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Die Bausteine der Natur in Griffweite gerückt

Kurzfassung der TA-SWISS Studie «Nanotechnologie in der Medizin» ▶

Les constituants de la nature désormais à portée de main

Résumé de l’étude TA-SWISS sur la «Nanotechnologie dans la médecine» ▶

Cutting nature’s building blocks down to size

Abridged version of the TA-SWISS Study «Nanotechnology in Medicine» ▶

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Neue Technologien bieten oftmals entscheidende Verbesserungen für die Lebensqualität. Zugleich bergen sie mitunter aber auch neuartige Risiken, deren Folgen sich nicht immer von vornherein absehen lassen. Das Zentrum für Technologiefolgen-Abschätzung untersucht die **Chancen und Risiken** neuer technologischer Entwicklungen in den Bereichen «Biotechnologie und Medizin», «Informationsgesellschaft» und «Mobile Gesellschaft». Seine **Studien** richten sich sowohl an die Entscheidungstragenden in Politik und Wirtschaft als auch an die breite Öffentlichkeit. Ausserdem fördert TA-SWISS den Informations- und Meinungsaustausch zwischen Fachleuten aus Wissenschaft, Wirtschaft, Politik und der breiten Bevölkerung durch **Mitwirkungsverfahren** (zum Beispiel PubliForen und publifocus).
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TA-SWISS
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Souvent susceptibles d'avoir une influence décisive sur la qualité de vie des gens, les nouvelles technologies peuvent en même temps comporter des risques latents qu'il est parfois difficile de percevoir d'emblée. Le Centre d'évaluation des choix technologiques s'intéresse aux **avantages et aux inconvénients** potentiels des nouvelles technologies qui se développent dans le domaine des sciences du vivant et santé, de la société de l'information et de la mobilité. Ses **études** s'adressent tant aux décideurs du monde politique et économique qu'à l'opinion publique. Il s'attache, en outre, à favoriser par des **méthodes dites participatives,** telles que les PubliForums et publifocus, l'échange d'informations et d'opinions entre les spécialistes du monde scientifique, économique et politique et la population.
Le Centre d'évaluation des choix technologiques est rattaché au Conseil suisse de la science et de la technologie, qui a pour mission de faire des recommandations au Conseil fédéral en matière de politique scientifique et technologique.

TA-SWISS
The Centre for Technology Assessment

New technology often leads to decisive improvements in the quality of our lives. At the same time, however, it involves new types of risks whose consequences are not always predictable. The Centre for Technology Assessment examines the potential **advantages and risks** of new technological developments in the fields of life sciences and health, information society and mobility. The **studies** carried out by the Centre are aimed at the decisionmaking bodies in politics and the economy, as well as at the general public. In addition, TA-SWISS promotes the exchange of information and opinions between specialists in science, economics and politics and the public at large through **participatory processes,** e.g. PubliForums and publifocus.
The Centre for Technology Assessment is attached to the Swiss Science and Technology Council, which advises the Federal Council on scientific and technological issues.

Cutting nature's building blocks down to size

Abridged version of the TA-SWISS Study «Nanotechnology in Medicine»

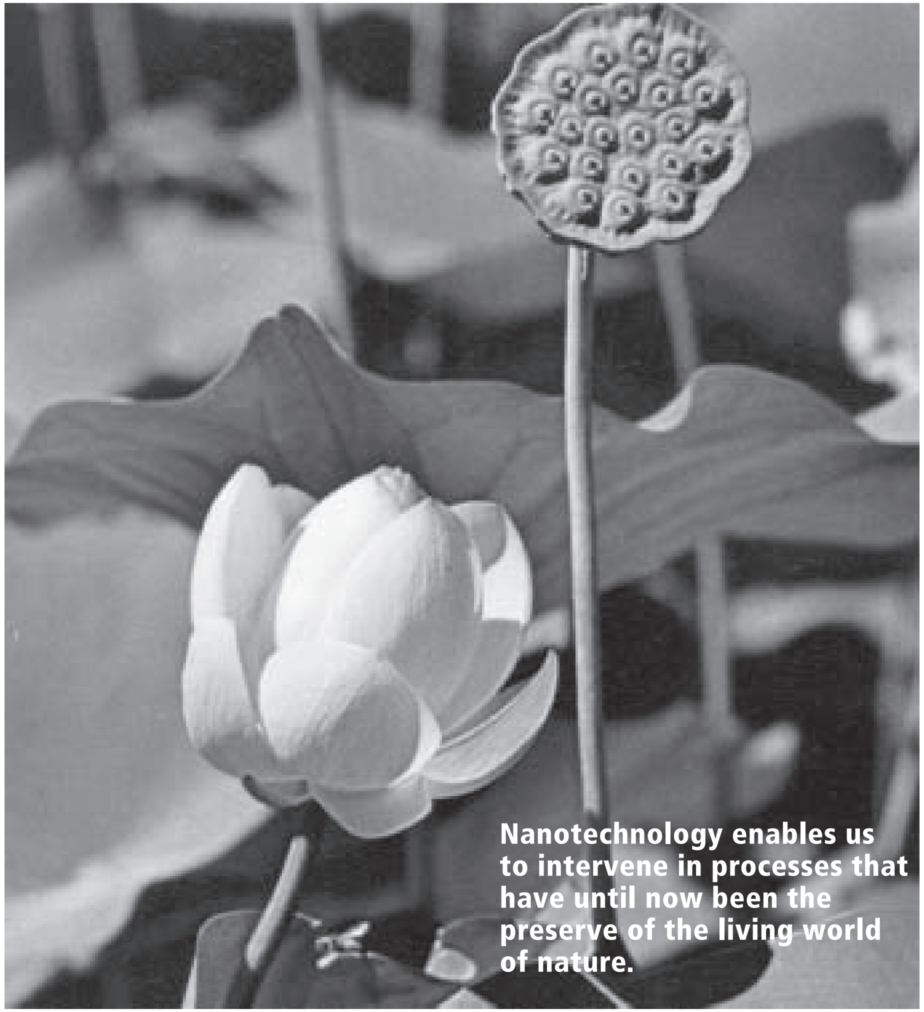


Photo: Bambouseraie du Prafrance, Generarues

Nature's model: the lotus flower's self-cleaning surfaces

Conquering the immeasurable

Man has already advanced to the very edges of outer space. But now we are on the point of conquering structures in the world of atoms.

