

# Nanotechnology – What is in store for us?

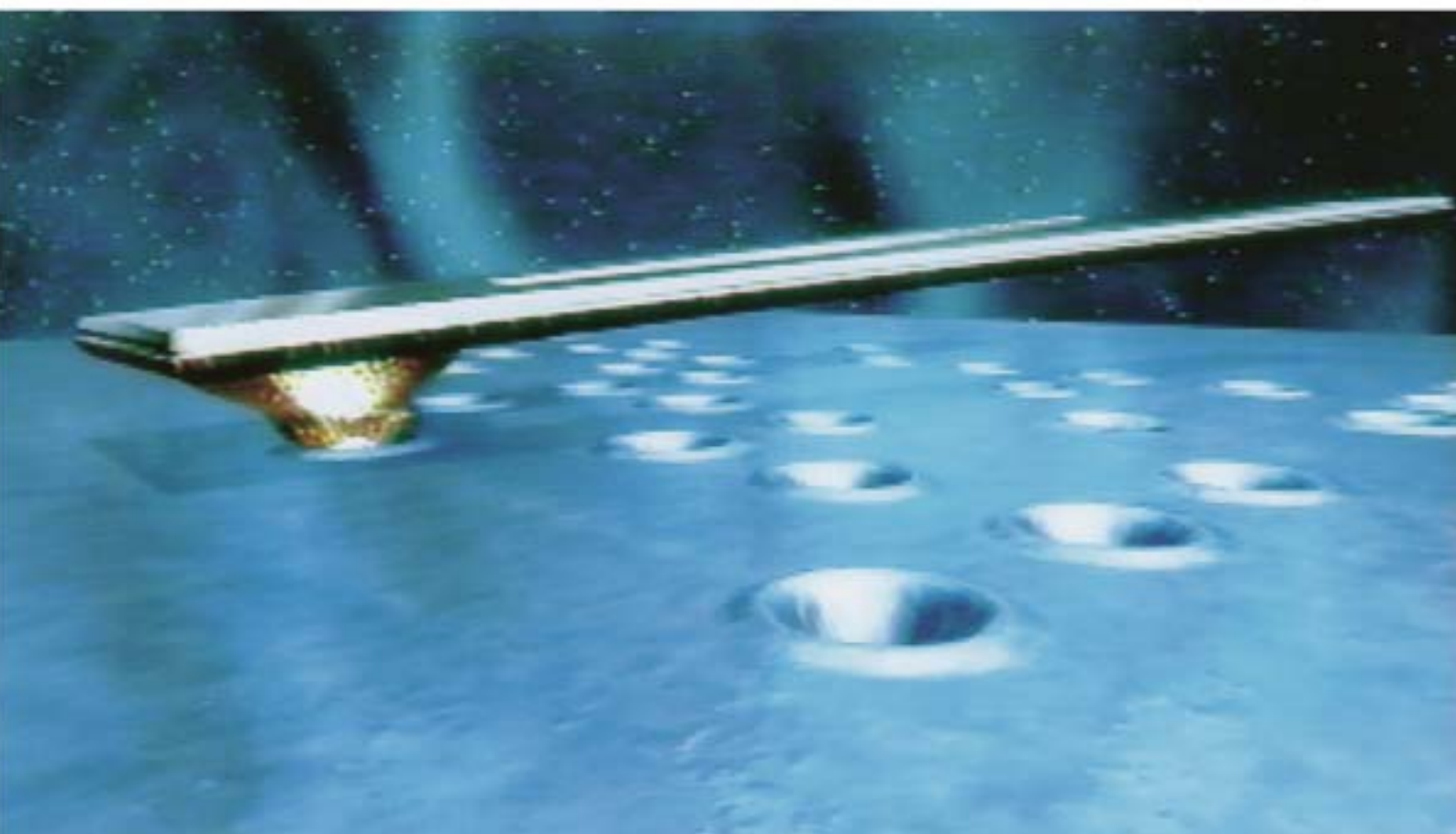
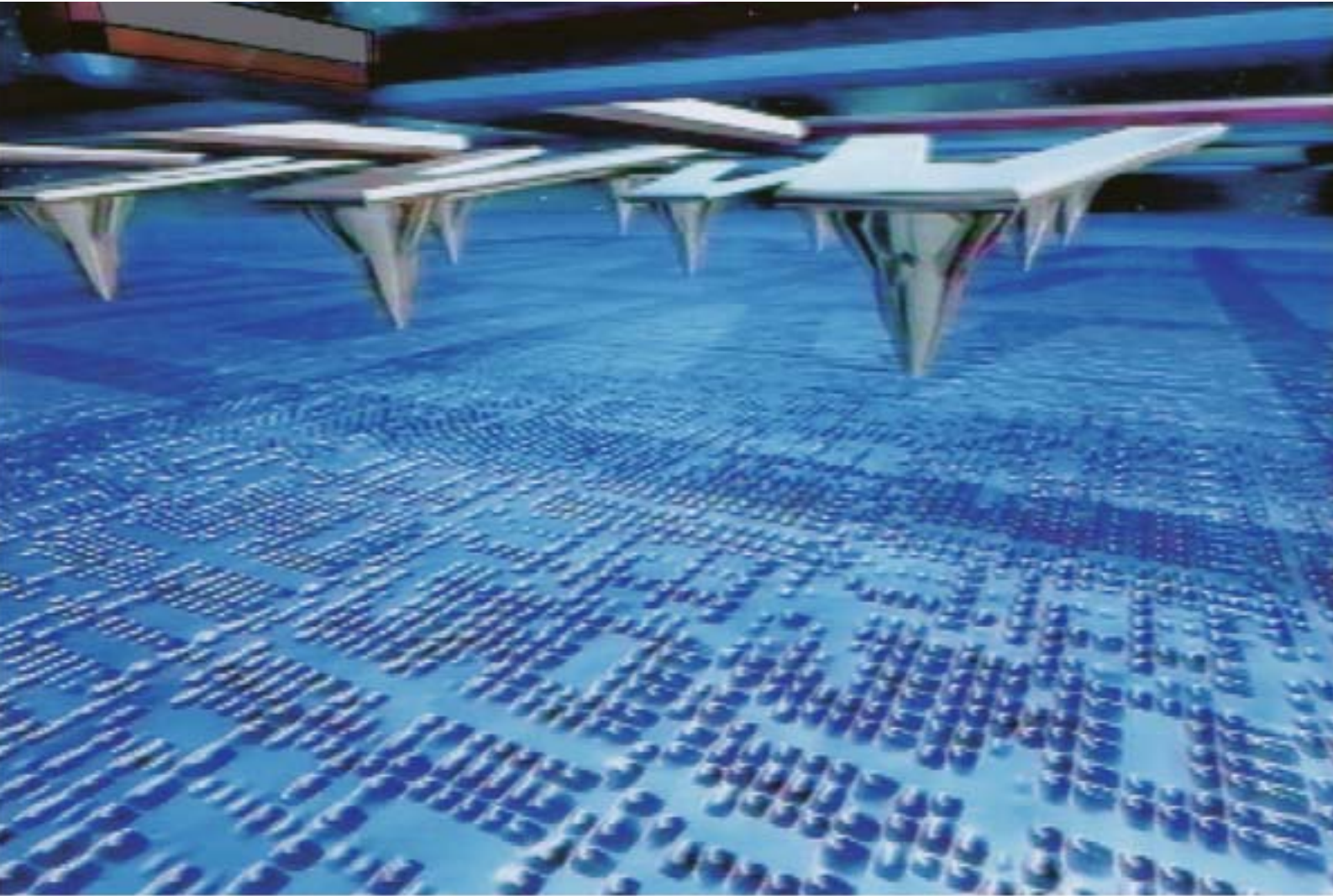


