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Nanotechnologies: potential risks and ethical challenges

Public hearing of the 7 November 2006 organised by

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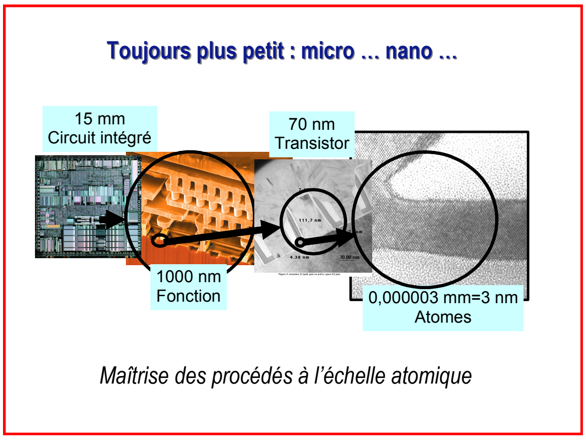
The aim of this hearing was to ensure follow-up to the Bureau's report on "the development of the semi-conductor sector and its links with micro and nanotechnologies" submitted by M. Claude Saunier in January 2003 and the report submitted by Messrs. Daniel Raoul and Jean-Claude Lorrain on "nanotechnologies and medical progress" in May 2004, as well as to add substance and in-depth analysis to current debates on nanotechnologies.

Summary

1 – Nanosciences and nanotechnologies: a scientific revolution?

"The nanometre is to the metre what the grapefruit is to the earth". On this scale, the frontiers of conventional disciplines such as chemistry, physics, biology and electronics become blurred at the edges and the major principles of physics are no longer applicable as such. Although nanoparticles (atomic clusters), less than 100 nanometres, have been present in our environment since the dawn of time, studying them has shown that their size makes their physical and chemical properties different and unpredictable. They are highly reactive and their composition offers new properties - certain particles remain in the environment and tissues, they cross cell barriers. On an atomic scale, nanotechnologies make it possible to manipulate constitutive elements of matter. They open up the perspective of a convergence between nanotechnology, biotechnology, information and cognitive sciences (NBIC), against the backdrop of an encounter between two worlds, the living and the inert, together with a closer man-machine, info-cogno interweave.



From an historical point of view, the beginning of nanotechnologies is generally situated around Feynman's 1959 talk: "there's plenty of room at the bottom". Although electronic miniaturisation began in 1965, the break occurred in 1981 with the scanning tunneling microscope (STM), an observation and manufacturing instrument. In 1986, Drexler carried out visionary work on the concept of molecular nanothechnology based on the works of Feynman. But, in 2003, Smalley called the latter's conclusions into question, asserting that "there's not that much room", particularly as a result of the limits of accessibility. From a concrete point of view, the STM tip pushes meshed molecules into a two-dimensional space. Three-dimensional action would make it possible to go even further, but current tools are not adapted. This is the "sticky and fat fingers" problem. And what complexity could be introduced "at the bottom"? The answer to this question determines the credibility of the hypothesis of the creation of independent future objects, something which, in all probability, will only be verified in 10 to 20 years time, but cannot be excluded.

2 – Nanoworld features

A great diversity

Nanotechnologies cover a wide scope of

technical fields: nanostructured materials featuring revolutionary strength and adaptation properties, nanoparticles, nano-objects, nano-electronics, nanodevices combinng nanometric objects and biotechnology. This sector is marked by fast-track innovations with optimised market-access time. It is characterised by a high diversity of objects, manufacturing sites and disciplines involved. While it is current to state that technological advances stem from scientific progress, the relationship seems to be the contrary where nanotechnologies are concerned.

A major economic challenge

Numerous figures of varying reliability are put forward, but expectations are huge in economic and strategic terms. The perspective is raised of a highly competitive market by 2020, of 1 to 3 thousand billion dollars. Nanostructured materials are said to represent a quarter of this future market.1,400 types of nanoparticles are today marketed throughout the world. It is reported that 10 million metric tons of carbon black were produced in 2005 and 3,800 metric tons of titanium oxide nanoparticles. There are already 700 everyday products which use nanoparticles, including cosmetics, revetment concretes, paints, tyres, windowpanes and electronic components.

Les attentes aujourd'hui et demain

Vital technological challenges

Several bottlenecks could be resorbed by nanotechnologies: information (securing, transmitting and miniaturising), materials, agribusiness (food quality and traceability), transport and the construction industry (lightening and strengthening of materials), the environment (purification and wastewater management), energy, medicine and metrology. Carbon nanotubes are one of the sectors currently being developed since, among other things, these help enhance conductivity and mechanical properties of materials.

Nanomedicine. The nanometric scale is essential to help customised medicine, drug targeting, molecular imaging and brain implant techniques move forward, and to observe the inside of cells, in particular via the use of biomarkers which make it possible to identify the presence of an imbalance indicating an illness or a forewarning of illness. "Chip laboratory" systems will soon be operational, making it possible to transmit data collected from the patient electronically to the physician.