Switzerland has always been very big in the world of small things: the scanning tunnel microscope (see box) was invented in 1981 by Gert Binnig and Heinrich Rohrer at the IBM research laboratory in Rüschlikon. This new type of microscope made it possible for the first time ever to gain «constructive» access to the world's molecular and atomic structures. And it brought the two inventors the Nobel Prize for Physics in 1986.

The conventional microscopes with lenses used in medical laboratories can certainly magnify specimens a thousand times. But while this may be enough to analyse blood samples, it is nowhere near enough to penetrate the structure of molecular or even atomic formations. And that is precisely what «nanoscience» is claiming to be able to do: it deals with structural dimensions as small as one millionth of a millimetre (exactly one nanometre), or even smaller. By way of comparison, the diameter of a hair is approximately 50,000, the thickness of a sheet of household aluminium film roughly 10,000 and the wall of a soap bubble around 750 nanometres. The nucleus of an iron atom measures 0.25 nanometre.

Nanoscientists, however, are not content simply to observe the world of atoms and molecules. Nanotechnology aims rather to directly penetrate the building blocks of the atomic structure and to reshape them. And unlike conventional chemistry, which alters molecules «en masse», as it were, by mixing in new materials, nanoscience aims at targeted access to the individual atom, to the specific molecule.

A logical progression

Dyes that repel dirt, or film applied to a car as a solar cell, giving it an environmentally friendly power source – these are visions that inspire nanoscientists. They often take their inspirations from nature itself: dirt-repellent dye, for instance, is something they copied from the leaf of the lotus flower. Its surface is covered with minute spherical-shaped irregularities that repel dirt and water.

Nanotechnology promises ground-breaking innovations. But it will also be continuing developments that have been occupying science for centuries. The endeavour to penetrate ever more remote domains – discovering new planets and galaxies with the telescope, or tracking down strange microcreatures under the microscope – is something that scientists from centuries ago share with the nanoscientists of today.

Against this background, nanoscience appears less like a clearly defined branch of science. It should be seen rather as a cross-sectional approach, a kind of subliminal objective that combines and characterises the most diverse scientific disciplines. That is because specialists in the field of coating technology are hoping for the same sort of revolutionary achievements from nanotechnology as experts in the fields of medicine and electronics.

Spotlight on medicine

An exhaustive investigation of the effects of a cross-sectional science in every field of application would be well beyond the scope of any topically-based analysis (and one endowed with limited means). The TA-SWISS study «Nanotechnology in Medicine» has therefore restricted itself to highlighting the potential consequences that could derive from advancing the field of medicine into the «nanodimension».

Medical applications of nanoscience are inevitably, and for a variety of reasons, a subject for consideration. Firstly, the public pays very special attention to advances in medicine – torn between the desire for effective and more considerate treatments on the one hand and concern about side-effects and constantly rising health costs on the other. Secondly, in medicine nanotechnology is quite literally getting under people's skin: its therapeutic use will bring them into particularly close contact with nanotechnological achievements – implants, for instance. In any event, the new technology enables us to intervene in processes that have until now been the preserve of the living world of nature, beyond the reach of man. The revolutionary potential of nano-sized particles and structures is all the more considerable because they are potentially able to organise and duplicate themselves, and therefore to copy essential characteristics of the living being. That makes it all the more prudent to identify the opportunities and risks that could be linked to nanotechnology.

The specialists show their cards

In Ancient Greece, if someone wanted to know what the future held, they consulted the oracle of Apollo: in Delphi Pythia gave those seeking advice enigmatic instructions about their journey through life. And today, we are reverting to the «Delphi method». One of the things it is ideal for is examining innovations more closely where those innovations are beginning to emerge at the very boundaries of possibility, and where conjecture about the consequences of such innovations is little more than speculation. But the modern-day Delphi works, not with mediumistic minded priestesses, but with renowned specialists.

For their «Delphi», the authors of the TA-SWISS study conducted three rounds of surveys covering a total of over 70 specialists. The first two survey rounds were directed at researchers who are themselves actively involved in nanoscience. The aim here was to work out how nanotechnology would be likely to develop: where are the earliest breakthroughs likely to be, how long is it likely to be before they arrive, and what are the technical hurdles that will have to be overcome? The third survey round focussed on the legal, social and ethical consequences of the new technology. Here there was an opportunity for experts from the fields of law, ethics and economics, but who also had a basic knowledge of nanotechnology, to have their say. Most of those questioned were from outside Switzerland: for the first two survey rounds on technological forecasting more than half were from the USA, for the third survey round some three-quarters were from Germany. The survey rounds were followed up by one-to-one in-depth interviews as a follow up to the third round of the Delphi survey.

The evaluation of nanotechnology that is summarised in the following chapters is therefore based on the assessment of specialists from different scientific disciplines.

Don't see, feel

Optical microscopes that operate with systems of lenses reach their limits with microstructures about 250 nanometres in size. The scanning tunnel microscope, by contrast, also delivers reliable magnifications in the atomic range below 1 nanometre. It doesn't actually «see» the specimens, it «feels» them: a fine point is placed up to a distance of several atomic diameters from the specimen. At the same time an electrical voltage is applied. The quantum-mechanical forces that are active in this subatomic range release what is known as a «tunnel stream» between specimen and point. While the point scans the surface, the gap between point and specimen remains constant because the tunnel stream is also kept constant. The point therefore «follows», as it were, the structure of the surface of the specimen; using imaging computer programs it is possible to project a three-dimensional diagram of the surface of the specimen from the movements of the point.

Further developments of the scanning tunnel microscope make it possible not just to scan the fine structures of specimens but even selectively to manipulate them. The «visual aid» is therefore becoming a gripping tool.

The nanotechnological toolbox

It is now, to some extent at least, possible to handle «nano-thin» coatings. The production of nano-dimensioned objects – in two dimensions – such as extremely fine semiconductor webs is already coming up against fairly major problems. The selective construction of objects that are as small in all three dimensions is proving to be especially difficult. But it is precisely these objects that are of particular interest for medical applications.

If a watchmaker tried to repair a wristwatch with a bulldozer, he would quite rightly get some very strange looks. In medicine, however, we have come to terms with the fact that physicians are working with instruments that are just as inadequate. Most diseases, for instance, occur at cell level. Selective interventions into the structure and function of individual cells are barely possible today. Nanoscience could change all that.