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The macro-photograph shows a molecule which has been artificially produced in the research laboratory and consists of eight caesium atoms and eight iodine atoms on copper. The aim of this research is to make it possible to develop minute machines and manufacturing processes in the molecular domain. The method applied here involves positioning individual atoms at precise points on a surface with the aid of tweezers. The data obtained from the scanning tunnelling microscope can be used to produce a computer image of the surface. The colours are caused by light refraction on the surface.

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When data are saved, the millipede is used to obtain a storage density of a trillion bits per square inch (the equivalent of having 25 million printed textbook pages on a postage stamp). By means of thousands of sharp tips, tiny indentations, representing individual bits, are punched into a thin plastic film. At the core of this technology is an array of v-shaped silicon cantilevers.

# Nanotechnology – What is in store for us?

## Nanotechnology – What is in store for us?

In the hunt for pathogens, doctors send tiny machines into the furthest recesses of the body. These “mini-submarines” are so small that they are not visible to the naked eye even as a speck of dust. Rotating cutting devices from the same dwarf world burrow their way through blocked blood vessels to eliminate the causes of heart attacks and strokes. In Berlin’s Charité hospital, scientists are carrying out experiments where minute iron particles are targeted at cancer tumours and then heated by an electro-magnetic field so as to destroy them.

Science fiction or realistic applications already found in today’s world? The building materials for these modern-day Lilliputian procedures are particles, so small that a million of them will fit onto the dot of an “i”. Scientists have given the name “nano” to this new technology. Nano comes from the Greek word for “dwarf” and signifies a billionth of a metre. Nanotechnology works with atoms which are barely one hundredth of a nanometre small, or 500,000 times tinier than the thickness of a hair.

It could well be this world of midgets which triggers the next major technical revolution, on a par with space travel, electronics or gene biology. The main hurdle was successfully cleared when, thanks to the high-resolution scanning tunnelling microscope, it became possible to probe, copy and transplant individual atoms, or to combine them with other atoms, at will. At the University of North Carolina in

Chappel Hill, the first machines are already in operation which can scan a sample, atom by atom, and produce a copy of it, atom by atom, in a different place. Are these the first minuscule robots capable, at least, of independent movement? The researchers’ main aim is to change the design plan of the sample in such a way that the copies can be used in new applications: according to Ralph Merkle, head of research at Zyvex, a nanotechnology company in Texas, the possibilities are so diverse that the final product could be “a micro chip, a transistor or a cheese sandwich”.

### **Starship Enterprise technology**

The central problem is not how to reproduce something from the box of atomic building blocks but how to develop design plans which can position each individual atom in the correct location. Eric Drexler, head of the Foresight Institute in Palo Alto, believes nanoassemblers could make steaks out of “grass, water and foodstuffs”, avoiding the cumbersome process involving the cow. Scientists at IBM’s Almaden Research Centre in San Jose, California, have succeeded in “drawing” a map of America in gold atoms on a mini-surface, one millionth of a square metre in area. It has a scale of one to ten billion and can only be seen through an electron microscope.

Gimmicks of this sort may continue to be a useful way of demonstrating technical potential but there is already a broad spectrum of serious applications. For example, Eric

Drexler, the guru of the new school, predicts a future generation of computers which will be both many times more powerful and much smaller. He envisages a cube-shaped computer, scarcely a millimetre high, which contains 100 billion atoms and is as powerful as today's PCs.

The spectacular product innovations are still pure fiction but we should make no mistake: the first DNA computers made with nanotechnology already exist and, beyond them, there is a wide range of technical applications, especially in medicine, pharmaceuticals, electronics, energy technology and surface technology.

