



Information Brochure

# Know Your Nano!

*publifocus* „Nanotechnology, Health and the Environment“

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## Imprint

You may order additional copies of this brochure directly from TA-SWISS or on the Web at [www.ta-swiss.ch](http://www.ta-swiss.ch).

This English translation was made possible by Swiss Re Zurich.

Cover picture: source BASF  
„Nanocubes“: pores in the nanometer range can store hydrogen.

# Editorial

Nanotechnology researchers and experimenters focus on materials at the level of individual atoms and molecules measuring 1 to 100 billionths of a metre. At these dimensions, the properties of a material are transformed, sometimes quite radically. This is precisely why nanotechnology opens up new possibilities – and new risks. A substance that is harmless at sizes down to a micrometre (one millionth of a metre) may pose health and environmental concerns at the nanoscale (one thousand times smaller). In May 2006, eight environmental and consumer protection organisations petitioned the U.S. government to remove from the market all cosmetic products with synthetically produced nanoparticles (mainly titanium oxide and zinc oxide in sunscreen). The reason: to prevent a potential health hazard. Both the U.S. health authorities and the cosmetics industry denied that there was any danger. There has been a similar discussion in Switzerland about sun creams that contain nanoparticles; and though the Swiss authorities, too, maintain that there is no risk, unsettled issues definitely remain concerning the regulation and labelling of such products. There is much research to be done, and many decisions to be made.

Policymakers are following attentively the evolution of this new technology. As with all things new, they want to find out as much as they can about its potential and its limitations. They also want to know if nanotechnology's benefits might make certain risks seem reasonable and acceptable. Studies assist them in weighing these opportunities and threats, and in assessing the consequences. Any legislation that is nee-

ded must also take the public's views into consideration.

TA-SWISS, Switzerland's Centre for Technology Assessment, wishes to record the public's opinions on nanotechnology as of 2006, including the arguments and reasoning that currently underlie those opinions. For this purpose, TA-SWISS is organising a publifocus in September 2006, with regional evening meetings throughout the country. Each publifocus meeting features a discussion involving 15 randomly chosen persons on a particular issue – in this case, nanotechnology. This brochure contains informative material for that discussion: it tells what nanotechnology is, what its applications are now and what the prospects for the future may be; where opportunities and hazards lie; and who within Switzerland is involved. Before the end of the year, the opinions expressed by the publifocus participants will be incorporated into a report serving to inform the Swiss Parliament and interested members of the public.

The publifocus „Nanotechnology, Health and the Environment“ is actively sponsored by the Federal Office for Public Health (FOPH) and the Federal Office for the Environment (FOEN), as well as by the Zurich University of Applied Sciences Winterthur (ZHAW). A broadly competent Advisory Group, comprising experts from politics, research, science, business, the social sector, the media and consumer protection organisations also provides critical support.

*Michael Emmenegger,  
Project head publifocus  
„Nanotechnology, Health  
and the Environment“*

# Nano – a Dimension Takes the Spotlight

*Nanotechnology is a new field of research, but one that is already generating a great deal of scientific interest. Swiss researchers are among the pioneers in this revolutionary area.*

Nanoguard shampoo can „stop your excessive hair loss“... Treating your windscreen with Nanoprotect will „allow the surface to deflect any dirt and water“... Yonex® NanoSpeed® tennis rackets ensure „maximum return of energy to the ball“... These are typical of claims surfacing more and more frequently in the media these days. „Nano“ is being hyped as a „magic formula“: a wondrous 21st-century technology that will change every aspect of our daily lives.

## What is „Nano“?

What actually is „nano“? The word is simply a prefix meaning „billionth“ ( $10^{-9}$ ). In the case of nanotechnology, the reference is to the „nanometre“ (nm), which is one billionth of a metre (or one millionth of a millimetre). To illustrate: a sugar molecule, which measures about one nanometre, is about as big in relation to an apple, as the apple is in relation to the earth. The „nano“-world is the world of atoms and molecules. A hydrogen atom is about 0.1 nm in diameter. A DNA molecule, which carries genetic information in the cell nucleus, is about 2.5 nm long. A human hair is huge in comparison – about 50,000 nm thick.

We generally think of nanotechnology as concerning materials and structures with dimensions between 0.1 nm

and 100 nm. In practice, however, „nanotechnology“ is not precisely defined. Is size the only criterion? If so, the soot particles in wood smoke are nanoparticles. However, the term is often applied only to synthetic, i.e. artificially produced particles, and some writers are even more restrictive, applying the word only to nano-materials that demonstrate novel physical or chemical properties that the same substance does not have at larger dimensions. For example: normal titanium oxide powder is white, and is used in paint as a pigment. As nanoparticles, however, it is colourless and transparent – to visible light, at least – and is used in sunscreen for its UV-blocking properties. It will be necessary to agree upon

an internationally binding definition so as to put future regulations and guidelines on a common, unequivocal basis: this applies particularly to products and applications using synthetic nanoparticles.

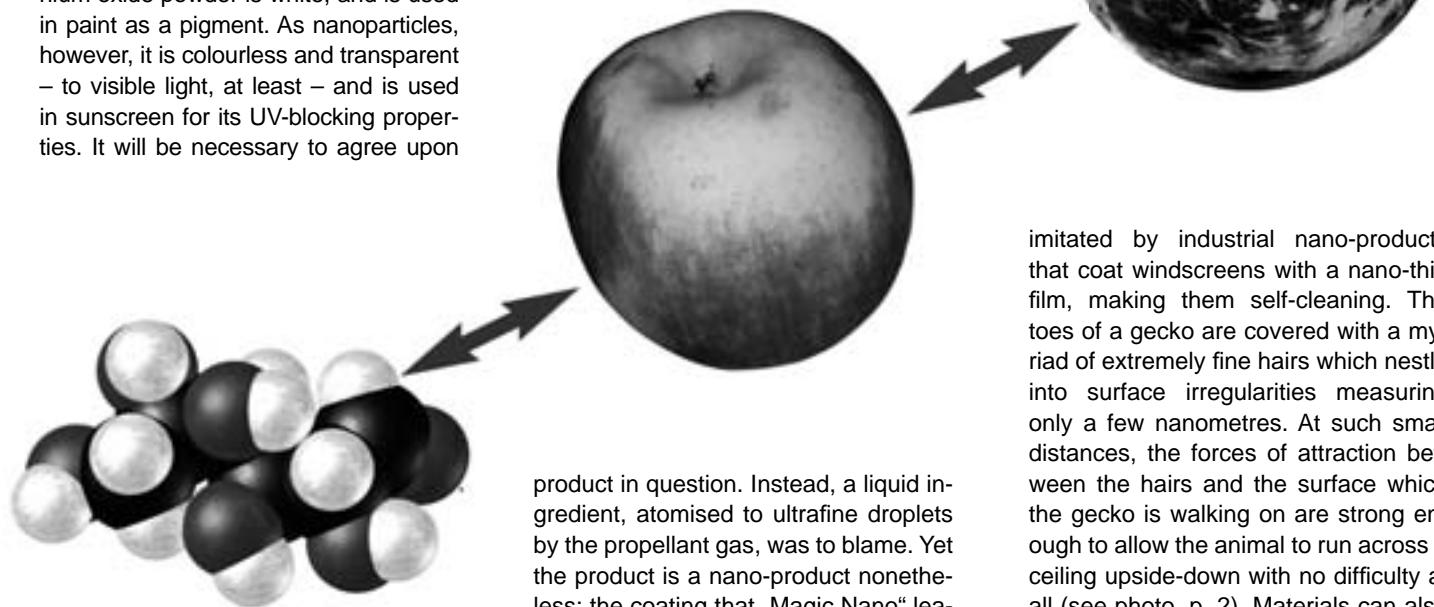
## Nano or not?