In the future, nanotechnology, in the form of micro-particles, multiple structures, surfaces or even highly complex nano-instruments fitted with chemical, electronic or mechanical functional units, could be used in diagnosis and therapy. Furthermore, methods of medical investigation and treatment that are still standard today could be fundamentally changed by nanotechnology. The TA-SWISS study «Nanotechnology in Medicine» coined the expression «nanotechnological toolbox» to characterise these five different forms that the new technology is most likely to assume in medicine (see box, p. 28)

Pinpoint identification with nanoparticles

Discovering the earliest signs of disease, even before the actual symptoms appear, is what modern medicine aims for and is required to achieve. That is because early treatment enables damage to be minimised. Procedures are called for that make possible the early detection of relatively low amounts of antibodies in blood or urine – and that is where nanotechnology can help. So-called optical quanta – nanocrystals that fluoresce under ultraviolet radiation – could be attached as tags to specific antibodies, helping to detect them quickly when they first appear in small quantities in a specimen.

In cancer therapy, too, much is promised for nanoparticles. If magnetic particles could be successfully and selectively attached to a tumour, they could be made to oscillate by a alternating magnetic field, in order to heat up the cancerous tissue. Complemented by traditional treatment methods such as radiation or chemotherapy, the idea is that this localised temperature rise would cause the tumour cells to die.

Nanoparticles could also serve as tiny drug capsules. With pinpoint accuracy they could transport the therapeutic substance to the place where it is needed. Research is, for instance, being done on dendrimers – spherical molecules with cavities. To make them release their cargo at the target point, they would have to be constructed in such a way that they would swell up and secrete their contents only in the presence of specific release molecules. Other concepts allow for the nano-containers to be steered through a magnetic field.

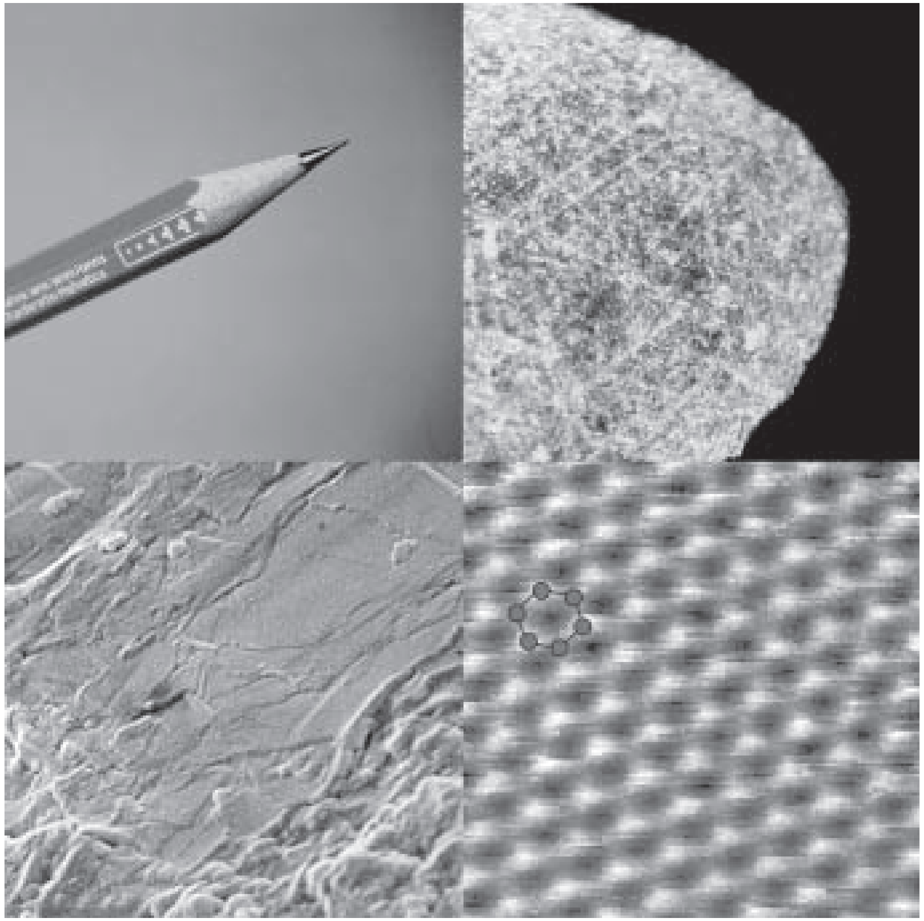


Photo: Peter Reimann, Universität Basel und Nanosurf AG, Liestal

Pencil tip: (1) with the naked eye (2) under a light-optical microscope (3) electron microscope (4) atomic force microscope

Discovering the earliest signs of disease, even before the actual symptoms appear, is what modern medicine aims for and is required to achieve.

Commercially, nanoparticles are only being used in individual cases. The specialists questioned in the Delphi surveys estimate that in cancer therapy, for instance, nanoparticles will be usable in five to ten years' time. We are rather nearer to the goal with the use of quantum points in diagnosis. In the period 2005 – 2008 this method, which is already being used in certain laboratories, could be available for wider application. Finally, according to the experts, targeted release of drugs by nanoparticles should be possible by about 2010— provided that over the next three to five years dendrimeres can live up to the expectations placed in them.

The five tools of nanotechnology

Nanotechnology will be applied in five different forms, namely as

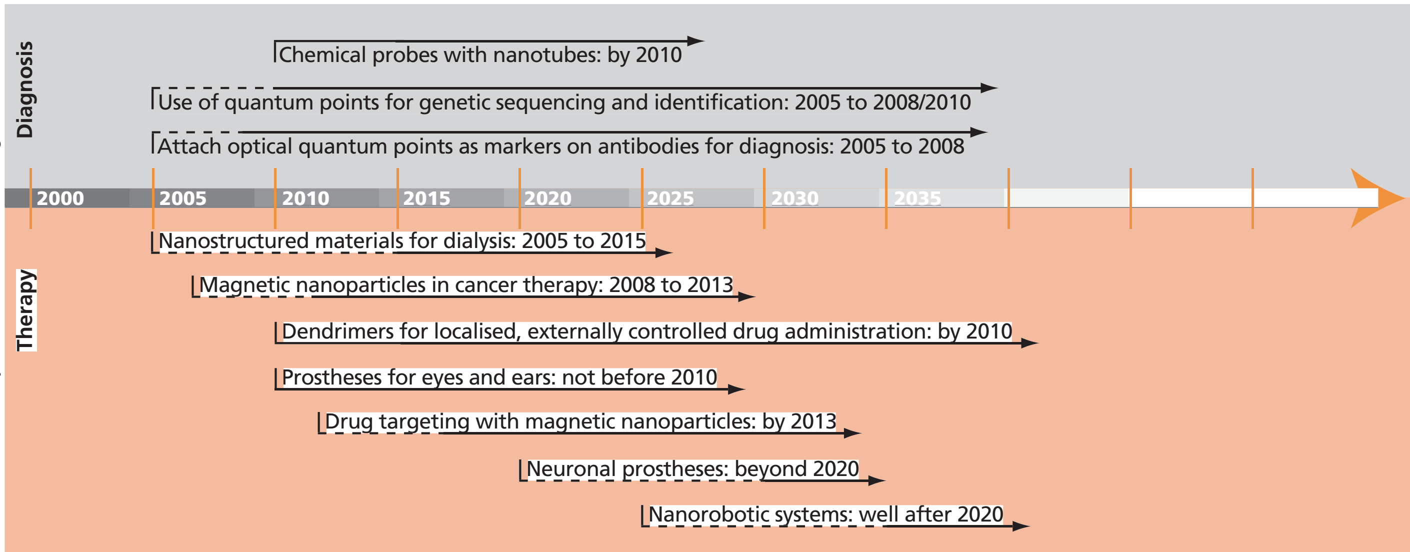
- simply structured particles
- systems of combined particles (structures)
- extended two-dimensional structures (surfaces)
- highly complex structures equipped with mechanical, chemical or electrical active units (nano-devices)
- procedures and methods