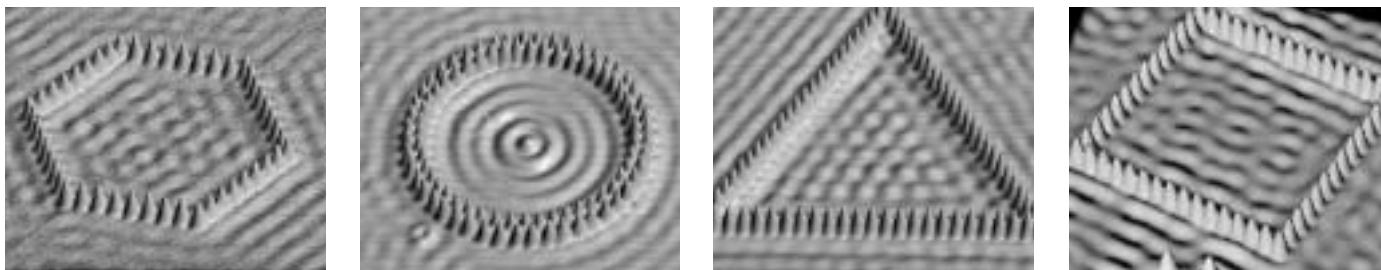
#### **Serious safety concerns**

Of course the new technology is not without its risks. Bill Joy, co-founder of the Sun Microsystems computer firm, warns that nanotechnology could destroy all life on earth. He fears an impending disaster where nanomachines run wild and reproduce themselves ad infinitum. They would dismantle anything in their path, atom by atom. He believes self-assembling molecules suitable for the mass production of miniature computer memory components, for instance, also pose a threat. They could transform themselves into artificial organisms which, like viruses, also destroy living cells. By 2030, in his view, we could well be able to develop machines a million times more powerful than the computers of today. We could not begin to imagine what capability such computers might have.

In contrast to the reaction to space flight, for example, which was initially hailed enthusiastically as a new departure, leaving small room for concerns about the associated risks, the current genetic engineering or environmental debates have heightened public awareness of the dangers posed by new technologies. For example, it is probably going to prove difficult to label nano products with their origin and producer, although it is something which is already feasible. This would mean that, in the event of a loss, it would not always be possible to trace the manufacturer responsible. A similar problem could arise from the threat of nanotechnology to natural resources, on a scale comparable only to that of nuclear accidents. If set free uncontrolled nano robots could, with the necessary constant power supply, transform organic substances in the environment into new materials or penetrate into the soil, causing permanent damage to crop cells or even destroying them. These would be totally new loss scenarios, likely to go far beyond anything experienced up to now in today's hi-tech world.

#### **Gigantic market**

Evidence that such concerns have a realistic basis is provided by the economic importance of the new atomic technology and the spectacular growth in potential applications. In 2001 alone, the worldwide market volume of nanotechnology applications was estimated at over €55bn. In view of the rising growth rates, the EU and most of the



The aim of nanotechnology research is to facilitate the development of minute machines and manufacturing processes in the molecular domain.

The photograph shows various atomic structures moulded and produced artificially. They consist of iron atoms on a copper surface.

industrialized nations, including China, Taiwan and Korea, have embarked on extensive promotion programmes.

In Germany, the Federal Ministry of Education and Research has been consistently stepping up its promotion of nanotechnology since the end of the eighties. For example, eighteen universities, twenty-three research centres and institutes together with fifty smaller and medium-sized firms, fifteen large firms and about a dozen consultants and risk capital investors have been combined into a single resource centre for chemical nanotechnology. The current level of government support is running at around €200m.

The Ministry for International Trade and Industry in Japan (MITI) has launched a number of promotion programmes. The first was the 1992 Angström Technology Project for the "ultimate manipulation of atoms and molecules" to which US\$ 396m was allocated for a ten-year period. In addition, about thirty national and foreign industrial concerns have committed US\$ 150m.

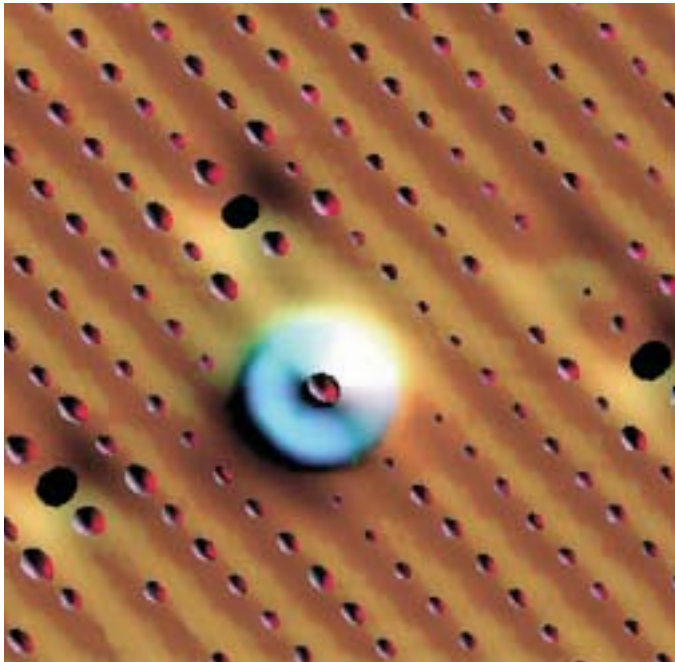
The USA, unlike Japan with its government-led promotion strategy, prefers decentralized structures. In addition to university and institutional research centres, it is above all the research laboratories of industrial concerns, such as IBM, which have assumed a leading role. Despite this, the National Science Foundation and the Departments of

Defense and of the Treasury have already started to consider the issue of coordinating the individual schemes. As a result, government support for the National Nanotechnology Initiative rose from US\$ 116m in 1997 to US\$ 495m in 2001.

