

Conseil General des Mines

*(CGM, general council for
mine engineering)*

*Conseil General des Technologies
de l'Information*

*(CGTI, general council on
information technology)*

**NANOTECHNOLOGIES:
ETHICS AND INDUSTRIAL PROSPECTS**

VOLUME 1

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NANOTECHNOLOGIES:

ETHICS AND INDUSTRIAL PROSPECTS

SUMMARY

Government policies will face a major challenge in the next thirty years: that of nanotechnologies. An ambitious relaunch of the main scientific and technological programmes is therefore on the agenda in France and the European Union to stimulate employment and competitiveness. In this respect, nanotechnologies will play a significant role.

The main countries of the OECD have already taken explicit measures in this field in terms of public support for research and innovation. On 24 September 2004, the Competitiveness Council took note of the role and major potential of nanosciences and nanotechnologies in many fields and recognized their potential contribution to the quality of life, sustainable development and the competitiveness of European industry.

Recognizing that the development of nanotechnologies is inevitable, the joint "Innovation and Enterprise" section of the *Conseil général des mines* (CGM, general mine engineering council) and the *Conseil général des technologies de l'information* (CGTI, general council on information technology) included in its work programme a task force to prepare the main orientations for assessment of French public policy with respect to nanotechnologies, based on an analysis of the European and international contexts, taking into account all aspects, particularly their societal and ethical implications.

The prospective approach led the task force to position nanotechnologies in a stronger dynamic process, i.e. the meta-convergence of transformative technologies such as information and communications technology, biotechnology, cognitive sciences and technology, and nanotechnologies.

The report concluded with thirteen recommendations, of which the most important in the short term, in terms of government action in France, were the creation of an interministerial coordinating committee to create synergy among all stakeholders, and in parallel an analytical entity responsible for the effective implementation of this public policy.

The active participation of France in emerging processes, whether this involves standardization or international discussions aiming at defining shared principles for the safe, sustainable, responsible and ethically acceptable development of nanotechnologies, is absolutely essential, according to procedures and means that remain to be defined.

**NANOTECHNOLOGIES:
ETHICS AND INDUSTRIAL PROSPECTS**

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INTRODUCTION

This document is a report on task force activities regarding the multidimensional impact of nanotechnologies and their implications in terms of regulation, included in the programme conducted by the "Innovation and Enterprise" section, a joint entity of the CGM and CGTI.

This task force, whose aim was to prepare the main orientations for assessment of French public policy in the field of nanotechnologies, in addition to conventional analysis and review work, gave rise to a series of interventions in various foresight or decision-making spheres, given the significantly increasing media interest for this subject on the international scene and within the European Union.

Relying in particular on the works produced by the science and technology committee of the French parliament, the French Academy of Sciences, the French Academy of Technology and the French Education and Research Ministry on the evaluation of French government funding for nanotechnologies, the task force decided to take a wider and more prospective viewpoint in order to make the relevance and scope of government action in this field more visible.

Based on this work, we have adopted the following definition of nanosciences: "any research whose aim is to analyse and study nano-objects with special physical, chemical or biological properties, as well as the discovery of assembly methods that can be used to obtain nanomaterials and organizational methods that could lead to the development of adaptive materials"¹. The prefix "nano-" designating a billionth of a unit, the nanometre is therefore a billionth of a metre.

Nanomaterials themselves can be defined as "materials composed or consisting of nano-objects that give these materials improved properties or properties specific to the nanometre scale (from 1 to 100 nanometres)"². They exist in the form of free or bound particles, fibres or tubes, crystals or lamellae, or microporous structures; there has been a spectacular industrial development in the field of carbon nanotubes. Semiconductor nanocrystals of a size between 2 and 10 nanometres are called "[quantum particles](#)"³ in the media terminology, because their properties are defined by the laws of quantum mechanics.

The main argument in favour of nanotechnologies, which explains why their development is inevitable, is that they alone are capable of providing workaround solutions to the immense difficulties (climate, ageing, health, pollution, energy, fair trade and sustainable development) which industrial and post-industrial societies are confronted with in their private and public affairs. But their very viability is subject to many conceptual, physical, industrial, economic and societal uncertainties.