Using nanostructures to obtain health data

Scanning tunnel microscopes and atomic force microscopes are handy instruments. Laboratory high-tech in this case takes up hardly any more space than a cigarette packet. The fine point that scans the nanostructure of the specimen could also be adapted for use as a chemical probe within the body.

Built into highly sensitive sensors, semiconductive nanotubes could also find a use in the sickbed, for instance, by measuring the fluctuations in electrical resistance that change when specific gases are emitted.

Clinical availability of selected tools - Experts' estimate 2003:



Source: TA-SWISS Study TA 47/2003 «Nanotechnologie in der Medizin»

The use of nanostructures is conceivable not just in diagnosis, but also in therapy – for example as a well-tolerated material that aids the growth of bone and also possibly other types of tissue. Nanotubes could ultimately be used to cultivate artificial muscles or produce pumps for controlled drug release.

The specialists questioned estimate the time horizon within which nanostructures will be in commercial use at between six and fifteen years. Chemical probes could be available relatively quickly, possibly by 2010. The experts were more pessimistic in their assessment of the time required to develop highly sensitive sensors and artificial bones.

Well tolerated replacement tissue thanks to nanostructured surfaces

Nano-based membranes for dialysis of kidney patients, artificial skin or well-tolerated films to cover implants – the potential for nanostructured surfaces is considerable. Nevertheless, some specialists take the view that there are as yet no convincing clinical indications that such surfaces could actually be realised for medical applications. Experts are similarly divided in their estimation of the realisation period: while some maintain that certain specific forms of nanostructured surfaces are already available, other are looking at a realisation period up to 2020.

Seeing and hearing, thanks to nano-devices

Most advanced in their utopian design ventures are those who are working on complex nano-devices. Prostheses for eyes,

Peppering the tumour with iron

The German daily newspaper «Die Welt» ran an article in its 3 September 2003 edition proclaiming that a cancer patient had been cured («Charité heilt ersten Krebspatienten»). Using a new nano-technological method, two cancer researchers, Andreas Jordan and Peter Wust, had treated a soft-tissue tumour that was proliferating under the patient's collar bone and was regarded as untreatable. The two researchers injected nanometre-sized iron particles into the growth. Then they heated up the iron particles by magnetic oscillation. The tumour «caught a fever» – and in combination with chemo- and radiation therapy, the localised rise in temperature succeeded in killing the cancer cells. Eight weeks after therapy, the 26-year-old was completely free of tumour cells, reported the newspaper.

ears or even for the brain could – if the hopes of those developing them are fulfilled – considerably improve the quality of life for sick people. But there are unlikely to be any results worth mentioning until 2010, and we will have to wait until 2020 at the earliest for neuronal prostheses or artificial organs and organ parts.

The successful application of nano-devices in «keyhole» surgery seems more within reach. The tiny openings used in this type of surgical intervention are easier on the patient, and nano-devices could in this case further refine already tried and tested micromechanical procedures. Specialists are expecting to see some crucial progress between 2005 and 2010, with the switch from micro- to true nano-based technology not coming until well after 2010.

More efficient, faster methods

If small probes based on the technology of the scanning electron microscope are able to scan molecular structures within the body with virtually no destructive effect, this will open up the potential for rapid and gentle diagnosis and therapy. Nanoscience could also be used to develop suitable instruments and procedures for identifying specific genes (see Box, p. 32). The experts questioned are of the view that it will take between two and seven years to make the corresponding techniques available.

Therapy comes after research and diagnosis

Nanoscience is holding out to medicine the prospect of a broad range of new instruments and procedures. Which of these will ever come to fruition is at present unclear. And whereas research and diagnosis might already benefit relatively soon from these new possibilities, specialists are much more sceptical when it comes to the application of nanotechnology in therapy. Compared with research and diagnosis, for the treatment of disease we will have to be patient for another ten to fifteen years until nanotechnology has become established. The problems that arise from gap between diagnostic and therapeutic capabilities are covered in the penultimate chapter of this brochure.

Using nanotechnology in the fight against seven plagues

The medical application of nanotechnology can be observed using as a starting point the procedures and instruments that are made available by the new science. There is, however, another conceivable viewpoint, starting from those diseases that it might be usefully applied to combat.
Statistics show that cardiovascular diseases and cancer are the leading causes of death in developed countries. These too could in future be combated by nanotechnological instruments and procedures – as could viral and bacterial infections, autoimmune and metabolic diseases and brain diseases.

The specialists consulted have different views on which diseases they regard as having the best potential for successful therapy using nanotechnology by 2020. They see the fight against cancer as offering the greatest opportunities for nanotechnological breakthroughs. Although the new types of procedures and instruments offer considerable possibilities for cardiovascular and metabolic diseases, the chances of these being realised are relatively small. Somewhere between the two – both in respect of healing potential and of technical implementation – are infections and autoimmune diseases. In the case of brain disease (especially Alzheimer's) however, experts see little prospect of the successful application of nanotechnicological treatment instruments and methods.

In the experts' view, there is little doubt that nanotechnology will have made possible some spectacular breakthroughs in medical research and diagnosis by the year 2020.

A revolution in miniature

Nanotechnology is likely to develop in small steps rather than in great and bounds. And the breakthrough could come later than many specialists imagine. The effects on society, however, could be so far-reaching that it is as yet virtually impossible to assess them.