These efforts have been rewarded with evident gains. In electronics, the market share of nanotechnology applications worldwide at the turn of the millennium was estimated to be €3bn per annum. In glass manufacturing alone, the market value of the complicated shapes and designs, only made possible by nanotechnology, is more than €1bn per year. The international automobile industry currently estimates nanotechnology applications to be running at a level of around €13bn per year. Nanotechnology anti-corrosion products have excellent prospects. It is estimated that damage caused by corrosion costs about €70bn every year in Germany alone.

Even though large-scale technical production is still in its infancy, three types of nanotechnology particle already stand apart which will acquire definite market significance in the near future, either as admixtures or as a vapour deposition:

- to reduce adhesiveness, for example in bearing seats;
- to prevent the build-up of dirt deposits, for instance in toilets or on the bodywork of cars;



The macro-photograph shows a xenon atom which has been positioned precisely at a given point on a surface made of the metal nickel, as if tweezers had been used. Using the computer, an image of the surface is produced from the scanning tunnelling microscope sample data.

– to improve surface structures, for example by making spectacle lenses more scratchproof or reducing the UV ray permeability of sun creams.

Although these practical applications may appear relatively modest, we should not forget that the breakthrough in being able to manipulate individual atoms using the scanning tunnelling microscope came only in 1990. Nanotechnology is, therefore, just a little over a decade old which means this new technology is setting a growth rate that leaves all other areas, including electronics or genetic engineering, well and truly in the shade.

#### **The next technological revolution**

In the field of medicine, in particular, there is considerable interest. One potential application already taking shape in practice is the transporting of active agents to the exact site of a disease. Miniature nano particles are structures whose size is measured in terms of only a few atoms which means that they can be combined into one unit together with cells or bacteria. The “mini-submarines” developed at Utah State University use the thread-like flagella of salmonellae to drive the screw propellers of drug-transporting vessels, less than a billionth of a millimetre in size and made up of living and dead matter. Are these early nano robots? At the IBM R schlikon research centre in Switzerland, Nobel prize winner Gerd Binnig is currently working on a silicon comb with tiny teeth, just a few atoms long. These combs would

be able to move around in the blood circulatory system, keeping a constant watch for cancer cells which would be recognized because they fitted the varying lengths of the comb’s teeth exactly. What would happen if a comb were wrongly programmed? Could it be retrieved? What about the risk management concept? Do we even have such a thing? Another important area is that of human tissue intolerance to implants, such as pacemakers for the heart or artificial organs. To solve the current problem of rejection by the immune system, the implants could be coated with a layer of nano particles acceptable to the body.

Nanoelectronics has progressed even more. According to a survey conducted by the Verband der Elektrotechnik Elektronik Informationstechnik (German Association for Electrical, Electronic and Information Technologies) around 300 experts believe that by 2010 a microscopic communications centre will have been developed, which can be carried about the person. Already the University of Delft is producing the first nano-sized, carbon-fibre computer chips. Their minute and, at the same time, dense structure could herald totally new computer capabilities, paving the way for authentic artificial intelligence. Nobel prize winner Gerd Binnig is convinced that the first ever millipede data-storage system will be on the market by 2004 at the latest: “This will be the first genuine nanotechnology product. Nanotechnology will be capable of performing far more sophisticated feats than today’s microelectronics. The

computer will acquire human characteristics. It will understand contexts and not react in the same obtuse way as computers today." The first prototypes already exist.

In the energy sector, increasing miniaturization has boosted the demand for small, efficient batteries. Nanotechnology points the way to the appropriate systems. A car equipped with hydrogen-based fuel cells could have a range of as much as 8,000 kilometres on a full tank, thanks to the large storage capacity of its "nano tank". Nanotechnologists are also trying to find ways of incorporating minute solar cells into building façades and road surfaces. These cells would produce energy costing 80% less than present systems and offering better protection to climate and environment. The key to applications such as these lies in assembling nanotechnological material, custom-built right down to its very atomic structure. In environmental protection this opens up the possibility of constructing nano particles with large inner surface areas which could be deployed as high-performance filters, dealing with specific pollutants.

Metals which are nanotechnically upgraded gain considerably in solidity. A survey carried out among nano scientists by the American computer magazine "Wired" gives some indication of the way ahead:

- We can look forward to computer memories with terabyte capacity by 2004.
- By 2009 we will have the first laws relating to nanotechnology.
- By 2011 there will be large-scale production of machines able to position and manipulate individual atoms with great accuracy.
- By 2029 nano machines will repair live cells using atomic building blocks.