In particular, the risks associated with nanotechnologies are not by their very nature comparable to those associated with known technologies, in particular with regard to the potential combination of nanotechnologies with other transformative technologies. Of course, the conventional manner of apprehending properties on a nanometric scale is through progressive miniaturisation, with the limits specific to the meso, micro and nanometric scales. But this alone is not enough. This method should be combined with what is referred to as "bottom-up reverse engineering processes" that refer to the theory of complex self-organized systems. European research programmes already take into account this concept, which is reflected in the name of certain projects, such as the "Bottom-Up Nano-calculator – BUN" that is coordinated by the CNRS.⁴

The specific drawbacks to the considerable advantages expected of nanotechnologies are difficult to assess. Large-scale studies to conceptualise, observe, manage and assess the risks involved must be conducted in collaboration with the international academic and industrial community. Meta-convergence implies meta-risk⁵, i.e. the very great difficulty of imagining procedures, standards or rules that would make it possible to overcome all the types of risks likely to be caused, directly or indirectly, by the impact of nanotechnologies on everyday life, structural powers, and relational powers.

The quality of societal adaptation to nanotechnologies will therefore depend on the ethical guidelines that societies will define to set socially acceptable limits for their use, in particular on issues involving the possibility of increasing human cognitive and physical abilities through converging bio-, nano-, info- and cognitive technologies, with potentially contrasting aims.

The task force report therefore focuses on the ethics and industrial prospects of nanotechnologies with respect to meta-convergence, while considering that the stakes for France, as well as its credibility and future influence, will depend on its ability to win acceptance of this technological orientation.

After a brief overview of the essential information available on industrial and research realities, the first part of the report deals with the question of the emerging risks resulting from nanotechnologies, in their dynamic and systemic dimensions, and the ethical questions raised by these technologies, synthetic materials and systems, whose main characteristic is that they will be incorporated, administered and disseminated in an invisible manner.

In the second part, nanotechnologies are put into perspective in terms of the new technology wave predicted on the 2020 horizon. This will involve an in-depth look at the expected social utility of nanotechnologies, not as such, but in terms of how they can be incorporated into existing or innovative production processes, for the industrial supply of goods and services that can be sold in public or private, civil or military markets. The problems posed by dual and critical technologies, as well as sovereignty will be developed, in addition to the anticipated economic competitiveness provided by what is referred to as "bio-nano-info-cogno" meta-convergence.

In the third part, a synthesis of the first two parts will naturally lead us to formulate certain answers to the question of subsidiarity in public action, based on the respective responsibilities of each level of subsidiarity and the roles of the players involved, such as we have been able to identify within the limits of our mission. The thirteen recommendations that conclude the report result directly from this.

Given the contributions produced by the authors during the investigation phase and in order to focus the report on the essentials, readers will be systematically referred to the appendices for descriptive details as well as for background reading.

PART 1: ETHICS AND NANOTECHNOLOGIES

There are two approaches that are commonly used in studying relations between society and technology, that were tempting to transpose to the history of nanotechnologies: the first approach consists in assuming as an axiom that science always precedes technology, and the second that society always chooses a technology on the basis of a rational argument between the expected advantages and disadvantages of its adoption.

The task force immediately distanced itself from such approaches. Why? Because they are, or will prove to be, unworkable in time.

New means of observation, simulation and manipulation of materials at the nanometer scale, such as tunnelling electron microscopes, relying on the most recent developments in metrology, will open up entirely new fields of fundamental research in traditional disciplines such as physics and chemistry, and also at the crossroads between the various academic scientific disciplines. Furthermore, when experimental scientific approaches can be conducted at the nanometre scale and last for periods approaching the femtosecond, the observational time scale then becomes the means of defining the phenomenon, which is vibrational in a normal state and fixed in an "error state", thus consecrating the "primacy of waves over corpuscles"⁶. Such is the case of femtochemistry, in which it becomes possible to film the chemical reaction itself using a stroboscope.

Nanotechnologies therefore have such a power of opening up new scientific fields that any delay would have considerable repercussions in terms of risks of dependency, with adverse effects on vital interests and national sovereignty, in a context of increasingly fierce economic conflict.

This first part will present the industrial foundations of nanotechnologies, a discussion of the nature of the risks they could pose, and a cross-examination of the ethical issue in light of legitimate concerns about quality and competitiveness.

1 The industrial facts about nanotechnologies

Nanotechnologies and nanomaterials do not constitute either a sector or a branch in terms of French national accounting, nor a sector in reference to the industrial economy. They are not mentioned in tables of inter-industry trade, nor in the foreign trade statistics, as they do not figure in any French or European classification of activities and products or, for example, in OECD correspondence tables. They do not figure directly in the classifications of patent offices, where they appear under the heading of the closest science (depending on whether they involve predominantly physics, chemistry, etc.). Since the end of September 2004 the question is open as to whether they should be taken into account in the existing classifications, particularly of chemical substances. In any case, it will be necessary to agree on a terminology, classification, nomenclature and language that will be shared by all parties throughout the world.