„Nano“ has become a buzzword, and this can sometimes lead to serious confusion. In late March 2006, there was a flurry of headlines about „Magic Nano“, a household spray recently put on the German market as a dirt-repellent coating for glass and ceramics. Over 110 users had experienced difficulty breathing; six were hospitalised with lung edema. At first, it was feared that nanoparticles in the spray had caused the health complaints; investigations, however, showed that there were no such particles in the

ves on the sprayed surfaces is only a few nanometres „thin“.

## Nano in Nature

The nano-world is not a human invention. A nanoscale texture on the surface of the lotus leaf causes water to bead and run off at speeds high enough to carry dirt particles away as well (see photos on p. 2). This „lotus effect“ is

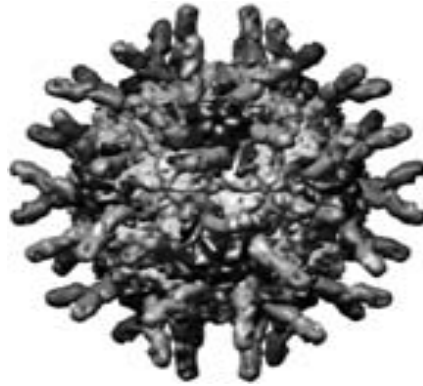


product in question. Instead, a liquid ingredient, atomised to ultrafine droplets by the propellant gas, was to blame. Yet the product is a nano-product nonetheless: the coating that „Magic Nano“ lea-

imitated by industrial nano-products that coat windscreens with a nano-thin film, making them self-cleaning. The toes of a gecko are covered with a myriad of extremely fine hairs which nestle into surface irregularities measuring only a few nanometres. At such small distances, the forces of attraction between the hairs and the surface which the gecko is walking on are strong enough to allow the animal to run across a ceiling upside-down with no difficulty at all (see photo, p. 2). Materials can also

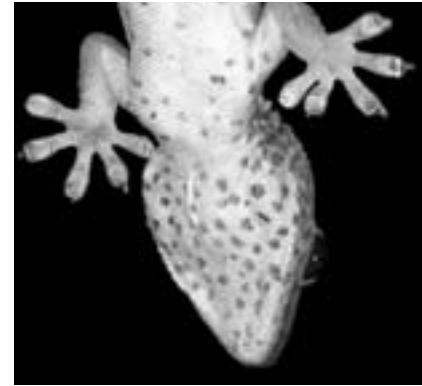
be stronger at nano-dimensions: calcium carbonate in the form of blackboard chalk is rather soft; but an abalone shell, a nanometre-fine layered structure of the same material, is extremely hard.

Nanoparticles are also found in numerous foods, in the form of natural colloids (small agglomerations of molecules). In milk, these include casein (100 nm) and whey protein (3 nm). Viruses (see photo at right), due to their small size (usually less than 100 nm in diameter), are able to slip into the cells of our bodies to carry out their nefarious work. Thus, nanostructures and nanoparticles have always been a part of our everyday lives, even though no one spoke about „nano“ until recently. That we do speak about it frequently today is due in large measure to the Swiss. Until a short time ago, the world of atoms and molecules



Model of a virus, University of California

was impossibly small for the human eye to see; now, however, new microscopes developed in Switzerland have made it possible to view nanostructures – and even to manipulate individual atoms.



Kellar Autumn, Lewis & Clark College

### How Nano Became Visible

Since the 17th century, researchers have used optical microscopes very successfully to further our knowledge of biology and medicine. Due to the wave properties of light, however, these instruments can resolve no objects smaller than several hundred nanometres, corresponding to a magnification of approximately 1500x. This allows us to see tissue cells and bacteria, but not viruses or individual molecules. The development of the electron microscope in the 1930s was an enormous step forward. These instruments increased magnification factors by 100 to 1000 times – into nanoscale – and permitted observation of strings of deoxyribonucleic acid: the „DNA“ responsible for the transmission of genetic information in the cell nucleus.

From 1981, the scanning tunnelling microscope (STM) provided researchers with even greater possibilities. Working at the IBM research laboratory in Rüschlikon near Zurich, Heinrich Rohrer and Gerd Binnig designed a microscope that used an „atomically sharp probe“

of tungsten: the tip consists of a single atom. When this probe is brought into the near proximity (~1 nm) of an electrically conductive surface, electrons begin to flow (or „tunnel“) between them, though they do not touch – a phenomenon explained by quantum mechanics. The closer the probe approaches the surface, the stronger this current becomes. By „scanning“ a surface – moving the probe over it in a tight grid and recording the fluctuations in the tunnelling current – a three-dimensional model can be produced. In this way, the STM allows us to visualise features measuring only hundredths of a nanometre – a landscape in which atoms take on the „appearance“ of billiard balls.

The STM allows us to „feel“ atoms as well as „see“ them. By touching the point of the probe to the surface, individual atoms can be made to „stick“ to it, and they may then be deposited at another position: nano-scientists and researchers find this trick quite useful. In a further development, the atomic force microscope (AFM) now allows us to visualise non-conductive surfaces, opening a window into the world of atomic biology (see photo, p. 3).

### Tremendous Economic Potential

These new microscopes opened a way for researchers and developers into the heady diversity of the nano-world. Recent years have seen financial support for these activities increase impressively. In 1998, the world's governments invested 600 million dollars in nano-research and development; in 2002, this had grown to 2.1 billion, and the estimate for 2006 is six billion dollars, with Europe, the U.S. and Japan in a



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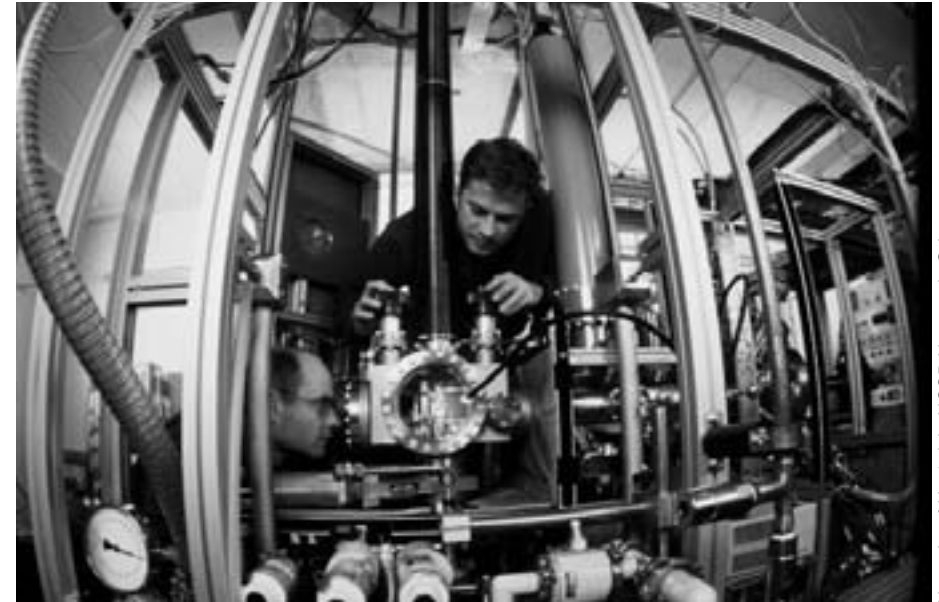
www.lotuseffect.de  
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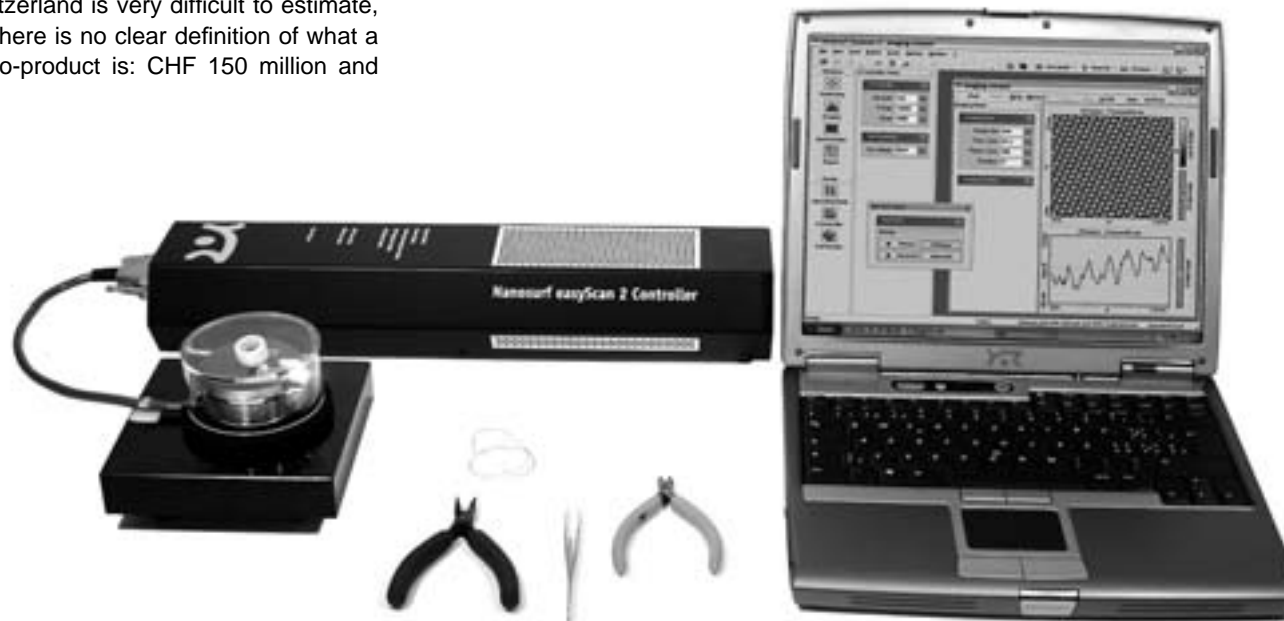
neck-and-neck race. At least the same amount, however, is being contributed by industry. In the U.S., two-thirds of the top 30 corporations have started nano-programmes, and throughout the world approximately 2000 new startups are busily at work. In Germany alone, it is estimated that 100,000 jobs depend directly or indirectly on nanotechnology. According to the Swiss NCCR (National Centre of Competence in Research) Nanoscale Science, approximately 500 persons are active in nano-research and a similar number in nano-industry. An annual CHF 50 million of taxpayers' money is believed to reach nano-research and allied areas. According to the State Secretariat for Economic Affairs, Switzerland is the world leader in the field – at least on the basis of expenditure per capita. The annual turnover of nano-products in Switzerland is very difficult to estimate, as there is no clear definition of what a nano-product is: CHF 150 million and