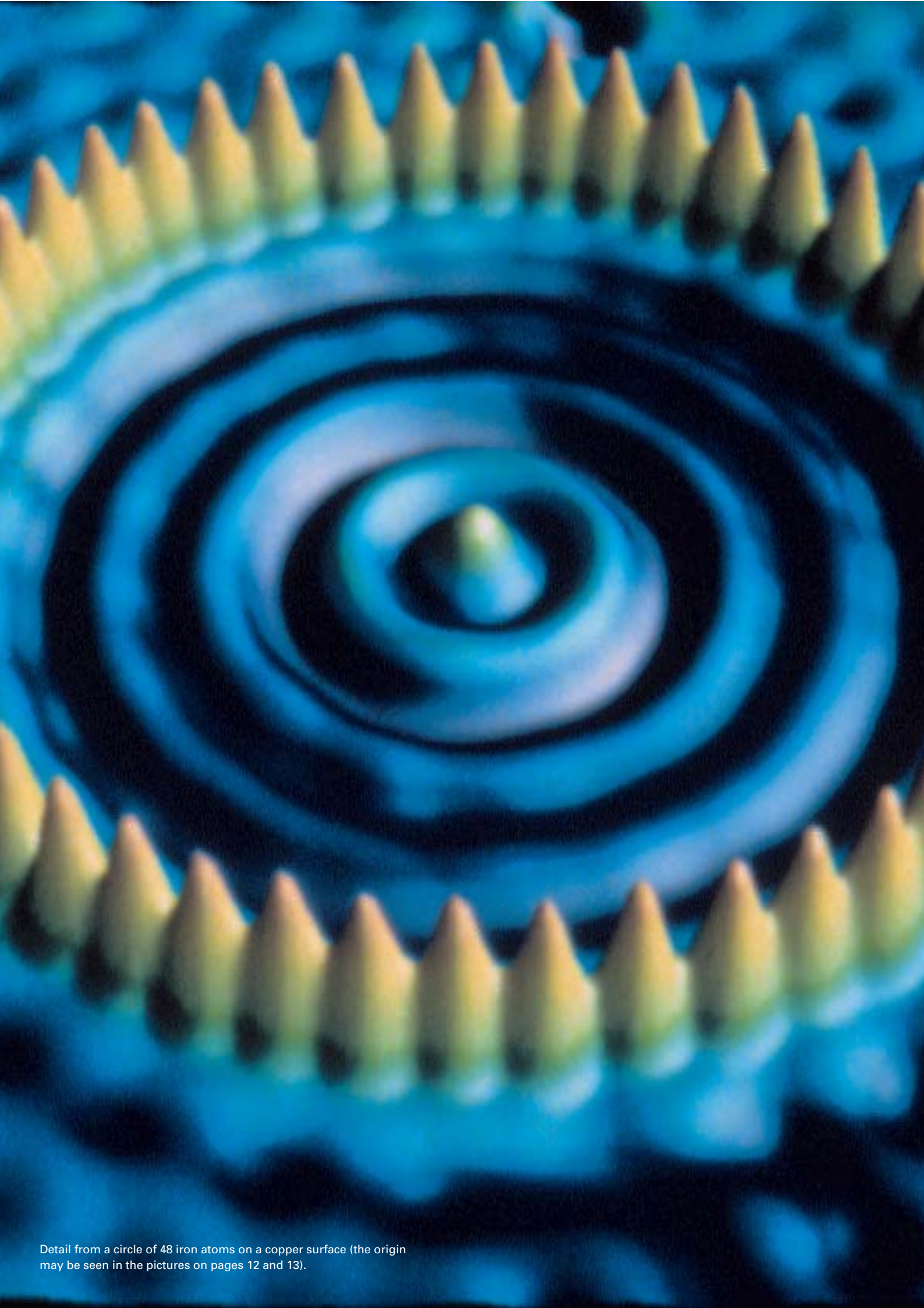
An investigation carried out in autumn 2001 by "manager magazin" in Germany, in collaboration with the Organization for Economic Cooperation and Development, to find the "seven major technologies of the future", named nanotechnology as one of the frontrunners, alongside fuel cells or optoelectronics. It is true that all these judgements are made from a turn-of-the-millennium perspective but they all concur that nanotechnology is not just a technological fad but something set to revolutionize even mature sciences, such as electronics, telecommunications or medicine, with all the attendant risks and side effects.

### **Need to gauge the risk**

It is this very multiplicity of development opportunities which may cause us to overlook potential risks. The application of nanotechnology products and processes could bring about a whole new dimension in personal injury, property damage and pure financial losses as well as third-party liability risks, for instance in product, environmental and third-party liability. From the underwriting point of view, this "risk of change" arises because, as scientific knowledge increases, so defects are discovered which are hidden in new products or processes. This leads to

- fundamentally new types of loss scenario, for example (resulting from new material properties, such as magnetic fluids), which did not exist in the past,
- exponentiation of existing loss potentials (incidence and major claims risk),
- more stringent bases of liability, as a result of changing legislation and jurisprudence,
- a new concept of damage resulting from a change in the socio-political or socio-economic environment.

This applies particularly because under liability law in many countries, third-party liability does not depend only on whether the apparently responsible party is at fault (fault-based liability). On the contrary, such liability also exists in cases where neither user nor manufacturer of nanotechnology products and processes had reason to foresee a risk of loss and where they were acting in accordance with the state of the art and science applicable at the time (no-fault liability).



Detail from a circle of 48 iron atoms on a copper surface (the origin may be seen in the pictures on pages 12 and 13).

## Examples of nanotechnology risks which can be described on the basis of the current state of the art

In particular, **product liability** could take on new dimensions in view of the complexity of the potential applications of nanotechnology products and processes. Basically, we are dealing with two distinct groups.

1 Passive nanotechnology products such as surface coatings, powders or similar products, already manufactured using non-nanotechnology methods and often featuring the following much-debated causes of loss:

– Development errors

These occur at the stage prior to mass production of the item. Usually, the result is that all products of that type are rendered unfit for the intended purpose.

– Design errors

These may arise before, but also during, mass production of the article. The effect of this type of error is that the goods produced are unfit for the intended purpose.

– Faulty manufacture

Although the product is essentially fit for the intended purpose, individual components (outliers) or particular batches of the articles have defects (serial losses) resulting from production errors, which can result in loss or damage for the purchaser or final consumer.

– Information errors

In this case, the cause of loss is not a flaw in the product itself but misleading or incomplete advice or erroneous instructions for use. This can lead to risks either in actual use of the product or because it is incorrectly stated to be fit for certain purposes.

