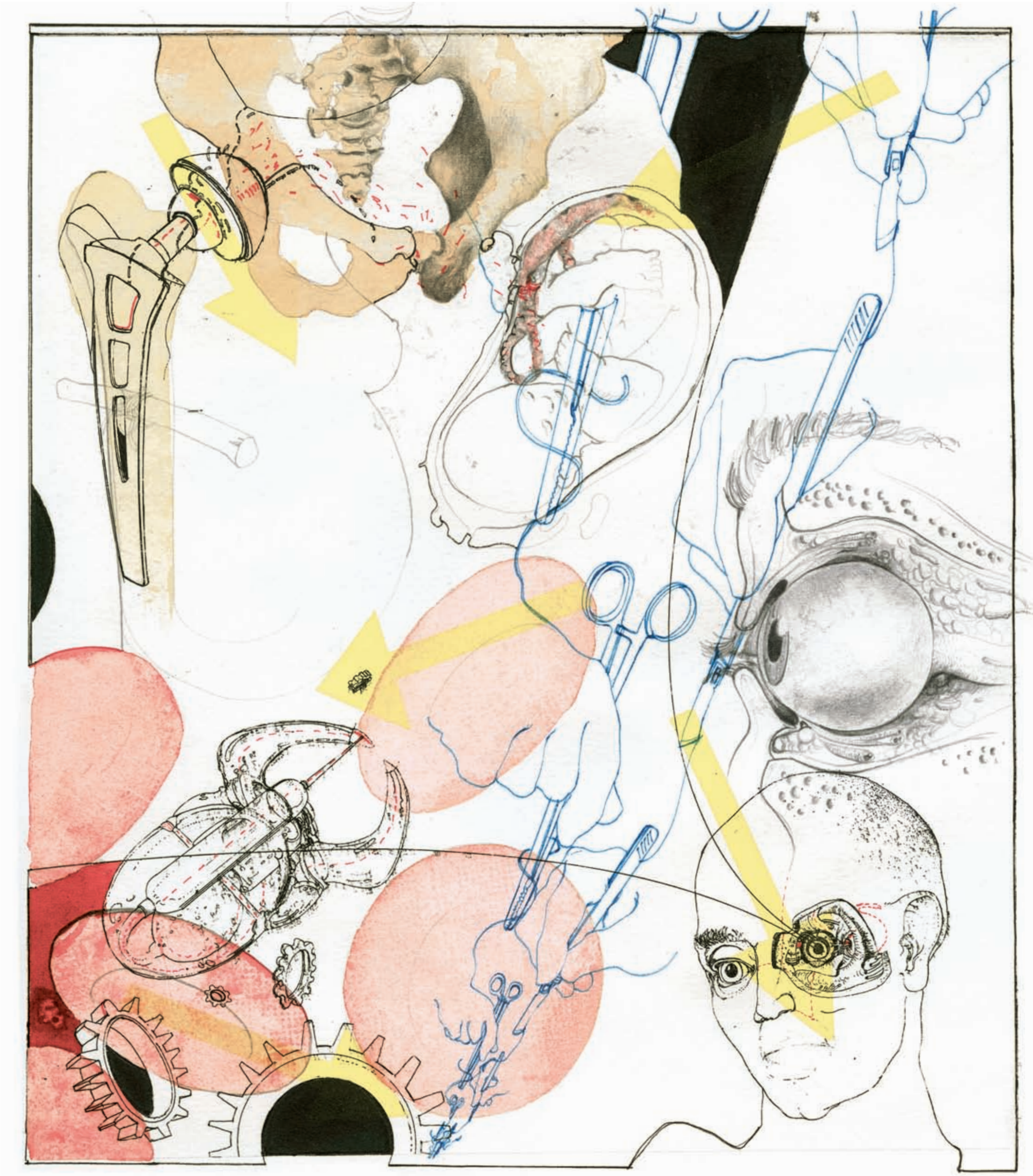
Crossing of barriers is inevitable. Nanoparticles integrated into a coating are regarded as relatively safe, but there are still some uncertainties. For example, an implant that remains permanently in the body constantly loses particles due to abrasion. Depending on their size, these can enter the bloodstream and break through natural barriers in the body, e.g. the placenta. Researchers in Louisiana (USA) have found traces of cobalt and chromium in the blood of newborn babies, originating from the mother's artificial hip.

Recent studies carried out by the Swiss Federal Laboratories for Materials Science and Technology (Empa) confirm that the placenta does not fully protect a foetus's circulatory system against nanoparticles. In simulations, scientists observed that particles between 200 and 300 nanometres in size can pass through the placenta.