climbing might be a reasonable guess. Injections of venture capital, which have now reached an annual CHF 1 billion, are another indication of the high expectations coming into play. A rising flood of nanotech products is engulfing world markets. Current sales may be around USD 80 billion; the estimate for 2015: around USD 1 trillion.

On the other hand, all sorts of tired, shop-worn products are being pepped up with a new „nano“ label. Any manufacturer of tyres, or of printer's ink – to name just two examples – might quite justifiably market their products as „nano“, for both have contained nanoscale soot particles for decades. In contrast, the „iPod nano“, which packs 1000 songs in an electronic box no bigger than a cigarette lighter, has little in common with



Hans-Josef Hug's lab, NCCR Nanoscale Science



Nanosurf, Liestal

nanotechnology – despite the mighty mite's marketing claim of being „unbelievably small,“. Even scientists have learned how to attract funding with this new prefix: a Swedish researcher recently confessed to receiving EUR 1.7 million from an EU „nanobiotechnology“ programme, though the description of his project – the production of miniaturised support structures for artificial tissue – might well have been written with no mention of „nano“ at all.

## A New World of Technology

**Materials take on completely different properties when they are in extremely small bits. Of particular interest are carbon nanospheres and nanotubes.**

Every chemical element has characteristic, defined properties: colour, hardness, elasticity, conductivity, melting temperature etc. However, if an object made of a particular substance is divided again and again until it falls out of the macro-world into the nano-world, these properties can change radically. A gold wedding ring is yellow in colour; but gold nanoparticles are red. Carbon (the graphite in pencil lead, for example) is relatively soft; but carbon in the

form of nanotubes is a hundred times stronger than steel. Hold a match to an aluminium can and it will not burn; but aluminium in the form of nanometre-sized particles is an explosive material used as a catalyst in rocket fuels.

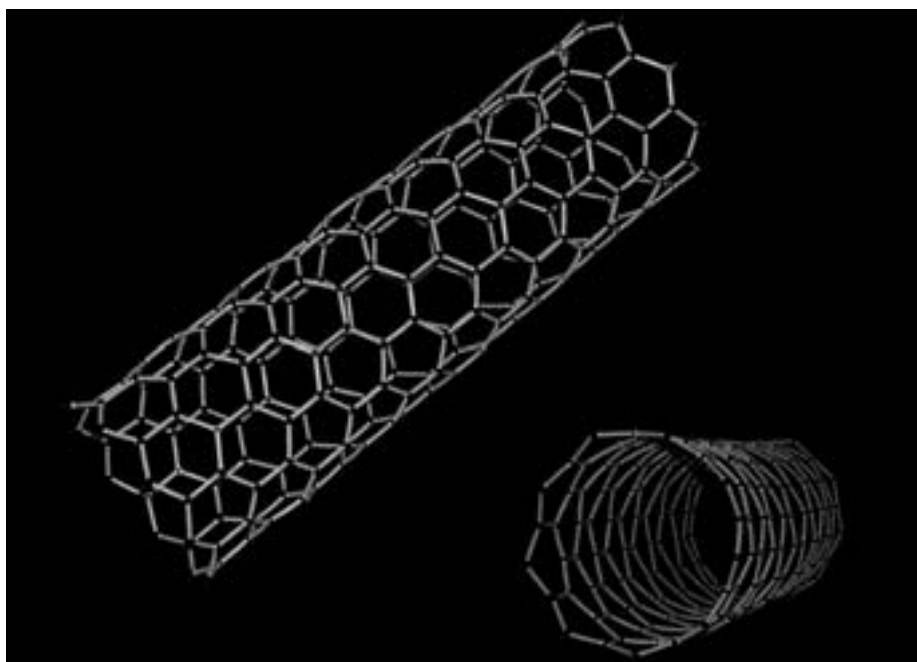
### Why Nano is Different

In some cases, the reason behind these transformations is a shift to different physical laws. While the laws of classical mechanics dominate the macro-world of

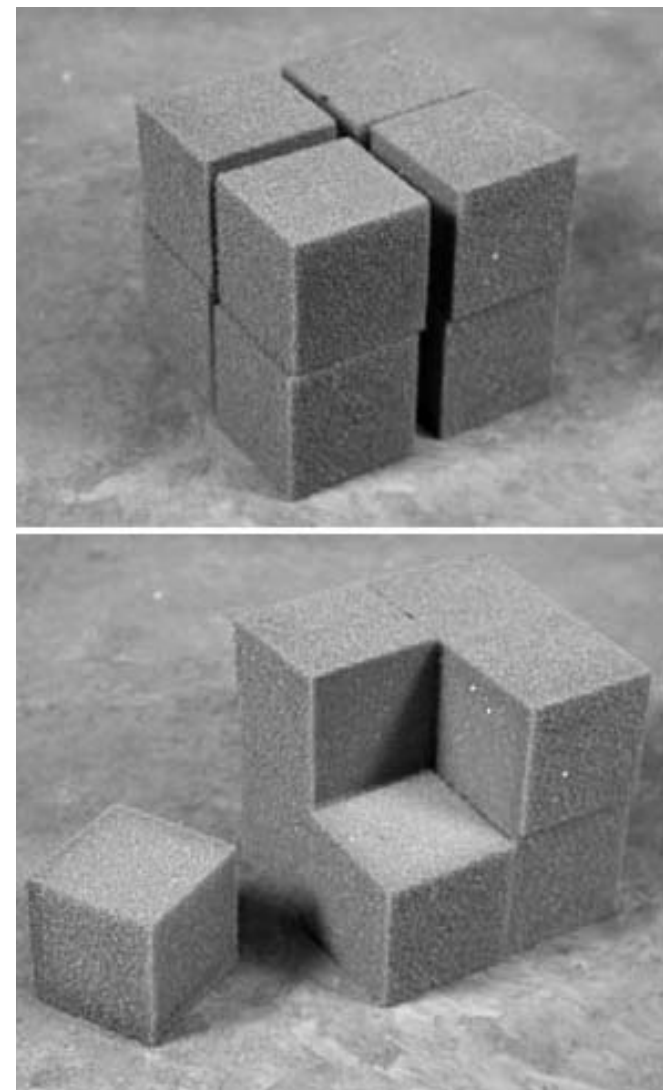
our everyday lives, it is the laws of quantum mechanics that rule the nano-world. These quantum forces are present at larger dimensions, too; but they are so small as to be negligible.