– Product monitoring

Due to a lack of product monitoring in the market, the defects which occur during application and use of the product in practice go unrecorded. Consequently, they cannot be passed on to research and development for product optimization purposes. A distinction must be drawn here between

– active product monitoring by the manufacturers themselves or by a company to whom they have outsourced the task

– and notification of defects to the manufacturer by consumers who contact the “customer service” department or its equivalent.

2 Active nanotechnology products able to act autonomously.

Defects in active nanotechnology products may be caused by the factors referred to above. However the active prod-

Scanning tunnelling microscope at the Ludwig Maximilian University, Munich, Chair of Crystallography/Center for NanoScience.

ucts differ significantly from their passive counterparts inasmuch as they are able to move around in the environment independently, and may even, in some circumstances, be able to transform or replicate themselves.

The following factors are a basic guide:

#### **State of the art, reproducibility, programming**

These reflect the sum total of findings from research and development, construction and manufacturing (RDCM). According to the state of the art, RDCM can be carried out by the active nanotechnology products themselves. This means the products are programmed in such a way that they have the ability to develop or change (through the recombination of individual atoms) or even to reproduce themselves in nano factories.

#### **Power supply**

This determines the length of time for which an active nanotechnology product is able to continue operating autonomously.

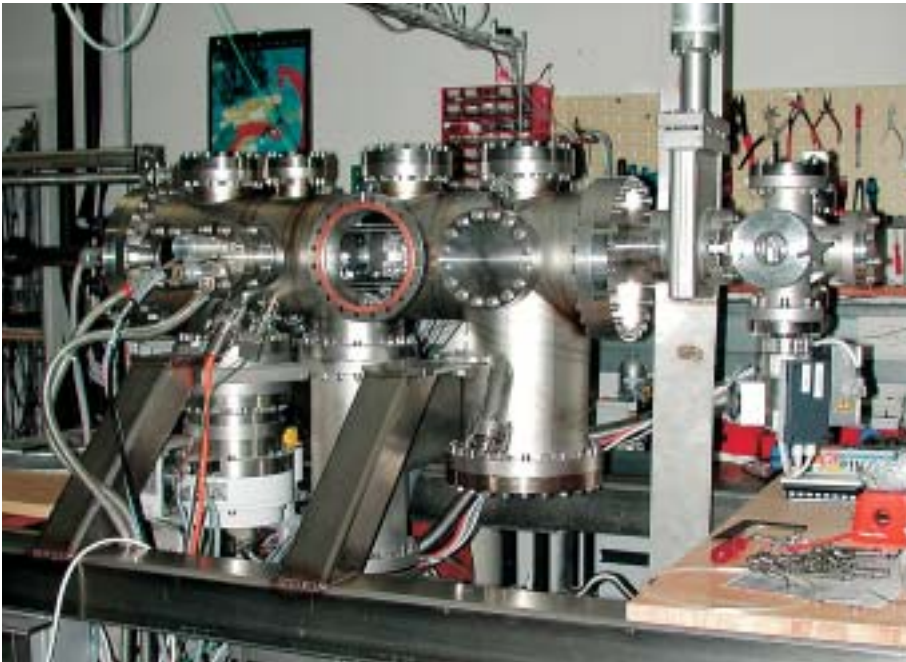
#### **Monitoring and retrievability**

A characteristic of nanotechnology products is that they cannot be seen with the naked eye. Therefore, if it is found that an active nanotechnology product can cause personal injury, damage to property or financial loss, it cannot be retrieved or recalled.

We are faced with two opposing trends. On the one hand, progress in nanotechnology increases the area of risk: in the case of the passive products through possible combinations of various material properties; with active products, mainly through their self-organization ability and the consequent incalculability regarding bodily injury, property damage and financial loss. On the other hand, it is that very progress in the realm of passive and active products which affirms society's claim to an even higher and better-protected standard of living. This mentality is flanked by product liability laws which are constantly being adapted. It is true that consumers are better protected in this way but, at the same time, it tends to encourage claims consciousness.

#### **Product recall**

In view of the innovative nature of the manufacturing methods and consequently increased risk of teething problems, there are likely to be more frequent product recalls. An example would be a manufacturer of façade windows or car windscreens who uses nano particles to reduce the reflection given off by the windows. Following a fault at the development stage, prolonged exposure to the sun's rays destroys the anti-glare properties. All the windows which have already been installed have to be removed and replaced with defect-free ones.



As recalls are not covered under product liability as a general principle, insurance companies can expect an increasing demand for product recall policies. However, that will not in itself solve the problem. Recall actions are especially difficult to organize in sensitive areas such as medical or pharmaceutical applications, due to the technical complexity of the nanotechnology products and processes. Moreover, a major technological effort is required to tag nanotechnology products and processes. This means that the manufacturer can only fulfil his duty to monitor the product to a limited extent; tracing the products is virtually impossible. What sort of machines will be able to retrieve nanotechnologically manufactured or modified products? What if nanotechnology-modified car paint is more dirt-resistant but starts to flake off the bodywork after twelve months. If the manufacturer has several paint suppliers, such is the miniaturization of the material that it will be difficult to assign the loss.

#### **Public liability**

In some countries product liability is incorporated into public liability. This increases the significance of public liability as far as nanotechnology products and processes are concerned. From the point of view of the insurance industry at least three aspects then increase the risk:

- As legislation strengthens the hand of the aggrieved party, the risk that companies which produce active nano-

technology products will be presented with a claim in the event of loss is statistically increased (cf. no-fault liability in the case of Environmental Liability Act facilities).