The further removed a new technology is from its practical realisation, the greater the lack of unity in evaluating its potential and prospects for realisation. This fundamental pattern is one that is evident from the specialists' answers given in the Delphi Survey on nanotechnology.

Uncertain about uncertainties

The experts failed to agree, for instance, about the fundamental question of whether the development of nanotechnology over the next twenty years is inevitably uncertain. There are virtually two opposing «factions» here, as there are almost as many of those questioned who completely disagree with this estimation as there are those who totally agree with it. And both extremes have similarly large followings. In other words, while some are prepared for nanoscience to come up against some unexpected obstacles and surprising solutions, others regard this new field of research as a relatively clear and predictable area.

Large gap between laboratory research and practical application

Specialists are, however, agreed on the estimation that the time span between the first successes in the laboratory and general everyday application is underestimated. Only an insignificantly small number of those questioned rejected this view, while the majority of the experts were largely or totally in agreement.

Specialists see problems in the lack of long-term stability of nanostructures and in the manufacture of sufficiently large, commercially viable quantities of nanotechnological products. Those questioned are also expecting difficulties in the manufacture of three-dimensional nanostructures. Single particles or two-dimensional, layer-shaped nano-surfaces, however, seem easier to handle.

No ethical shortcomings

Public debate often assumes that researchers are afflicted with ethical blindness, going about their work undeterred by any negative consequences of their actions. In the view of the scientists themselves, however, this image is an untenable one. The vast majority of those questioned for the survey denied, for instance, that ethical and social issues were insufficiently anticipated and taken into account by researchers.

It is still not clear whether this assessment is itself lacking that very sensitivity that gave rise to the question in the first place – or whether nanoscience, operating on the boundary between animate and inanimate matter, prompts those people who are pre-occupied with it to pose fundamental existential questions. The authors of the TA-SWISS study emphasise in any case that during the discussions for the survey there were also spontaneous comments that lead them to conclude that quite a number of the researchers are very much in favour of ethically motivated concerns (for instance, concerns about regulatory «crash barriers» or about foresighted reflection).

Where does disease begin, if therapy is applied even before the symptoms have appeared?

Photo: Martin Stolz, Biozentrum Universität Basel

Measuring head of an atomic force microscope

Expectations too high in medicine

There is, ultimately, relative unity among the specialists questioned when it comes to assessing the expectations placed on nanotechnology. These are particularly unrealistic in the field of medicine, according to most of those questioned. The expenditure over the time between the initial laboratory costs at the research stage and application in clinical practice tends to be underestimated. The fact that the prospects of success for the new science are talked up by the researchers themselves, raising expectations accordingly, is simply because of the way the science industry works. The more promising a discipline the more lavish are the research funds that are poured into it. But exaggerated hopes could in turn ultimately inhibit nanotechnological progress. If, for instance, expectations are repeatedly dashed, there is less willingness to invest money in this type of research.

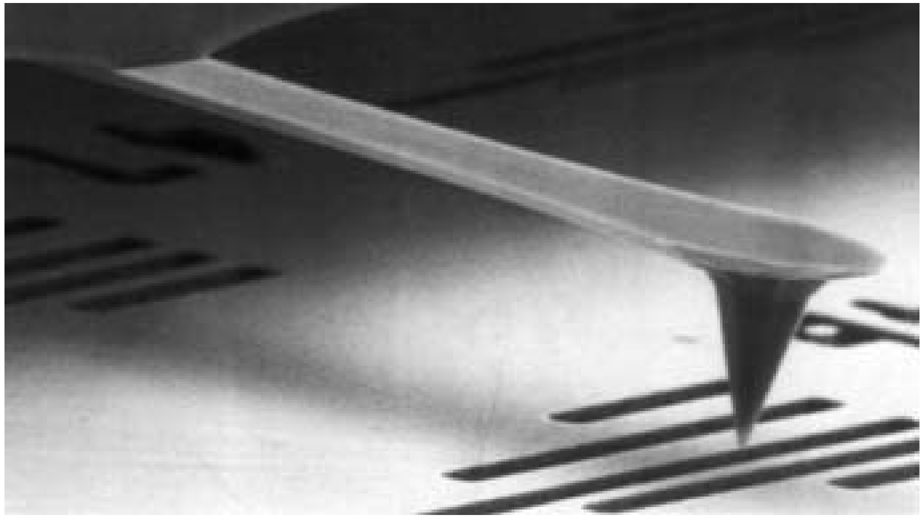


Photo: Martin Stolz, Biozentrum Universität Basel

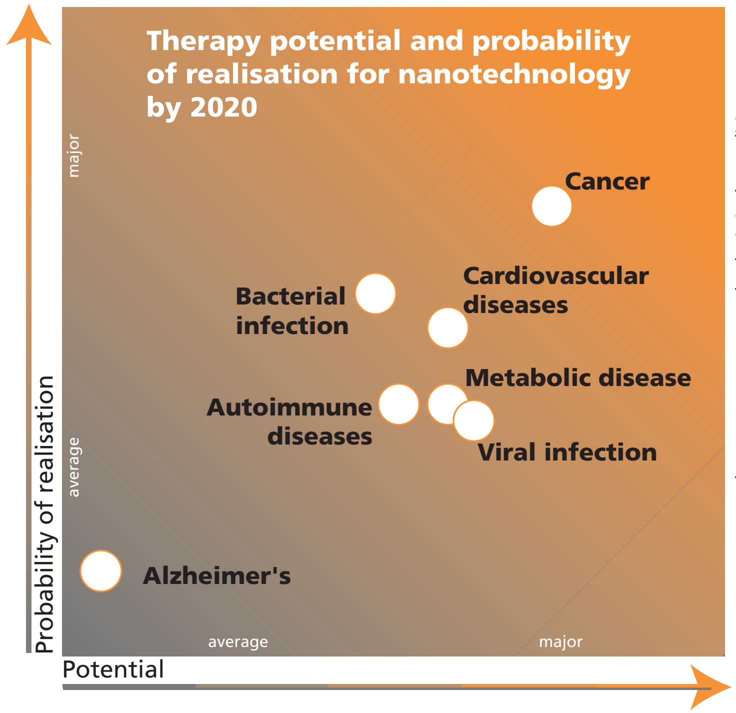
Cantilever array: atomic force microscope's sensor and tool for the nano-world

The fact that a fundamental achievement of evolution – the body's own defence system – could be circumvented by nanoparticles, is not necessarily a bad thing, but might even be an advantage for certain therapies.