Another reason for the „otherness“ typical of nanoscale objects is the wavelength of the visible light spectrum. We see a particular colour when light of that colour is reflected from an object. As the wavelength of visible light is 400 - 800 nm, some nano-materials composed of smaller particles may be transparent – as we saw in the case of the titanium oxides used in sunscreens. In many cases, the nano-effects depend on changes in the ratio of surface area to volume. If we were to split a cube into smaller and smaller cubes, its surface would become larger and larger in relation to its volume (see photo at right). Thus a cube measuring one micrometre (1000 nm) on each side will contain roughly a billion molecules, of which 0.6 % are at the surface. A cube measuring 10 nm on each side will contain only 1000 molecules – but 50 % of them will be at the surface. It is this enormous increase in the surface area of finely divided nanoparticles that can change relatively inert substances into highly reactive ones. The material can then melt faster, absorb more (a biosensor, for example, can bind more molecules) or simply become explosive. Gold, which in the macro-world combines with other elements only with great difficulty, becomes – at the nanoscale – a highly reactive catalyst used in fuel cells.

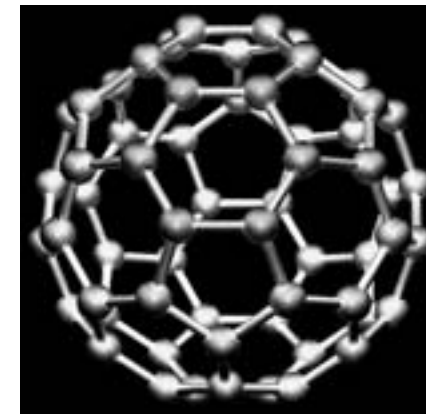
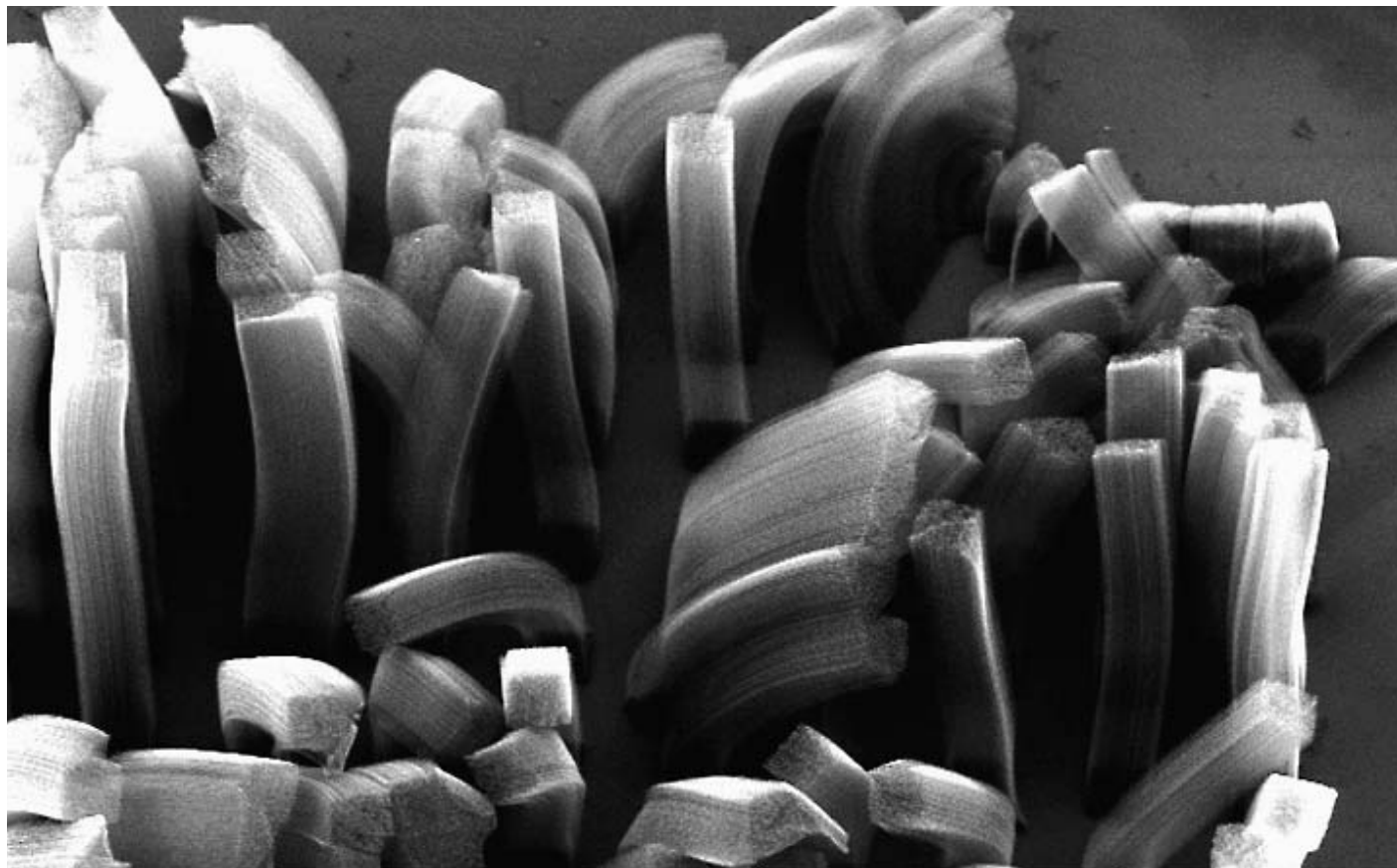
The Woodrow Wilson International Center for Scholars in Washington D.C. published an inventory in March 2006 describing 212 nano-products on



www.nccr-nano.org/nccr



the world consumer market: 128 in the U.S., 42 in Asia, 35 in Europe and 7 in the rest of the world. There are in addition an estimated 600 different primary nano-materials and components, as



www.nccr-nano.org/nccr

www.nccr-nano.org/nccr

well as an unknown number which contain nanoparticles or nanostructures but which have not been declared as such by their manufacturers. According to the product descriptions of the 212 declared nano-products, the main nanoscale elements used are carbon (29 products); silver (25); quartz (14); titanium oxide (8); zinc oxide (8); and cerium oxide (1).

### Nanotubes and Buckyballs

At nanoscale, the most commonly used form of carbon takes on completely novel structures, making it the star of the nanotechnology scene – but also its „problem child“, as we will see. In 1991, NEC, a Japanese electronics company, produced the first carbon nanotubes (see photos, p. 4 and p. 5 left). When an electrical or laser discharge occurs in a highly pressurised atmosphere of carbon-rich gases, some of the carbon

atoms bind together to form long, hollow cylinders.

One nanometre in diameter and up to several thousand nanometres in length, this „carbon spaghetti“ is six times lighter than steel, a hundred times stronger – and flexible. It is extremely heat-resistant, and conducts heat better than diamond, another excellent heat conductor of pure carbon. By varying the production method, electrically conducting, semiconducting, or insulating

nanotube products may be obtained. Nanotubes are the perfect example for the potential of nanotechnology. They make tennis rackets and golf clubs lighter and stiffer; they may be spun into extremely high-tension yarn; they can be used to manufacture transparent films that are able to transfer heat, or glow. Nanotubes may be used as molecular „delivery containers“ for the active ingredients in medicines; they may replace the transistors in ultrafast computer chips, or dramatically boost TV-screen resolution.