a. Nanosciences and nanotechnologies

According to the European Commission, nanosciences and nanotechnologies constitute new approaches to R&D aiming at controlling the fundamental structure and behaviour of matter at the atomic and molecular level. They offer the possibility of understanding new phenomena and may lead to new properties likely to be exploited at the microscopic and macroscopic scale.⁷

This field is in the process of being defined, which implies that any attempt to understand or interpret its reality, and even more so any forecasts or prospects, cannot be guaranteed in terms of their scientific rigour. Market studies that have been conducted, accessible only at a very high cost, are based on declared values of entities included in panels and other samples. They are based on a fine segmentation of markets for products (e.g. cosmetics) or processes that can have a dual character (fire retardants, air filtration by carbon nanotubes, etc.) and only rarely provide an overall assessment. Although they are useful for enlightening public decision-makers on the intentions and expectations of the players, it would on the other hand be foolhardy to base any definitive conclusions of a general nature on the basis of them alone, because of their identified methodological bias.

For example⁸, the American group Nano Business Alliance, bringing together the major American private-sector firms in the business, estimated that the world market was worth 45.5 billion dollars and forecasted a market of 700 billion dollars by the year 2008. The American National Science Foundation published a forecast of 1,000 billion dollars by the year 2015, distributed as follows: 57% for IT, 32% for materials and 17% for life sciences. However, the method by which these figures were obtained was not disclosed. It is therefore necessary to return to a factual approach, based on observation.

For the most part, market segmentation remains to be defined and covers some areas that are very much consumer oriented, such as textiles, cosmetics and sporting goods .

Nanosciences are often qualified as horizontal because they can belong to many of the sectors identified by the European Commission:

- Information and communications technology, because data storage media have very high recording densities (1 terabit per square inch). Activities such as molecular and biomolecular nanoelectronics, spintronics and quantum computing suggest that disruptive technologies may be in view in developments designed to achieve or accompany miniaturisation. Cryptography methods for data transmission, or nanolithography are also involved.
- Energy technology. Several fundamental contributions are expected in this field, not only for energy savings (by insulation, transport and lighting efficiency), but also for renewable energy sources (solar photovoltaic cells) and on-board energy sources for use in transport (fuel cells, light nanostructured solids that could be used for storing hydrogen).
- Medical technology (*medtech*) and neurotechnology: surgery, tissue engineering, biomimetic materials, bioactive and biocompatible implants, targeted thermal treatment of tumour cells, producing heart valves, test kits using DNA chips and kits for the early diagnosis of diseases. The neuroprotheses market is being pulled by demand (cochlear and retinal implants, development of flexible electrode matrices, etc.).

- Ecotechnology and in particular that of water: detection and neutralisation of micro-organisms and pesticides, water and soil purification, possibility of nanomarking products), reduction of waste production over the lifecycle of manufactured products.
- Security technology: sensors that can be installed in the environment or in hostile places to detect the presence of chemical or biological agents and that are selective at the molecular scale, food safety by nano-labelling.

To be complete, this list should include very important sectors for an industrialised country, such as transport, building materials, ceramics and glass, textiles and clothing, cosmetics, chemicals, leisure activities through new, "augmented reality" services and education.

Nanomaterials deserve special attention, since they constitute the "building blocks" of the manufactured products. All economic sectors benefit from their development and their inclusion in the manufacturing process. The firms developing nanomaterials include both large multinationals such as EADS, Rhodia, Michelin, Atofina, Saint-Gobain, Air Liquide and Snecma and SMEs (DGTec, Alchimer, Inanov)⁹. A database of those companies involved in nanomaterials in France has been produced under the impetus of the DiGITIP (General Directorate for Industry, Information Technologies and the Post Office).¹⁰

They have been the subject of bilateral exchanges under the impetus of government organisations, particularly in 2004 with Germany and Austria for their contribution to the low-emissions vehicle and sustainable development.¹¹

France has officially recognized at Brussels that nanotechnology applications are cross-disciplinary, covering the entire industrial and economic world, and will affect all sectors¹².

b. Public support for nanotechnologies and public-private synergies.

Public initiatives to support nanosciences and nanotechnologies have taken place in Europe (mainly the United Kingdom, Germany, France), in the United States (National Nanotechnology Initiative [NNI] of the NSF), Japan, South Korea and Taiwan. The Popular Republic of China has identified these advances as being critical and is also increasingly investing, as shown by the references to academic and industrial partnerships that were reported at the second SINC¹³ conference in Shanghai in December 2004.