Targeted and faster, but hardly cheaper

In the experts' view, there is little doubt that nanotechnology will have made possible some spectacular breakthroughs in medical research and diagnosis by the year 2020, and will be the method of choice for clarifying clinical pictures. Most of those questioned took the view that nanotechnologically supported medical investigations will be more targeted and faster, and will reveal diseases sooner than is the case today. Specialists are less certain about whether this means that the diagnosis will also be much cheaper.

In the treatment of diseases, however, nanotechnology is advancing much more slowly than in research and diagnosis. Although most of those scientists questioned estimate that treatment methods are likely to have fewer side-effects because of nanotechnology, and that therapies will become more effective. These beneficial effects are, however, not expected on a relatively large scale until after 2020. Nevertheless, rather more than half of those questioned think that nano-based therapies will lead to major changes in medicine over the next 20 years. Also with a view to the therapy, the assessment of the financial consequences of the new technology is also somewhat sceptical. Experts regard it as rather unlikely that nanotechnology will make individual therapy cheaper.



Source: TA-SWISS Study TA 47/2003 «Nanotechnologie in der Medizin»

english

Existential, redefined

If the potential promised by nanotechnology should actually be realised, we are faced with redefining central social categories. Where does disease begin, if therapy is applied even before the symptoms have appeared? Where do we draw the boundary between dead matter and animate body if nanoprostheses take over vital functions in our bodies?

Nanotechnology operates in the boundary area between inanimate matter and living material: by penetrating down to the level of the atomic and molecular structure of objects, the new technology is able to influence processes that have hitherto been subject to natural development and beyond the reach of man. Nanotechnology could equip homo sapiens with instruments to intervene deep into biological processes.

Targeted treatments, fewer side-effects

In medicine the new nanotechnological instruments could have a perfectly beneficial effect. With refined methods for early detection of diseases or simply their disposition, precautionary intervention would be possible: therapies could be applied even before the first symptoms started to affect physical wellbeing. With preventive measures, in certain cases it would be possible to delay or even prevent diseases from breaking out.

A clear majority of those specialists questioned is, in any case, agreed that nanotechnology could substantially improve people's quality of life. There is a good chance that the disease-free lifespan will be extended. In addition, for many illnesses – including fatal ones – the prospects of a cure are greater, and the side-effects of the new therapies will be less frequent than with the conventional methods used until now. But the question of whether higher life expectancy could at the same time prolong the phase of age-related dementia must for the time being remain the object of speculation.

The burden of self-responsibility

A health service based on prevention and early therapy has undisputed strengths. To enable them to be used, however, a comprehensive system of «screening» – a procedure of systematic pre-investigations for the entire population – would have to be set up, which as many people as possible would have to undergo. But by making it a «must» for everyone to deal with any afflictions that might occur, however, the boundary between healthy and ill is shifted. That is because physical wellbeing is no longer regarded as evidence of physical intactness. But exactly how physical awareness will change in people who observe themselves on a constant basis and are therefore always anxious about their health, is difficult to say. Carefree enjoyment of life could in any case be increasingly open to question.

If the means are available to detect and combat health problems at an early stage, the pressure from society to make use of these possibilities increases. But this also means that there is a greater risk of sick people being treated as outcasts, because it is tempting to make a rash judgement and shift the blame for their illness to them, because they failed to undergo the necessary tests at the right time and to take the appropriate measures to preserve their health.

When we know more than we can cure

In the medium term, nanotechnology will lead to diseases being recognised early, or earlier, but without necessarily having effective therapies available. This will aggravate a problem that already concerns many people today for whom a genetic test shows that there is a high probability that they will develop some incurable genetic disease – such as the serious and fatal brain disease Huntington's Chorea. They are compelled to confront anxieties about their very existence, with no hope of finding respite from medical science.

The possibilities of using nanotechnological instruments and procedures to make relatively precise health predictions could also awaken the greed of third parties. It would be tempting for life insurers, as well as for employers, to gain access to details that might

More effective genetic analyses thanks to nanotechnology

The US company Quantum Dot Corporation (www.qdots.com) sells cadmium selenide nanoparticles that are used as biological labels to mark proteins or molecules of the genetic material. Because the crystals fluoresce, they reveal the location of the marked molecules – much more precisely than current conventional dyes do. Thanks to the new marker particles the genetic material of a specimen can be compared with samples of known DNA sequences, thereby establishing which genes are active in specific cells. Nanotechnology can help to make genetic testing more effective.

allow them to draw conclusions about possible afflictions that might threaten a policyholder, or the future ability of an employee to perform. Seen in this way, nanotechnology could increase the trend to the «Big Brother» society. The law on genetic testing on human beings that is currently in preparation will lay the first «crash barriers» to prevent the misuse of those data that are acquired in genetic tests using nanotechnology.

Small does not necessarily mean cheap

No-one today who is concerned with medical issues can get round the question of cost. Many of those specialists who were interviewed for the Delphi Survey are agreed that nanotechnology could speed up both diagnoses and therapies, and make them more effective. But the costs are unlikely to fall as a result. Seen overall, there are even fears that the opposite could be the case. Because people's life expectancy will continue to increase and therapies that are technically simple to put into practice will become available, these could be used in greater numbers than hitherto. Nanotechnology could also help to push health costs even higher. Cost-curbing effects from nanotechnology would be expected in the very long term – for instance if it were possible to do without expensive medicine in old age, because they would have been rendered superfluous by medical advances in people's youth.

This does mean, however, that «two-class medicine» will be encouraged. For virtually all of the experts questioned, it is evident that the problems of distribution between the well-off and the not so well-off will intensify if progress in nanotechnology does not lead to a substantial reduction in the cost of medical services. As we have seen, however, the signs are not good. The variable degree of information among the population will also encourage a medical multi-class society: while persons who are responsible about their health will use nanotechnology as an opportunity to plan their own lives based on prophylaxis, there is a danger that less well-informed people will not be able to cope with the multitude of options and the growing need to make their own decisions.

Physical wellbeing is no longer regarded as evidence of physical intactness.

Unpredictable nanoparticles

The fact that we don't necessarily have to be able to see something that presents a mortal danger is something we have learned most recently from the hole in the ozone layer. The nuclear debate, as well as the public debate about the dangers of gene technology show that we are well aware that risks can be invisible. This fear has also arisen in the case of nanotechnology: what effects will nanoparticles have if they are released in relatively large numbers into the environment? Could they be poisonous to living beings, so that we will have to beware of nanotoxicity?