Other nanostructures include buckminsterfullerene ( $C_{60}$ ). Commonly known as the „buckyball“, this structure is a hollow sphere 0.7 nm in diameter, formed by 60 atoms of carbon arranged into a pentagon-and-hexagon pattern reminiscent of an old-style football (see photo above). It is thought that buckyballs may be used to deliver the active ingredients in medicines, or in other similar applications; another prospective application is in high-efficiency solar cells.

## From Window Panes to a Cure for Cancer

*Browsing through the palette of existing nano-products and the catalogue of future nano-ideas and visions shows nanotechnology's versatility and promise.*

The Woodrow Wilson Center inventory also categorises the 212 nanotech consumer products according to application. The „Health and Fitness“ group accounts for more than half (125), followed by „Electronics and Computers“ (30), „Home and Garden“ (21) and „Food and Beverage“ (19). There are 10 products in the „Automotive“ category; three products were developed especially for children. In „Health and Fitness“, the largest category, 34 products fall into the „Clothing“ sub-group, followed by „Sporting Goods“ (33), „Cosmetics“ (31), „Personal Care“ (23) and „Sunscreens“ (8). Already widespread are nanometre coatings. Filling microscopic depressions in glass, ceramic, metal or painted surfaces with a durable layer of nano-

particles (e.g. titanium oxide) produces a surface so smooth that water runs off and dirt particles do not stick. Self-cleaning window glass and building facades are presently available; so are shower partitions which show no water spots and stainless steel kitchens which show no fingerprints. Nano-coatings can also make automotive paint more scratch resistant, and protect metallic surfaces against rust. In Germany, a toothpaste has been developed for teeth sensitive to heat or cold: the active ingredient, a mixture of nanoscale calcium phosphate particles and proteins, imitates natural tooth material, sealing the microscopic cracks in the tooth enamel that are responsible for the pain.

A layer of silver nanoparticles on the

inside of a refrigerator can be effective against bacteria and fungi. The same effect is exploited in treating the synthetic yarn used in sports clothing – cycling shorts and jerseys or sport socks, for example – thus inhibiting growth of the bacteria that cause body odour. Soaps with silver nanoparticles are already on the market, as well as washing machines that „disinfect“ the wash by dispensing silver ions during the wash cycle.

Titanium dioxide or zinc oxide are already commonly used in sunscreen as UV blockers: acting as tiny mineral mirrors, they reflect or absorb UV rays and protect the skin. These particular substances are used mainly for aesthetic reasons: the nanoparticles appear colourless, while the pigments previously used left a white film on the skin. C<sub>60</sub> fullerenes are used as a preservative in facial creams: the carbon atoms on the surface of the nanoparticles bind the molecules that cause the fats in the cream to turn rancid. It has recently become possible to coat building facades,



www.lancome-usa.com

window glass, furniture, carpeting or interior walls with titanium oxide, allowing sunlight to reach dirt, grease, coffee or ink stains and gradually fade them away. With the same procedure, it is also possible – at least in the laboratory – to reduce the concentration of organic pollutants in room air.

### Nanotech in the Food Industry

Nanoparticle additives of aluminium oxide, silicon dioxide, zinc oxide or titanium dioxide in plastic films and containers result in a product that is more resistant to tearing and impact, and less pervious to water vapour, oxygen and UV light. The exchange of silver ions supplied by a silver nanoparticle additive can inhibit bacterial growth on the surface of the packaged food, keeping it fresher longer. A nano-coating inside bottles and cans can prevent carbon dioxide loss, improving beer freshness. One vision is to produce protective packaging that changes colour when the contents have gone bad.

Even foods themselves may con-



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tain nanoparticles. Natural food dyes, aromas and vitamins are already being packed in nano-capsules before being mixed into drinks. The ingredients then dissolve more readily in the liquid and are taken up and metabolised more rapidly by the consumer's organism. Not yet on the horizon are those science-fiction pizzas with different nano-capsules keyed for activation by different microwave oven wattages: 400 watts for Margherita, 800 watts for Prosciutto e funghi and 1200 watts for Quattro stagioni!

Though the food industry is working intensively on nano-food, the sector – in clear contrast to sports equipment manufacturers – is very discreet regarding their nano-projects. This may reflect their experience with genetically engineered foods, where vocal critics and consumers concerned about the safety of such products prevented their launch in many regional markets.

### Bright Hopes for Medicine

The medical applications of nanotechnology are generating intense interest. Development is under way on devices that – within minutes – can test a single drop of blood for a broad range of substances. These „labs-on-a-chip“ carry reagents for hundreds of different types of molecule on a surface of only a few square centimetres. Also under development are „nano-crystals“ that glow under UV light. The body produces specific antibodies in response to an infection: if the glowing nano-crystals could be engineered to „stick“ to these antibodies, it would be possible to detect them in blood or urine samples, even at extremely low concentrations.

Work is also being done on nanomedicines. It is thought that hollow nanoscale structures might be used as vehicles for active ingredients: equipped with specific search molecules, the structures could be „sent“ directly to the diseased tissue. The amount of active ingredient would be only a fraction of that needed today, making long-term drug treatments more patient-friendly.

Successful initial tests have been carried out in the U.S. on a nano-capsule that contains insulin-producing cells. It is envisioned that such capsules might circulate permanently in a diabetic's bloodstream, providing the patient with the needed insulin.

There is even hope that nanotechnology will find applications in cancer therapy. Nanoscale iron oxide particles have already been tested on humans in Germany. These particles, which can be magnetised, are injected directly into a tumour. This part of the body is then exposed to a strong magnetic field; the iron oxide particles begin to vibrate, and the resulting heat damages the malignant tissue. Preliminary clinical testing has been carried out on brain tumours as well as on ovarian, cervical and prostate cancer; but whether this „magforce nanocancer therapy“ will fulfil the high expectations remains to be seen.

Several experiments are also being carried out with cancer medicines that are injected into the tumour and deposit themselves there. Prostate cancer in mice has been successfully treated by

Nanosphere, Inc.  
Northbrook USA

packing plastic nano-spheres with the cancer medicine. When injected, they stick to the cell wall and are ingested by the cancerous cell, along with their deadly contents.

Injected into the bloodstream, it is hoped that such pharmaceutical „Trojan horses“ would even be able to combat malignant cells that had already metastasised throughout the body.

## Could Nanoparticles Become a Problem?

*Despite the promise of nanotechnology, little is known at present about the potential side-effects. Particularly synthetic nanoparticles, with structures and surfaces not encountered in nature, could hold dangers in store.*

The most serious concern discussed by experts is the possibility that nanoparticles might enter the human body and cause damage there. Where nanoparticles are solidly bound in a matrix, as in automotive paint or tennis rackets, the danger does not seem as present as in cases where nanoparticles are liberated into the environment. Such free nanoparticles might easily be inhaled into the lungs, or taken in through the skin or the alimentary tract. Obvious sources would be nano-products used daily in contact with our bodies, such as cosmetics, textiles, food packaging – or indeed nano-food or beverage products, where nanoparticles are intentionally ingested. Nanoparticles that the body digests or decomposes like biological molecules would not seem to be particularly worrisome. Such nano-substances might be found suitable as food additives and used as vehicles for vitamins or colouring. However, if a nanostructure is foreign to the body and does not dissolve or decompose in it, then it must be assumed that it will remain long-term as a foreign substance. Of these non-soluble nanoparticles, substances such as nanotubes and fullerenes (buckyballs and similar structures) might turn out to be a particular headache.