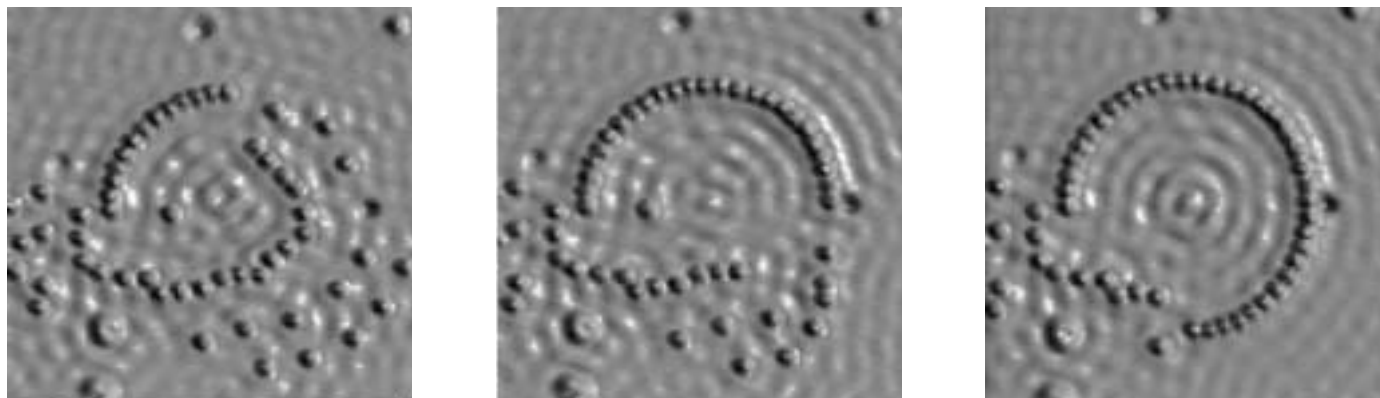
- More stringent liability standards will apply to the manufacturers of active nanotechnology products.
- Where the manufacture of active products is concerned, the consumer-friendly interpretation of those standards will further increase the third-party liability risk.

#### **Environmental impairment liability**

The manufacture of nanotechnology products will aggravate the conventional risks of third-party losses and damage to natural resources. Not only people, property and capital but also the environmental constituents of earth, air and water are threatened by losses in any number of

- laboratories,
- manufacturing plants,
- warehouses,
- waste management and waste disposal plants,
- outdoor trial areas,
- as well as by damage caused by the products themselves.

For example there could be a loss in a nanotechnology laboratory when a gas cylinder explodes. The resulting pressure wave destroys the development centre and the departments which are normally hermetically sealed off from the outside world. Magnetic nano particles are



The macro-photographs show four stages in the origin of an artificial, ring-shaped structure. Using the scanning tunnelling microscope, each of the 48 iron atoms can be manipulated one by one onto a copper surface.

released which not only adhere to electronic installations in the vicinity of the laboratory but also destroy information stored on data media. At the same time, nearby businesses are affected and this results in business interruption losses.

This example and its implications illustrate the advisability of assessing each risk on its own merits, particularly since we lack experience with losses of this type.

#### **Workers' compensation**

The special features of nanotechnology with its infinitely small-scale products make it essential that sterile, clean room technology working conditions be provided to protect employees. Nonetheless, accidents could happen, causing breakdowns in the sealing system. Active nanotechnology products might then be released during manufacture, endangering the lives of workers and environment.

#### **Medical malpractice**

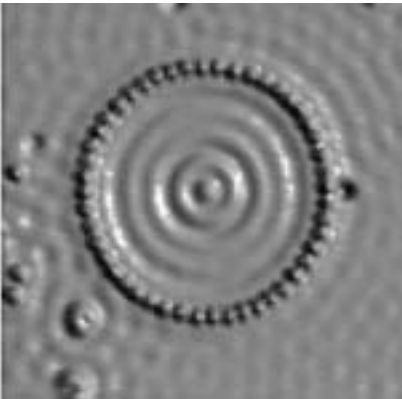
Medical malpractice insurance for hospitals and community-based physicians will doubtless be subjected to increased risk of loss due to the use of nanotechnology, as is the case with current gene therapy techniques. This issue has three important aspects:

- Nanotechnology changes atoms and molecules and so encroaches on a sensitive area which is prone to errors and oversights, the type of therapy being brand new.
- There may also be unforeseeable interactions with other, possibly gene technology-type, therapies.
- Nanotechnologically created products, which can sometimes have unpredictable effects, are administered to patients.