Finding out how these nanoparticles behave within the living body is something that will take some doing, as they are small enough to trick the immune system. Analysis of antibodies therefore seems of little use in detecting nanoparticles in the bloodstream or in tissue. An immunological research team from the University of Montpellier in France has in any case demonstrated that nanometre-sized carbon particles are able to sneak unnoticed into rat cells, where they are tolerated. It was only when the carbon particles reached one micrometre in length that they caused immune reactions. Nevertheless, the fact that a fundamental

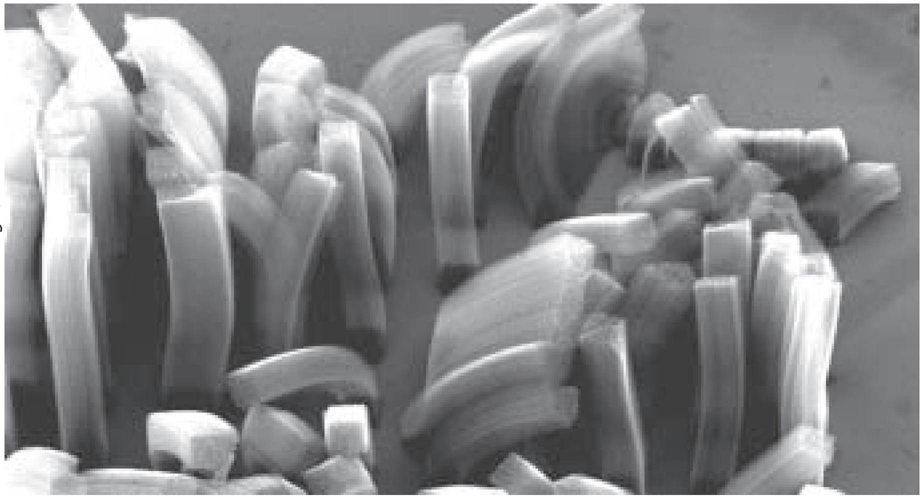


Photo: Prof. Christian Schönenberger, Universität Basel

Growing nanotubes

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achievement of evolution – the body's own defence system – could be circumvented by nanoparticles, is not necessarily a bad thing, but might even be an advantage for certain therapies.

Also unclear is the effect nanoparticles have on the brain. This is because they are so small that they are able to pass though the hitherto impregnable blood-brain barrier.

In any event, the specialists consulted certainly do not exclude the possibility that nanoparticles used in medical applications might be toxic or somehow «dangerous». A majority of experts regard the theory that nanoparticles from medical applications could prove toxic as fairly plausible. The first laboratory experiments are suggesting that these fears are justified: a group of researchers from Texas injected carbon nanotubes into mice lungs. After several months it came to light that the nanotubes had become stuck together as lumps in the lungs, surrounded by immune system phagocytes. This reaction caused scarring in the lungs. In other experiments the lumps have actually been large enough to obstruct the bronchi, causing the laboratory rats to suffocate.

Also difficult to estimate are the risks that might arise from an uncontrolled release of nanoparticles into the environment. It is conceivable, for example, that nano-based material is taken up by bacteria and could thus be smuggled into the food chain. Experiments are currently under way to clarify whether toxic compounds that are taken up by different nano-materials might be smuggled into cells, «on piggyback», so to speak.

Nanotechnology offers freedom from injections

Two insulin injections daily – that is the lot of many diabetes sufferers. The team headed by bioengineer Tejal Desai at the University of Illinois has developed a nano-capsule containing cells that secrete insulin. The capsule circulates constantly around the bloodstream. To prevent the therapeutic cells from being destroyed by the immune system, the capsule had to be constructed in such a way that its pores were large enough to enable the insulin to escape and to maintain the cells' supply of nutrients' – but not so large that antibodies could slip through. The nanocapsules have not yet been tested on people. Diabetic laboratory rats have, however, been cured by this method.

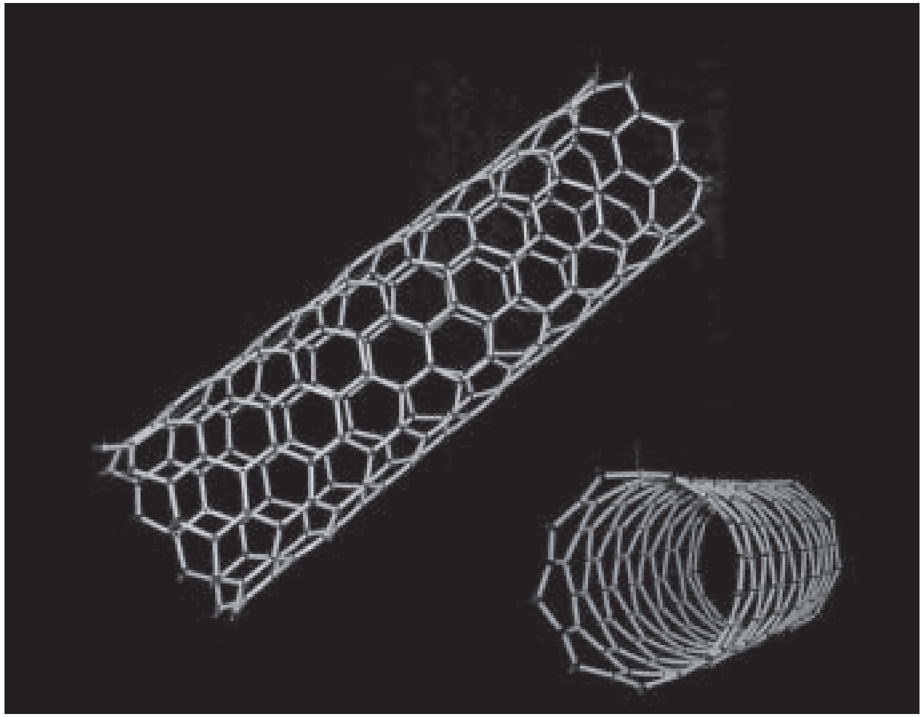

Photo: www.nccr-nano.org/nccr

Model of a nanotube

While the TA-SWISS study focuses on medical applications of nanotechnology, it nevertheless singles out facets of the debate surrounding nanotechnological risk. In medicine, considerations of risk generally exhibit a particular profile: where the greater good of health is in the balance, risks – or in medical parlance, side-effects – are comparatively unimportant. But if a relatively diffuse benefit comes up against any kind of technical risks it will be assessed much more critically, and usually rejected.

Nanotechnology intensifies existing trends

The explosion in health costs is a cause of concern for us, irrespective of nanotechnology, and the recently completed «genetic mapping» of mankind could already have led to shifts in our self- and physical perception. Accordingly, nanotechnology has nothing essentially new to offer. But it could help to strengthen general lines of development that are only just starting to emerge.