### Animal Experiments Provide the First Clues

Experiments on mice and rats in the U.S. indicate that nanotubes might endanger the lungs. Introducing large amounts of carbon nanotubes into the animals' bronchial tubes resulted in infections and lung lesions. The extent to which these results can be transferred to the human world is still uncertain: such large amounts of nanotubes would not normally be inhaled. Fullerenes, too, are potentially toxic, as shown by experiments with juvenile largemouth bass. Dissolved in the water of an aquarium, buckyballs (C<sub>60</sub>) resulted in cellular damage to the brain tissue of the fish.

### Environmentally Harmful?

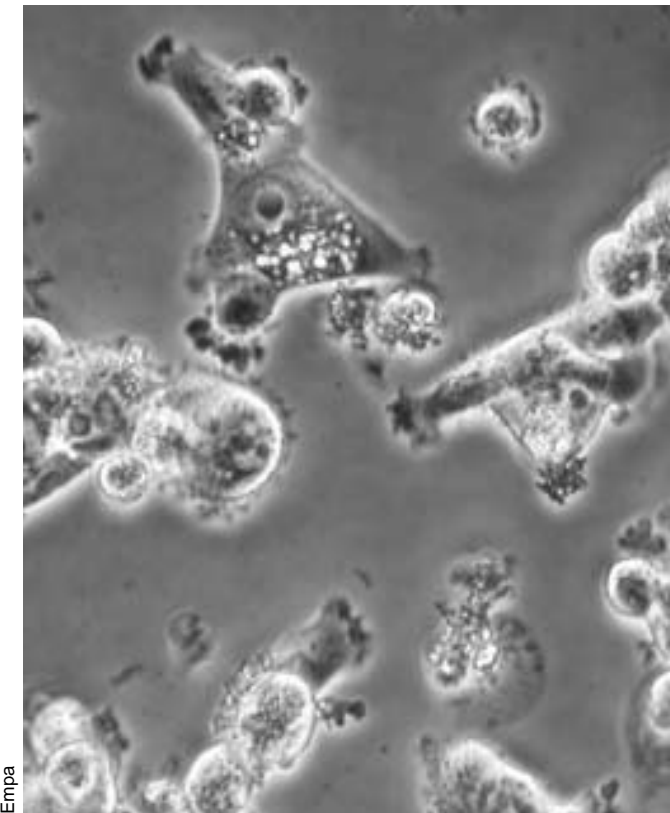
There are also many open questions as to the potential harm that nanoparticles and nanotech products might cause to the environment. Depending on the manufacturing process and the type of product, nanoparticles could contaminate bodies of water, the air, the soil and ground water: for example, much of the nanoscale silver particles used in treating clothing will unavoidably be washed out. Though these particles may not be a danger to humans, an American clean water advocacy organisation maintains that they are highly toxic to aquatic life (Washington Post, June 2006). Nanoparticles are also

being used increasingly in disposable articles that, sooner or later, will be discarded or recycled. Even nanoparticles that seem solidly integrated into a product may be released at some time through abrasion, corrosion or ageing. Many synthetic nanoparticles will be foreign to the environment as regards type and amount; they could become a new class of non-biodegradable pollutant. Almost nothing is currently known about their long-term effect, making the impact difficult to assess. It is also impossible to say at present whether any damage might be corrected over the long term, or whether it would be irreversible. Above all, nanoparticles released into the environment could present a problem after they had entered the food chain and pervasively contaminated animals, plants and humans. We have long known of the negative environmental effect of foreign substances such as the ultrafine soot, carbon particles of less than 100 nm, from diesel exhaust. The more of these particles there are in a cubic metre of air, the higher the mortality and incidence of disease in the local population.

### What About Humans?

Few details are presently available on the hazards that nanoparticles and nanostructures pose to humans. Tests have shown, however, that cell cultures take up and retain a large proportion of the nanotubes to which they are exposed. These remain in the cells where they can potentially cause damage. A research team at Empa St. Gallen, working together with the Laboratory for Functional Materials at the Federal Institute of Technology in Zurich, tested

the toxicity of various industrially significant nanoparticles and nanotubes on human lung cells (these were brief tests of up to six days). As comparison, a reference material was also tested whose effect on cells is well documented. The Empa tests revealed that nanoparticles of silicon oxide, titanium oxide and cerium oxide impair lung cell metabolism in the short term, while nanoparticles of iron oxide and zinc oxide cause significant harm (see photo below). And the nanotubes? Though 1000 times smaller than asbestos fibres, nanotubes stick



together to form larger needles resembling asbestos in appearance and toxicity, and were particularly harmful.

For humans, inhalation would appear to be the route most vulnerable to the involuntary entry of nanoparticles into the bloodstream. In the alveoli, the tissues separating the air and blood may be as thin as 100 nm. Once in the blood, the nanoparticles could enter the brain, as they would presumably be able to penetrate the blood-brain barrier that stops most contaminants. Little is known about the effect of persistent foreign substances in the brain; already, however, there are indications that they may cause inflammatory lesions in brain tissue.

It would also be possible for nanoparticles to enter the bloodstream through the mucous membranes of the stomach and intestine, even though the tissues there are at least 10,000 nm thick. It might also be possible for cosmetics or sunscreen, for example, to pass from the skin directly into the blood by way of the hair follicles, the pores and sweat glands, or skin injuries.

### A Regulatory Grey Area

Under Swiss law, manufacturers must ensure that their products pose no hazard to life, health or the environment. However, the physical „differentness“ of nanostructures means that they do not fall under existing laws and regulations, making it difficult for companies to fulfil their statutory duty of care. For example, the toxicology of nanoparticles presumably depends less on the traditional criteria of amount and mass, and more on the number of particles, their total area and the nature of their surfaces –

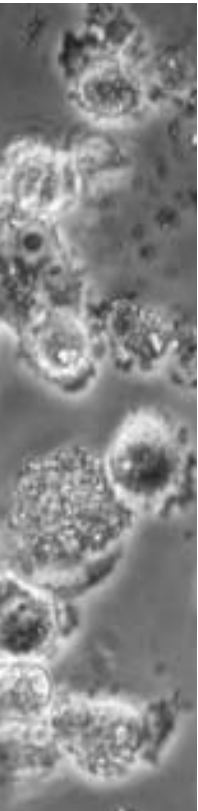
Infineon Technologies AG, Neubiberg DE



because these are the factors that influence reactivity. The nano-industry and companies that market nano-products are becoming more active in their prevention measures, both nationally and internationally, and are pushing ahead in coordinating risk research.

However, not only antiquated regulations or the lack of toxicological knowledge make it difficult to assess nano-risks reliably: there is also a lack of appropriate test facilities in nanotech research laboratories. Indeed, we do not even know what an „appropriate“ test would be, or how to carry it out. Thus, products with synthetic nanoparticles have been launched in some markets with no idea whatever of the possible risks. Given these omissions, an increasing number of stakeholders are becoming convinced that they should act. ETC Group, a Canadian environmental organisation repeated on 6 April 2006 its call for a moratorium, not only on all

nano-products, but also on research in nanotech laboratories. Others would intensify research into nano-safety and appeal for all social, political and economical levels to work out a responsible arrangement for dealing with nanotechnology risks; these players consider that updated regulations and production methods would keep hazards at an acceptable level. Insurers are showing a particular interest in improving nanotech knowledge. For them, nanotechnology is a completely new field whose future applications, products and risks they cannot clearly assess.



## Prospects: Environment and Society

***Nanotech products may also benefit the environment. Applications in electronics and telecommunications show great promise, but some stakeholders have misgivings.***

Despite the fears of environmental damage due to the spread of synthetic nanoparticles, nanotechnology does have an environmentally friendly side. The Australian government recently issued a brochure of environmentally beneficial products produced in Australia. Nanotech ion exchangers remove 99 % of the ammonia from waste water, for example; the ammonia is then used as fertiliser. Nanotech biosensors using

acoustic surface waves detect even very low levels of legionella or *E.coli* bacteria in water reservoirs. A nano-polymer produced from cornstarch is being developed as a rapidly biodegradable material for the manufacture of packaging, carrier bags and drinking cups; this would eliminate much of the discarded plastic that currently pollutes our waters and landscape.