Public support for nanotechnologies, for all countries combined, accounted for 3.5 billion euros in 2003. It is growing at a rate of 40% per year. Compared to the 350 million euros in the European Union budget for 2003, the member and associated states spent 800 million euros (Germany spent 250 M€, France 180 M€, and the United Kingdom 130 M€). Japanese public expenditure amounted to 810 M€ and that of the United States to 1070 M€, of which 300 was accounted for by individual States and 770 from Federal programmes. The other countries spent 511 M€ (in particular China, Brazil, India, Israel, South Korea and Taiwan).

The proposed American budget has a provisional allocation of 982 M\$ for NNI in 2005, to be divided between 10 federal agencies, including the NSF, not included in government funding by non-civilian agencies. As an example, the federal Environmental Protection Agency (EPA) has estimated that the amount needed for studying the toxicity of nanomaterials and their interaction with the environment will be 5 M\$ in 2005; the NIOSH (National Institute for Occupational Safety and Health) will probably spend 2.3 M\$ to obtain a better understanding of nanoparticles occurring free in the air and to determine whether the carbon nanotubes are liable to have adverse effects on the heart and lungs. The Department of Defense (DoD) plans to spend 5.5 M\$ in 2005 to develop a simulation model and a model for preventing toxicity from nanoparticles, in addition to the 20 M\$ reserved for the study of nanostructures that could be used detect and protect against ionising radiation and bacteriological agents. The national toxicology programme has started a five-year study, with a budget of 3 M\$, on the toxicity and the carcinogenic potential of nanoparticles.

The State of California, anticipating the need for a "second wind" to keep up the momentum of its international specialisation in silicon technologies, threatened by delocation and the consequences of the turn in the new economy boom, has invested 100 M\$ to create the California Nanosystems Institute (CNSI), whose main research subjects are high yield white-light emitting diodes to replace tungsten filament bulbs, photonic structures for optical connections, the handling of light using photonic crystals, information and communications technology (molecular electronics, spintronics, photonics and quantum computing), pharmaceutical screening methods using nanotechnologies, and the development of medical diagnosis tools¹⁴.

Comparing the efforts made by France and the United States does not make much sense, as the large macroeconomic aggregates in the former country are the size of those of the state of California rather than the entire USA. Only the combined power of the European Union would provide a relevant comparability with the United States. And even then, the significance of numbers still requires attention: for example, should these statistics include the wage bill for researchers?

France has not really announced any similar initiative to the American National Nanotechnology Initiative. There is nevertheless some funding, which is divided between the Ministry Delegate for Research, the *Ministère de l'Economie, des Finances et de l'Industrie* (MiNEFI, ministry of the economy, finance and industry) the *Délégation Générale pour l'Armement* (DGA, the French arms procurement agency) and the *Agence Nationale de Valorisation de la Recherche* (ANVAR, national agency for the promotion of research), depending on programmes with specific purposes.¹⁵ Moreover, the government authorities expressed their interest in and their support for the development of nanosciences and nanotechnologies as early as 2003 and confirmed this in their forecasts in 2005. The interweaving of research functions in micro- and nanotechnologies makes it difficult to distinguish them clearly, especially in the statistics relating to research scientists¹⁶. To be exhaustive the data should at least also include the budgets of the *Institut National de la Santé et de la Recherche Médicale* (INSERM, national health and medical research institute), the *Office National d'Etudes et de Recherches Aérospatiales* (ONERA, national bureau for aerospace studies and research) and the *Centre National d'Etudes Spatiales* (CNES, national space studies centre) allocated to nanotechnologies, even though these do not appear as such in the figures.

In practice, the Ministry Delegate for Research remains the leader in this field, as shown by its leading role in preparing the French position in the debate on the conclusions of the Competitiveness Council held on 24 September 2004, which became increasingly interministerial as applications developed in many directions (especially industry, home affairs, health and agriculture), and now also involve the MiNEFI and the *Ministère de l'Ecologie et du Développement Durable* (MEDD, ministry for ecology and sustainable development).

It is planned that the future *Agence Nationale pour la Recherche* (ANR, National Research Agency) will include nanosciences and nanotechnologies (nano-objects, nano-components, nanobiosciences and nanomaterials) among the major technological subjects identified as being priority. With this respect the *Network Micro Nanotechnologie* (RMNT, micro-, nanotechnology network) should be granted a budget of 4.1 M€, 2.3 M€ of which will be for joint activities with the DGA actions.