The fact that a foetus can be affected by medical treatment of the mother is a dilemma not only for nanomedicine. "In order to carry out ethical studies, I need to know whether a nanomaterial in fact represents some kind of risk for the child," explains ethicist Andreas Bachmann (FOEN Biotechnology Section). He prepared a variety of expert reports on this topic at the request of the Federal Ethics Committee on Non-Human Biotechnology. "Just because something is called 'nano' does not necessarily mean it's hazardous." In the case of a pregnant woman and her foetus, consideration also has to be given to moral status. "The importance of an embryo may be viewed differently from that of a newborn child or the mother." Bachmann continues this line of systematic ethical thinking: "We can only estimate potential damage if we are familiar with scenarios and their probability of occurrence." In Andreas Bachmann's view, if the necessary data are not available the precautionary principle has to be applied: "Before we have identified the risks, we must not expose people to danger."

Targeted interventions. The use of microscopic instruments at the molecular level can greatly enhance the effectiveness of medical treatment. For example, research is being carried out on microscopic containers that can transport therapeutic substances precisely to the location at which they can take effect. Substances that are poorly absorbed or even broken down by the body before they reach their target can be encapsulated in nanocontainers which are so tiny that they are not detected by the body's immune system and, if required, can even penetrate the blood-brain barrier.

Nanotechnology can also be used where scalpels and radiation were once required, e.g. for the treatment of cancer, in which diseased tissue needs to be removed in its entirety while healthy cells have to be protected. The development of magnetic fluid hyperthermia by the Charité clinic at the University of Berlin made headlines. In this procedure, ferrous oxide nanoparticles in a sugar-coated capsule are injected directly into a tumour. The nanoparticles are then heated via a magnetic field and attain much higher temperatures than larger ferrous oxide particles. In this way, cancer cells can be accurately targeted and destroyed. In clinical studies, this new pro-



Abraded metal particles from an artificial hip joint in a pregnant woman can also enter the bloodstream of the foetus via the placenta. The potentials of nanomedicine range from a broad variety of early diagnoses through to the targeted destruction of cancer cells and increasing the performance of the central nervous system, e.g. through the use of visual prostheses. A representation of this problematic by illustrator Lorenz Meier (Zurich).

cedure has been trialled successfully, especially for treating malignant brain tumours.

A hint of science fiction. One day, it may be possible for precisely targeted incursions into the brain to be used not only for treating diseases, but also to bring about a general increase in the performance of the central nervous system. Futurologists are speculating on neuronal visual prostheses that can process more images per second than the natural optical cells and could thus increase reaction capacity.

In science fiction, the cyborg (cybernetic organism) is an established concept. It may be bizarre, but a combination of organism and machine is not necessarily questionable from an ethical point of view. "Why not, as long as we are talking about reasoning human beings who want to increase their mental capacity?" asks Andreas Bachmann. But advantages of this sort brought about through technology should be available to everyone who is interested – regardless of their financial capacity. Placing advantages created by nanotechnology solely at the disposal of a wealthy clientele would be contrary to the principle of social fairness. "But even then, a prohibition would not be the only possible response. Full legalisation and secured access for everyone could also be a solution," notes Andreas Bachmann. On the other hand, the use of nanotechnology for self-enhancement should not be allowed to become a "must", since society has to respect an individual's right to choose not to make use of certain technological benefits.

More knowledge – but not necessarily more ability. Nanotechnology has the potential to revolutionise medical diagnosis, since nanosensors would be able to detect the slightest changes in tissue even before the initial symptoms of disease become apparent. Permanent medical monitoring is another potential use for nanosensors. For example, tiny sensors could be used for monitoring the blood values of pregnant women or the blood sugar levels of diabetics. It would even be conceivable to combine nanosensors with an implanted insulin pump that automatically releases insulin as soon as the blood sugar exceeds a certain level.

However, where personal data are collected in large quantities, the private sphere is at risk. If a person's lifestyle can be deduced from key data relating to their metabolism, this could place them at the mercy of, for example, health insurance providers whose premiums are based on the requirement that their clients have a healthy diet and are not predisposed to serious illnesses. Progress in the area of diagnosis also has two sides. If ever more diseases can be predicted even before they manifest themselves, or before a corresponding therapy exists, this is likely to have consequences in terms of body image and attitude to life.

Separate assessment of each case. The use of nanotechnology in medicine may be new, but the related ethical aspects are not. "There are no fundamentally new ethical issues in this area," Andreas Bachmann points out. "Instead, the known ethical rules – for example, the principles of precaution and solidarity – need to be specified in relation to problems associated with nanotechnology. This makes good sense, but it's by no means revolutionary." Unlike certain non-governmental organisations, Andreas Bachmann is opposed to the definition of any specific nanoethics. In his view, it is more important that each application should be assessed separately based on as much knowledge about its potential consequences as possible.

Lucienne Rey

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Nanotechnology has the potential to revolutionise medical diagnosis, since nanosensors would be able to detect the slightest changes in tissue even before the initial symptoms of disease become apparent.

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