### Thrifty Nano-paints and Motors

Case studies of the automotive, rail and aeronautical industries by the Institute for Ecological Economy Research in Berlin demonstrate that the use of nanotech paint could boost resource efficiency fivefold, as well as significantly reduce the consumption of energy and solvents. Future goals include the reduction of vehicle weight through the use of nanotubes in metal alloys and plastics; improved tyres using nanoparticles in the rubber formulas, and optimised combustion processes in motors through the use of nanotech catalytic converters. Other projects involve fuel cells that store their hydrogen in nanotubes; high-efficiency solar cells; and film-like light sources using organic light-emitting diodes (OLEDs).

### What to Expect in Nano-electronics

Nano-electronics also holds great expectations. The ongoing miniaturisation of memory and processor chips has led to structures as small as 100 nm, and it is becoming increasingly difficult to dispose of the unwanted heat produced in such small areas. Nanotubes now offer the prospect of chips with billions of switching elements. This would not only save significant amounts of energy in data processing, but would lead to completely new applications. It might become possible to implant clothing or other articles of daily use with circuits that would continuously monitor the quality of the object or the health of the user, and signal its findings via a telecommunications link. New military applications are also on the horizon: the U.S. defence industry is intensively researching nano-weapons and equipment improvements.

### Misgivings in Society

People often express social and ethical reservations regarding a technological „Big Brother“: an all-embracing information and telecommunications net that could threaten privacy rights and human rights in general. A network of nanosensors, computers and microscopic nano-cameras and microphones could enormously increase the ability to monitor individuals. This poses questions as to how abuses may be avoided and how new data protection issues may be solved. Similar concerns arise with respect to the use of nanoscale instruments in medical diagnosis: new, improved diagnostic procedures are developing more rapidly than new therapies. It is questionable whether patients will always be able to assert their „right not

to know“. The nanotechnology vision for medicine includes the use of implants connected directly to the nerve cells. Though the intention is to improve the quality of life, such developments raise the question as to where the boundary lies between a human and a bionic hybrid, and whether this boundary should be crossed.

Quite literally existential fears grew from a vision conjured up by the Californian scientist Eric Drexler in 1992: that of a plague of self-replicating nano-robots. These robots, like the cells in our bodies, would be capable of synthesising virtually any material or structure, quickly and in any amount. According to Drexler, a mutation – accidental or intentional – might allow these molecular nano-helpers to run amok, multiply uncontrollably, and ultimately transform the earth into „grey goo“. Though such worries are somewhat remote, given that the production of such self-replicating nanostructures belongs to the distant future, the example nonetheless shows that the range of conceivable nanotechnology risk scenarios is indeed vast.



# The Risk Debate and Nano-research in Switzerland

*Switzerland is a nanotechnology leader. In addition to numerous research and development programmes, an action plan is under way to address the new technology's legal and health aspects.*

The Federal Offices of Public Health and of the Environment (FOPH and FOEN), which are responsible for safe chemical and food products in Switzerland, are preparing an action plan to define and manage the risk posed by synthetic nano-materials. The plan is being worked out in cooperation with experts from various scientific areas and an advisory group representing government, industry, environmental and consumer organisations and the unions. Preparations are slated for completion by late 2006. The plan will inventory current nanoparticle applications in Switzerland to determine how and how much of these substances could accumulate in the environment, and how they would compare with current ultra-fine pollutants such as diesel exhaust soot. Other areas of activity include the formulation of harmonised definitions, which are absolutely necessary if laws and regulations are to address nano-materials at all, as well as test guidelines for assessing health and environmental hazards. The authorities plan to encourage researchers and scientists to exercise self-regulation, but to adjust regulations where safety requires. Immediate measures are planned for the protection of the working population.

## An International Task

At present, no country has issued any regulations for governing nanotechnology. Future legal or regulatory initiatives should be coordinated internationally, most obviously for economic and trade reasons. This is why the Swiss action plan coordinates with EU, OECD and UNEP bodies. Of these, the EU is implementing a five-year nano-science and nanotechnology action plan over the 2005–09 period. On the standardisation front, both the SNV and the ISO (the Swiss Association for Standardization and the International Standards Organisation, respectively) have extensive programmes aimed at bringing improvement to a range of issues including nanotechnology standardisation, methods of measurement, safety and health.

## Nanotechnology in Switzerland: Extraordinarily Interdisciplinary

Switzerland is a leader in nanotechnology, nano-research and nano-industry. This position is due to the large number of very different nano-research programmes within its borders: programmes that are associated with a broad range of institutes and companies. Nanotechnology, more than any other future technology, is by nature interdisciplinary. It embraces virtually every branch of knowledge and technology, from physics, chemistry

and biology to materials science, energy, transport, IT (information technology), textiles, cosmetics, foods, pharmaceuticals and medicine. The table below is far from comprehensive, but may serve

to give a general overview of the main centres where nano-research is carried out in Switzerland and provide several concrete examples.

### Centres of Competence and Programmes

#### National Centre of Competence in Research (NCCR Nanoscale Science, since 2001)

Areas: nano-biology, quantum computing, atomic and molecular nano-systems, molecular electronics, functional materials and nano-ethics  
Management: University of Basel; network of nine Swiss universities, research institutes and companies, approx. 200 scientific employees. Cooperation with research teams in Europe, Japan and the US. Has offered degree in nano-science since 2002.

#### Empa, Dübendorf, St. Gallen, Thun

Nanotechnological microscopes and tools; nano-electronics and nano-photonics; nano-structured materials and coatings; risk research; safety in the nano-workplace; nanotechnology and society.

#### Swiss Center for Electronics and Microtechnology (CSEM), Neuchâtel, Zurich, Alpnach

Nano-electronics and nano-mechanics for the watch, electronics and computer industries.

#### Zurich University of Applied Sciences Winterthur (ZHAW)

Applied research; participation in a European master's programme in micro- and nanotechnology. Institute for Chemistry and Biotechnology (ICB), Center for Computational Physics (CCP), Centre of Competence for Safety and Risk Prevention (KSR).

### Examples from Various Research Institutes

#### Swiss Federal Institute of Technology in Zurich (ETHZ)

Nano-robots at the ETHZ's Institute for Robotics and Intelligent Systems can be used for surgical procedures on individual cells or for the precise delivery of active ingredients.

#### Swiss Federal Institute of Technology in Lausanne (EPFL)

Development of nanotechnology processes for very-high-performance solar cells and lithium-ion batteries.

#### Paul Scherrer Institute (PSI), Villigen

The Swiss Synchrotron Light Source uses X-ray lithography to engrave structures of less than 20 nm on polymers.

#### Institute of Anatomy of the University of Bern

Interaction of nanoparticles with lung tissue; assimilation of particles in red blood corpuscles.

#### Micro- and Nano-system Technology (MINAST)

The nano-mechanical NOSE (Nanotechnology Olfactory Sensor) is capable of smelling a large number of chemicals in concentrations of only a few molecules (IBM, Novartis, ETHZ, University of Basel, PSI, 1996–2001).

#### University of Lausanne (UNIL)

„Nanopublic“: a platform for interdisciplinary exchange on nanotechnology for science, research, industry, government and all Swiss citizens and residents (since April 2006).

A number of Swiss companies are developing nanotechnology applications or already working with them. These range from large companies such as Novartis, Roche and Phonak, to Zurich's up-and-coming 2004 startup HeiQ, that uses silver nanoparticles in antimicrobi-

al additives for sport clothing and medical plastics. Another company, Bühler AG in Uzwil, is a worldwide pioneer of industrial nanotechnology – notably the large-scale production of various nanoparticles used as primary materials in a wide range of products.