3 - Need we be afraid of nanotechnologies?

Risk management must go hand in glove with progress. There must be a reasoned acceptance of nanotechnologies. What are the challenges that have to be met?

Potential risks for health and the environment

The basis of knowledge of nanoparticle toxicity is different from conventional chemical toxicity. Size determines the rules of penetration and settling into cells, directs the mechanisms of nanoparticle internalisation in cells, migration in the cytoplasm and the nucleus, even passing through the hematoencephalic barrier. The significant reactivity of nanoparticles produces a negative impact at a biological level. It is no longer the toxicity of the particle itself which must be taken into account, but that which it conveys. The combination of these effects with the biopersistency of particles that are difficult to detect via global analyses risks provoking, at cell level, a loss of function, hyperactivity or a disruption in their cycle. Such abnormal cellular responses can bring about an inflammatory reaction which, when it persists and is self-maintaining, is liable to engender fibroses and cancers. Nanoparticles, in particular those of carbon and titanium dioxide, have a high degree of penetration in the respiratory apparatus and the capacity to pass through cellular membranes. The residues and additives used to produce them also represent a toxicity risk.

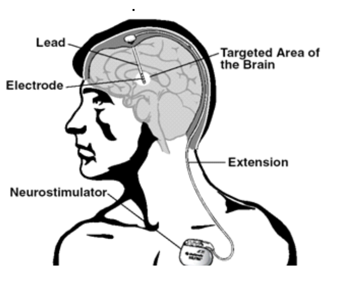
A nonetheless difficult evaluation

Works on toxicology do not always give rise to high-impact articles, which is why many researchers leave such studies to one side. The result is that knowledge on this topic is not really stabilised and questions of interpretation or correlation between publications also persist. There are few experts in this field and their independence is sometimes challenged. Doses currently used during these experiments are very excessive in relation to those to which man might be exposed in normal conditions. Long-term effects are difficult to analyse and pose a serious problem when setting up research projects since the longer the manipulation, the more costly it becomes. Adapting nipulation, the more costly it becomes. Adapting evaluation methods presupposes new equipment for occasional and routine readings, and the establishment of a new relationship between science, technology and the market. Costs of laboratory measuring instruments can be as much as €300K.

Ethical questions

A transgression? Man has allegedly created a technique that is now beyond his control, against a backdrop of transgression of fundamental cultural values. He has apparently generated a new science, with new, hybrid materials using parts of the biological machine. A technology has seemingly been born which, as a result of biomimetism, is said to have the power of controlling and enslaving nature and man. Human society would have to submit to the advent of the nano-era, and even to a transhumanism announced by certain promoters of the "nano" project in the U.S.

An acceleration in the transition from fundamental research to industrial application, making ethical reflection difficult or pointless? The particular characteristic of nanoscience and nanotechnology research is the impossibility of dissociating fundamental and technological research. It produces synergies through nano-bio-info-cogno convergence (NBIC) whose effects are unpredictable. As for the military use of nanos, by essence, this cannot be transparent. But can we carry out an ethical reflection on something about which we know nothing? Must we produce innovations and diffuse them before understanding and being able to control them? In this area, ethics cannot be condensed into a benefits/risks analysis by experts and cannot be normative. The necessary seamlessness is constantly jeopardised by increasingly unfair competition and patent management methods.



Implant

Insufficient account taken of the economy's ethical dimension? Nanotechnologies will be used to replace and reduce the consumption of natural materials and mineral resources which are essentially to be found in developing countries. The medium- and long-term economic impact will be considerable and increase the technological divide.

Is traceability a solution? It can have ambivalent effects, either positive or negative, since traceable nanomaterials would make man himself traceable.

How to manage the situation of an individual who has been "modified" by nanotechnologies? At diagnostic and therapeutic levels, the consequences of a nano-drug, the perspectives of brain doping and the use of brain implants must be correctly appreciated. What, for example, would be the legal status of a man with an implant who develops behavioural problems? And that of "enhanced" humans?

Impacts on society

Widespread fears. The perception of risks by the public is expressed by the widespread fear that man might become mechanised, that his health and the environment might irreversibly suffer, that accidents might occur, military means be heightened and tools developed that are liable to be used by terrorists, while some people wonder about the usefulness of such technologies for the citizen. These technologies have become the focus for certain criticisms of techniques developed by Jonas, Arendt or Ellul. They are liable to rekindle the fears expressed when IT&C technologies first began to emerge and, in particular, biotechnologies and the anger sparked off by errors committed in risk management, such as with asbestos. At the same time, they arouse expectations and hopes, essentially in the medical field, and are situated in a legal framework deemed by some to be sufficiently accomplished and by others incomplete.