Making use of the good starting position

Switzerland is well positioned to make use of the benefits of nanotechnology: the new science has taken fundamental steps in research on Swiss soil, and the Confederation has created favourable conditions for its further development with a National Research programme «Nanotechnology». Now it is a matter of learning from mistakes that were made in the past in handling other new branches of technology.

«Out of sight, out of mind» – this proverb does not apply to the risk debate. On the contrary: with the public debate about nuclear energy and gene technology general attention focused on two invisible dangers. Nanotechnology can in various ways be compared with gene technology: how the one affects the other in vital processes. The fact that in so doing we are giving ourselves creative powers, without appreciating the consequences of its actions, could give rise to widespread fear.

Supervision and critical discussion

In order to avoid a polarising and ultimately paralysing debate, it would be appropriate to take precautions. Any procedure would have to involve setting up a competent body that would follow, in the sense of monitoring, the further development stages of nanoscience and identify early on any dangers that could derive from this new discipline. This body would have to be comprised of specialists from different branches of research and from different countries – and it would have to be given the requisite means to fulfil its task.

The new institution would have to ensure that potential risks from the new technology were discovered early on and limited. Another function of the body could be to maintain an open flow of information between science and the public, and to report on the positive potential without concealing the drawbacks. Additional tasks could be to launch campaigns to consolidate the population's health awareness, and to equip them better to evaluate and to use nanotechnology as a possibility for their individual health planning. The interdisciplinary body of experts could also give its consideration to questions about whether society needs a new form of «health counselling», and make recommendations.

Need for research in terms of content and method

It is still largely unclear how nanoparticles behave in biological systems and in an ecological context. There are strong indications that the application of nanoparticles could give rise to fundamentally new medical situations. The first of these is that foreign bodies are able to «get round» the immune system and circumvent the blood-brain barrier. There is a substantial need for research here. There are presently still a great many unanswered questions relating to the toxicity of the nanoparticles themselves and to their ability to transport toxic compounds into cells.

Whatever toxicity nanoparticles may have can be tested in laboratory experiments by tailoring proven methods to the special object of investigation. What is not clear, however, is which methods can be used to determine the dangers that might evolve from releasing nanoparticles into the environment. For a comprehensive analysis of the risk, it would be worthwhile first of all to develop suitable instruments.

Support of the structures for nano-research

Switzerland is a world leader in nanoscience. At the Swiss Federal Institute of Technology (ETH) in Zurich, the new discipline is treated alongside Life Sciences and Information Sciences as a priority area of research. For this purpose, in a joint collaboration the ETH Board and the Commission for Technology and Innovation (CTI) have started up a research programme called «Top Nano», which is to receive CHF 62 million for its provisional 4-year term. The Swiss Federal Council also regards the new research domain as important: after the research programme «Nanoscience» had ended in 2000, having been endowed with CHF 64 million, it approved a CHF 15 million credit line for the National Research Programme 47 «Supramolecular Functional Materials». Since 2001, the University of Basel has been supporting, with the National Centre of Competence in Research of Nanoscience, a research centre endowed with an annual budget of CHF 16 million, and at various other institutions too (e.g. at the Paul Scherrer Institute or at the Swiss Federal Laboratories for Materials Testing and Research (Empa)) this future-oriented research field is being investigated.

No cost is being spared to move nanoscience forward. The funds being made available to present the new technology to the public, and to enter into a dialogue with the public about any hopes and reservations that they might wish to express, appear extremely meagre by comparison. In the USA, in the UK and – to a lesser extent – in Germany, there is already a controversial debate about nanotechnology, but in Switzerland the subject has barely entered into public discussion.

Nanotechnology can in various ways be compared with gene technology: how the one affects the other in vital processes.

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Die Studien des Zentrums für Technologiefolgen-Abschätzung TA-SWISS sollen möglichst sachliche, unabhängige und breit abgestützte Informationen zu den Chancen und Risiken neuer Technologien vermitteln. Deshalb werden sie in Absprache mit themenspezifisch zusammengesetzten Expertengruppen erarbeitet. Durch die Fachkompetenz ihrer Mitglieder decken diese so genannten **Begleitgruppen** eine breite Palette von Aspekten der untersuchten Thematik ab.

Le Centre d'évaluation des choix technologiques TA-SWISS se doit, dans toutes ses études sur les avantages et les risques potentiels des nouvelles technologies, de fournir des informations aussi factuelles, indépendantes et étayées que possible. Il y parvient en mettant chaque fois sur pied un **groupe d'accompagnement** composé d'experts choisis de manière à ce que leurs compétences respectives couvrent ensemble la plupart des aspects du sujet à traiter.

Studies carried out by the Centre for Technology Assessment TA-SWISS are aimed at providing information concerning the advantages and risks of new types of technology which is as factual, independent and broad as possible. For this reason they are conducted in collaboration with groups of experts in the corresponding field(s). Thanks to the expertise of their members, these so-called **supervisory groups** cover a broad range of aspects of the issue in question.

Folgende Personen wirkten bei der Studie «Nanotechnologie in der Medizin» in der **Begleitgruppe** mit:
Le groupe d'accompagnement de l'étude «Nanotechnologie dans la médecine» se composait des personnes suivantes:
The following people were members of the **supervisory group** for the «Nanotechnology in Medicine» study:

Dr. Andrea Arz de Falco, Bundesamt für Gesundheit (ab Mitte 2002)

Dr. Markus Ehrat, Zeptosens AG

Dr. Hans-Joachim Güntherodt, Universität Basel, Institut für Physik

Prof. Dr. Philipp U. Heitz, Universitätsspital Zürich (Präsident der Begleitgruppe, Mitglied des TA-SWISS Leitungsausschusses)

Karl Höhener, TEMAS AG

Dr. Patrik Hunziker, Kantonsspital Basel

Margrit Kessler, Schweizerische Patienten-Organisation

Bernhard Nievergelt, Forschungsstelle für Sozial- und Wirtschaftsgeschichte

Dr. med Flavia Schlegel, Bundesamt für Gesundheit, Abt. Gesundheitspolitik, Forschung und Bildung (bis Mitte 2002)

Herr Prof. Hans-Peter Schreiber, TA-SWISS Leitungsausschuss (bis Mitte 2002)

Dr. Louis Tiefenauer, Paul Scherrer Institut, Laboratory for Micro- & Nanotechnology

Barbara Vonarburg, Tages-Anzeiger, Redaktion Wissen

Tatjana Weidmann-Hügle, Universität Zürich

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