## publifocus Perspective

*Our goal in writing this introduction is to assist readers in identifying areas of tension in the broad nanotechnology landscape; in forming their own opinion; in formulating questions; and in articulating their expectations and reservations.*

Nano-products, as we have demonstrated, will shape our everyday lives in coming years even as developments in nanotechnology will impact our environment. High demands will be placed on nanotechnology. Balancing the great expectations that are arising – particularly with regard to medicine, IT, reduced energy consumption and the conservation of raw materials – there are far-reaching questions as to how synthetic nanoparticles will effect our health and environment. Virtually no reliable data is presently available: indeed, there is not even consensus as to what should be measured and how. Thus, nothing can be said as to the nature and form of any necessary regulation. These issues must be worked out. In the meantime, the number of nano-products and applications is steadily increasing. Unavoidably, these products will provide ever more concrete answers to the question of nanotechnology's impact – in a form, whether positive or negative, that ever broader segments of the populace can relate to.

The public, say the experts, is still largely indifferent to the new technology, despite some slight interest. TA-SWISS is interested in how Switzerland's inhabitants will react to a new technology offering both benefits and risks. We would like people to tell us what they think of nanotechnology in general; their

opinion of present and future products and applications in particular; and their perception of its advantages and risks. We are also interested in their views on the proper way to regulate nanotechnology; on how trust can be built up, and on what would compromise that trust. At the atomic or molecular level, there is no longer any difference between „natural“ or „synthetic“; at nanoscale, there is no differentiation between „animal, vegetable or mineral“. That is a novelty in social debate, and poses ethical questions such as the desirability – as in some science-fiction novel – of using nano-implants to improve human performance. Will participants in Switzerland's different regions differ in their opinions? We eagerly await a stimulating series of discussions.

### Further Reading

#### Overviews and Nano-products

„Nanotechnology – A Future Technology with Visions“: information folios issued by the (German) Federal Ministry of Education and Research, Berlin. <http://www.bmbf.de/en/nanotechnologie.php>. Possibility of ordering the brochure „Nanotechnologie – Innovationen für die Welt von morgen“ (in German).

„Nanotechnology“: summary of Working Report No. 92 by the Office of Technology Assessment at the German Parliament (TAB). [www.tab.fzk.de/en/projekt/zusammenfassung/ab92.htm](http://www.tab.fzk.de/en/projekt/zusammenfassung/ab92.htm).

The European Commission maintains a good nanotechnology homepage at [www.cordis.lu/nanotechnology](http://www.cordis.lu/nanotechnology). [www.nanoforum.org](http://www.nanoforum.org), which styles itself the „European nanotechnology gateway“, is a source for numerous documents and studies such as the Nanoforum Reports. One of these, „Benefits, Risks, Ethical, Legal and Social Aspects of Nanotechnology“ in particular contains information on experimentation with animals and human cells: see „Part 3: Potential Risks of Nanotechnologies“.

The „Project on Emerging Nanotechnologies“ at [www.nanotechproject.org](http://www.nanotechproject.org), is the information platform of the Woodrow Wilson International Center for Scholars in Washington, D.C.. It features an inventory of nano-products currently on the market at: [www.nanotechproject.org/44/consumer-nanotechnology](http://www.nanotechproject.org/44/consumer-nanotechnology).

For information in French, consult the French government's Portal „NanoScience et NanoTechnologies“ at [www.nanomicro.recherche.gouv.fr](http://www.nanomicro.recherche.gouv.fr).

#### Nano-medicine

„Cutting nature's building blocks down to size“, abridged version of TA-SWISS's 2003 study „Nanotechnology in Medicine“. [www.ta-swiss.ch](http://www.ta-swiss.ch): Publications > Life Sciences and Health > Document TA 47a/2003.

#### Environmental advantages of nanotechnology

„Nanotechnology and Sustainability“ is a publication of the Institute for Ecological Economy Research (IÖW), Berlin. See [www.ioew.de/english/index2.html](http://www.ioew.de/english/index2.html) / Downloads.

#### Risks

The report „Nano-science and nanotechnologies: opportunities and uncertainties“ by the UK's Royal Society and Royal Academy of Engineering gives an extensive introduction into the chances and risks of nanotechnology. See [www.nanotec.org.uk/finalReport.htm](http://www.nanotec.org.uk/finalReport.htm).

„Nanotechnology – Small matter, many unknowns“, published by Swiss Re. At the company website, [www.swissre.com](http://www.swissre.com), click on Research & Publications > Risk & Expertise > Risk perception > Nanotechnology.

Visit VivantInfo's „Espace Nano“ for material in French on the purpose, application, ethics and risks of the nano-sciences: see <http://www.vivantinfo.com> > Espace Nano.

#### Critical voices

The Canadian NGO „ETC group“ offers various reports critical of nanotechnology at its website. See [www.etcgroup.org](http://www.etcgroup.org) > Publications > Nanotechnology.

Friends of the Earth, the international environmental organisation, on the Web at [www.foe.org](http://www.foe.org), criticises the use of nanoparticles in cosmetics.

#### Nanotechnology in Switzerland

„Nanoscale Science“ is a national centre of competence in research (NCCR) of the Swiss National Science Foundation. Download its publications at [www.nccr-nano.org](http://www.nccr-nano.org).

Empa presents its nano-research activities at [www.empa.ch/nano](http://www.empa.ch/nano). At the site, you can order or download an entertaining brochure (German only) for schoolchildren, „Reise in die Welt des Nanometers“.

The Laboratory for Micro- and Nanotechnology of the Paul Scherrer Institut, Villigen, offers a detailed list of its current research topics at <http://lmn.web.psi.ch/>.

<http://www.unil.ch/nanopublic>: list of activities initiated since April 2006 by the University of Lausanne at its „Nanopublic“ platform. The site's goal is to provide a communications centre between researchers, companies, policymakers, NGOs and citizens.

CTI, the Swiss Confederation's Innovation Promotion Agency, assists in the transfer of knowledge and technology between universities and corporations, and fosters the development of marketable solutions – also in nanotechnology: <http://www.bbt.admin.ch/kti/projektfoerderung/index.html?lang=en>.

## TA-SWISS, Centre for Technology Assessment

TA-SWISS has assessed the impact of new technologies and advised the Swiss Federal Assembly and Federal Council on scientific and technological issues since 1992. Through scientific studies, the Centre captures trends in the fields of biomedicine, information technology and nanotechnology; and through participation models, it seeks to involve citizens in the debate. The publifocus „Nanotechnology, Health and the Environment“ is an example. TA-SWISS is financed by the Swiss Federal Government under the auspices of the Swiss Science and Technology Council.

## The publifocus method

A publifocus is a participation model developed by TA-SWISS to produce early input for serious debate on the possible consequences of technological progress. Heart of the publifocus process is a discussion, by around 15 randomly chosen persons, on the various aspects surrounding a particular technology. Such a publifocus meeting lasts four hours, and is professionally moderated. Minutes are taken. At the beginning of the evening, experts give short presentations to „break the ice“ and start the discussion rolling. Participants of the publifocus meeting are supplied with a brochure on the subject, produced especially for that occasion, about a month in advance. It is written to be balanced and easy-to-understand, and summarises the present status and the future prospects of an emerging technology – in this case, nanotechnology – and the risks possibly associated with it. The opinions expressed by the participants

are collected in a report, which is distributed to the Federal Assembly and interested members of the public for their information. Publifocus meetings do not produce any recommendations; nor do the results claim to be representative for Switzerland as a whole. They do, however, represent the public's view of that technology, and give concrete indications of areas where future action might be necessary.

## The „Nanotechnology“ publifocus

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## Imprint

„Know your nano!“ Information brochure of the publifocus „Nanotechnology, Health and the Environment“. TA-SWISS, Bern, 2006.

Author: Dr. Herbert Cerutti, science journalist, Wolfhausen

Concept, editor: Michael Emmenegger, Anne Boesch, TA-SWISS, Bern

Translations: Viviane Mauley, MVM Communication, Chesalles-sur-Moudon (f), Giovanna Planzi, Minusio (i), Griffin Anderson, Swiss Re Language Services, Zurich (e)

Layout: Fernand Hofer, Rheinfelden

Print: Bundesamt für Bauten und Logistik (BBL)

August 2006

**Published and distributed by:**

Centre for Technology Assessment (TA-SWISS)

at the Swiss Science and Technology Council

Birkenweg 61, CH - 3003 Bern

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