Contrasting viewpoints. Although 40% of Europeans think that nanotechnologies will enhance the quality of life over the next twenty years and 42% are "don't knows", 49% of Americans think that the risks outweigh the benefits, with 7% of "don't knows". Emerging Asian countries seem, however, to be less reticent.

Insufficient financial means

In 2006, the U.S. devoted approximately 40 million dollars to ethical problems, mainly safety-related, out of a total of one billion dollars of expenditure. Is this enough? Is it possible to convince people that one is attentive to preserving health and the environment with such a small proportion of financial means earmarked to developing nanotechnologies?

4 – The French response

The tricky application of the precautionary principle against a backdrop of uncertainties

Substances often arrive on the market before precautionary procedures are implemented. The French Agency for Health and Safety in the Environment and at Work (AFSSET, *Agence Française de Sécurité Sanitaire de l'Environnement et du Travail*) and the Committee for Prevention and Precaution (CPP, *Comité de la Prévention et de la Précaution*) feel that it is not currently possible to carry out a satisfactory evaluation of the risks for man. The CPP has put forward several recommendations in application of the precautionary principle:

Ensuring real coordination of cross-

disciplinary research involving physics, chemistry, biology, medicine and human sciences.

Compiling an inventory of nanoparticles resulting from nanotechnologies and manufacturing sectors, with standardisation of nomenclature, and creating an exhaustive database.

Producing new knowledge with regards to identifying particles and exposed populations, metrology, risk evaluation and development of new tests via high-throughput toxicological screening.

Adopting precautionary measures without waiting for new data and proposing them to the populations directly in contact with the production of nanoparticles, their use or destruction at the end of material life.

Protecting the population at large and carrying out a reflection on ecosystems. "Sun barrier" creams containing titanium dioxide, for example, go into the wastewater systems in the form of nanoparticles and end up in ecosystems.

Fostering research ethics

We need to ask ourselves about the sense of the nanoworld being constructed in laboratories together with the research being carried out. To meet what needs? Who will benefit? Are the investments made justified? Who will be responsible in the eventuality of a problem? The National Consultative Committee on Ethics, the Ethics Committees of the CNRS and INSERM have addressed and are still addressing these issues. They have put forward proposals.

Researchers' deontology and the transparency of results and sources must be encouraged, on the basis of fundamental research, knowledge sharing, good practices and reasoned management in cases of conflicts of interest.

Ethical centres and places for debate must be created in laboratories for researchers, engineers and technicians to express their questionings and voice their points of view.

Permanent contact between scientists, public and civil society must be established so as to act in consultation when defining and monitoring research programmes.

5 – The contributions of the international community

Several international institutions have addressed the problems raised by nanotechnologies with a view to producing guidelines.

At UNESCO, a programme is devoted to the ethical challenges of nanotechnologies and prospective studies are underway aimed at taking into account their social and ethical impact, via a cross-disciplinary approach. This work covers nanoparticle characterisation, environmental impact, toxicity, nanomedicine, privacy, confidentiality, public surveillance and military applications but also dissemination of knowledge and issues of intellectual property. Proposals converge towards the need for ethical education and a voluntary ethical guideline for scientists.

European Union actions

The 7th Framework Programme for Research and Development should provide 3.5 billion euros of finance for nanotechnologies. At the same time, the European Action Plan covers not only the enterprise & industry dimension but also the risk aspect, the safety of workers, citizens, consumers, the environment and the international issue. Specialised committees have been formed, particularly with regards to methodology for the evaluation of risks and regulatory aspects.

Directed by the CEA for France, the *NanoSafe* project focuses on risks. *NanoSafe1* has enabled a current inventory to be drawn up. Scheduled over four years with a budget of €12.5M, *NanoSafe2* is more ambitious and comprises four sub-projects: development of detection technologies with a substantial reduction in cost; risk assessment via screening and fast toxicity analysis; securising industrial systems and procedures; environmental and societal aspects, with recycling and life cycle analysis.

With regards to ethical questions, the general European legislative framework seems suitable. A strategic reflection on ethics is, however, being carried out via *Eranet* and *NanotoLife* networks, as well as the *NanoMedicine* platform which has drafted a document on the strategies of development and European programmes focusing on nanoparticle toxicology and communication.

Responsible international dialogue

Since 2004, this informal authority has provided government representatives from all countries a framework for debate on the governance of nanotechnologies and convergence in order to anticipate developments. 25 countries, including France, Japan and the U.S. take part each year. It recommends earmarking a higher percentage of public and private funding for research into risks, based on heightened international institutional cooperation, the creation of a database on nanoparticle characteristics, the adoption of a harmonised methodology for multi-criteria evaluation of their impacts and a societal observatory.

Conclusion

While problems for assessing risks and ethical challenges are identified at national and international levels, funding earmarked for these fields is clearly insufficient. These issues need to be taken into account upstream, within the scope of more integrated and open research programmes.

Against the new and increasingly clearer backdrop being outlined, OPECST intends to ensure monitoring of actions engaged in this area.

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