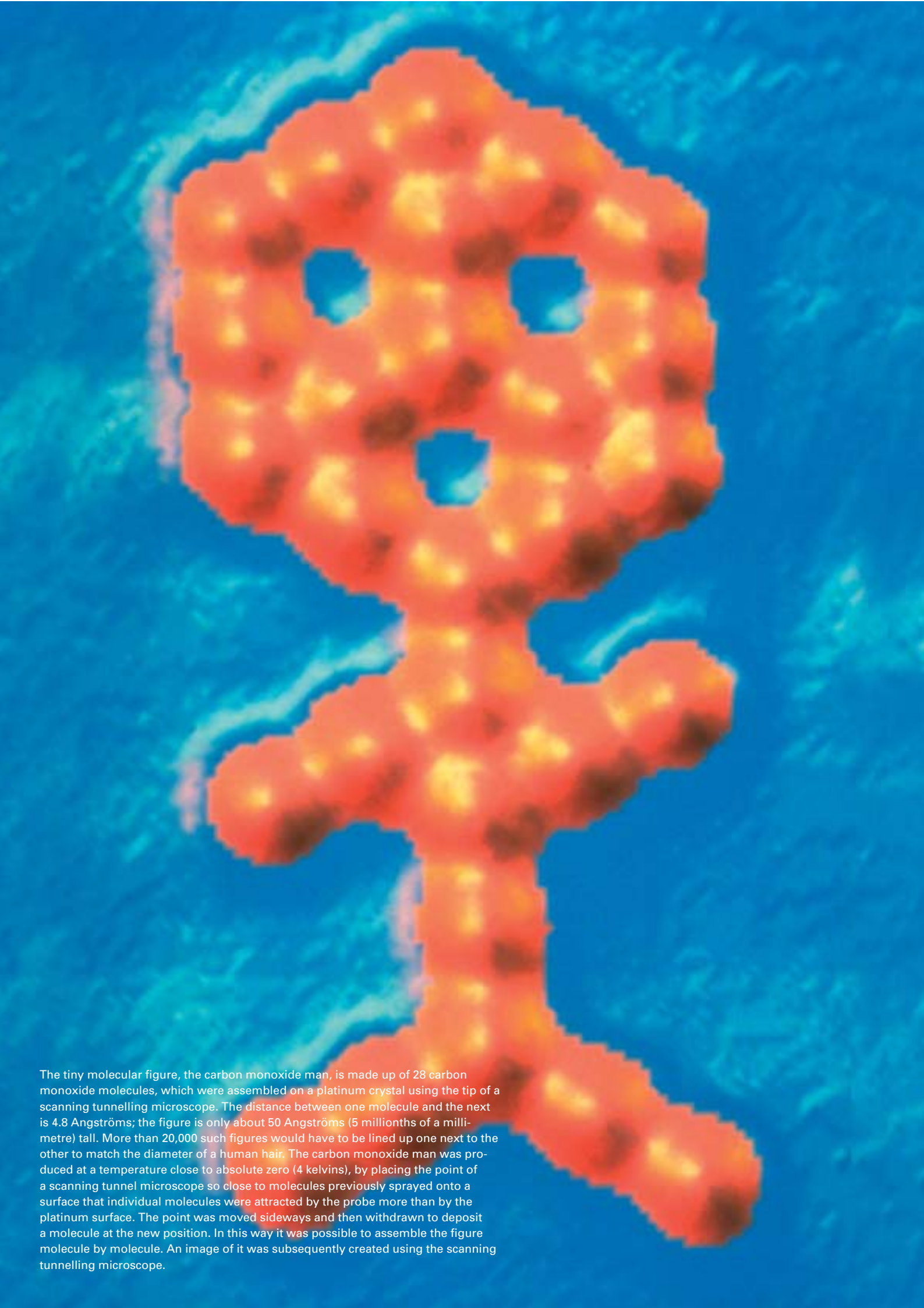
For example, efforts are currently underway to implant nano robots in human cells so as to remedy defects in them. If, however, there has been a programming error, the doctors might destroy the wrong components, thereby causing fatalities.

#### **Motor third-party liability insurance**

A further area of risk is when nanotechnology products are transported. An example would be an accident occurring during transportation of nanotechnology robots. Once freed, the robots can replicate themselves, provided they have a constant supply of power, and subsequently find their way into the ground with lasting consequences. In the long term, they alter the genotype of crops. Moreover, nano robots, spread by the environmental constituents of air and soil, cause further damage to natural resources.



The new element with this kind of loss scenario is that, up to now, losses involving dangerous products were on a relatively manageable scale whereas, taken to extremes, nanotechnology products can even cause ecological damage which is permanent and difficult to contain. What is, therefore, required for the transportation of nanotechnology products and processes is an organizational and technical loss prevention programme on a scale appropriate to the hazardous nature of the products.



The tiny molecular figure, the carbon monoxide man, is made up of 28 carbon monoxide molecules, which were assembled on a platinum crystal using the tip of a scanning tunnelling microscope. The distance between one molecule and the next is 4.8 Angströms; the figure is only about 50 Angströms (5 millionths of a millimetre) tall. More than 20,000 such figures would have to be lined up one next to the other to match the diameter of a human hair. The carbon monoxide man was produced at a temperature close to absolute zero (4 kelvins), by placing the point of a scanning tunnel microscope so close to molecules previously sprayed onto a surface that individual molecules were attracted by the probe more than by the platinum surface. The point was moved sideways and then withdrawn to deposit a molecule at the new position. In this way it was possible to assemble the figure molecule by molecule. An image of it was subsequently created using the scanning tunnelling microscope.

# Risk management

All the above examples show that the real risk lies in our ability to control nanotechnology. This control cannot be achieved by devising new insurance concepts. Nor is it logically possible to calculate suitable premiums, risk loadings or rebates as long as we are unable to estimate the potential claims cost. Consequently, we should concentrate on developing risk management tools designed to prevent and reduce losses. This is an area where the insurance industry is reliant on cooperation between scientists and safety engineers: with the aid of technical and scientific data, the essential issues and problems of nanotechnology can be analysed and evaluated and condensed into a product safety and crisis management system. The aim of risk management is, thus, to reduce the risk to such an extent that the third-party liability insurer covers only the residual risk. Both in-house and external expertise are required to determine the scope of this risk. However, what is even more important is to establish an ongoing dialogue between insurers and the manufacturers and consumers of nanotechnical products and procedures, so as to reduce the risk for all concerned.

Specifically, risk management should cover the following:

- Technological assessment and an appraisal of the effects of each nanotechnologically produced article.
- Differentiation between passive (e.g. passive surfaces) and active (e.g. robots in the human cell) nanotechnology products.
- Active nanotechnology manufacturing only under controlled, high security laboratory conditions (HPR approach).
- Use of active nanotechnology products with guaranteed, continuous monitoring.
- Lifecycle-monitoring obligation on the manufacturer and devising of recall strategies and technical options.
- Decoupling of function and power supply for active nanotechnology products.
- Compulsory tagging of products which incorporate active and passive nano components.
- Setting up of discussion and decision-making organs on social, corporate, ethical and political levels, to give all interested parties a chance to voice an opinion.



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