The status of *Groupement d'Intérêt Public* (GIP, public interest group) for this agency announced¹⁷ by the Ministry Delegate for Research seems to be adapted to a transitional period during which the funding of priority research oriented by the government, is switched to funds not included in the budget act (loans, public-private partnerships). However the European dimension must become dominant in a fairly short space of time, opening the way to the implementation of a recommendation of the Strategic Council for Information Technology, according to methods yet to be defined, such as, for example, a European economic interest group¹⁸, which will associate in a public-private, civil and military partnership, the funding of R&D judged to be priority and strategic in terms of knowledge, employment and competitiveness.

The 6th Research and Technological Development Framework Programme (RTDFP) is planned to have a budget of 1.3 billion € for nanosciences and nanotechnologies. The European Commission envisages that this budget should be tripled in the 7th RTDFP, whose major orientations are currently being defined. To these data, should be added the budgets that finance the nanotechnologies pertaining to information and the communications technology, biotechnology, medical technology and technologies for sustainable development using Community funds, and those for projects reserved for new and emerging concepts (NEST programme). Here again, an avenue for searching for the best criteria for a rigorous, reliable and ongoing evaluation is to be explored.

The construction of the *Espace Européen de la Recherche* (ERA, European research space) will open new opportunities for outsourcing the coordination of large-scale European projects. In the case of priority programmes that will be supported by the ANR, there is a certain overlap with the priorities sketched out by the 7th RTDFP. This is why the status of the ANR should be conceived to benefit from decentralisation of the Research DG action Research, from the first call for tenders of the 7th RTDFP.

Because it is necessary to set up programmes of excellence sized to ensure indisputable international credibility, a status associating two or more European partners (such as Germany and the United Kingdom, to start with) seems to be more appropriate than a purely national legal status.

c. Emerging markets

The identification of civil, dual or military emerging markets, and their segmentation on the basis of applied research can only be conducted, in the current state of statistics, by approximation and panels among companies, from start-up firms to the large multinationals, that import or produce information technology, biotechnology or medical technology, in a highly competitive field where business secrecy reigns. The statistics on use within companies are almost inaccessible.

This is the reason why our task force has recommended that a tool should be made available to government organisations and the European executive (e.g. a European monitoring body), to obtain reliable information on the impact of scientific and technological progress, in terms of the economic, social and ethical implications and the impact on the behaviour of the parties involved. This recommendation has been taken up in the wording of the official French position in the debate of the Competitiveness Council with respect to the responsible development of nanotechnologies. It was received with great interest when it was presented on 14 and 15 September 2004 at the Conference on Converging Technologies for a Diverse Europe.

The *Direction des Relations Economiques Exterieures* (DREE, directorate for foreign economic relations) office C5 included in its programming for 2004, under the heading of the Life Sciences network, a report on the future of nanotechnologies in almost all the world's markets (except for sub-Saharan Africa and South America). Planned to be published in November 2004, this report was to provide much information on the development of biotechnologies through nanotechnologies.

The markets for instrumentation and scientific equipment for use in laboratories that will conduct critical technologies come upstream of those of business and consumers.

Instrumentation and metrology are tools that empower the development of nanosciences and nanotechnologies. They are **sectors where the risk of strategic dependency already exists and is very serious**. They therefore deserve high priority in cutting-edge R&D, while ensuring adequate industrial production capacity in France, or at least within the European Union, with a guarantee that no one will refuse the sale of the latest instruments available at an affordable price. These sectors already constitute a considerable, but dual market, where temporary embargoes on the export of goods and technology transfer are a possibility. The world market is estimated by the NSF to reach 22 billion dollars per year by 2012.

Offers of services to industry are developing in the field of dimensional contact-free metrology, in particular in the automobile, aerospace, nuclear and research fields (synchrotrons). Integrated by multidisciplinary teams, they provide a "seamless" service from the sensor to the associated engineering and IT¹⁹.

Major research is currently being conducted in the field of corrected and quantitative subnanometric microscopy, whose applications will make it possible to accurately measure objects the size of an Angström, i.e. a tenth of a nanometre, with a single pause time, and therefore minimum distortion. This advance will make it possible to discriminate between isotropic and anisotropic materials, by obtaining the signature of the anisotropy (e.g. by a crystal, whose properties vary from one direction to another). The development of and the market for nanoparticles and nanostructured materials depend closely on scientific and technical progress derived from observation and simulation.

The time factor is vital in terms of patent applications on new materials and their properties. Any delay, for budgetary or more strategic reasons, in the availability of laboratory equipment would have very adverse effects for the scientific and academic community, for industry and for the economy in general. The current situation is one where French and European SMEs no longer obtain orders from the major laboratories, who prefer to procure "off-the shelf" supplies from Japan (see the positioning of the JEOL group^{20, 21}) or the United States.

There are also existing military and security markets, and funding for dual technologies is provided by American agencies such as the DARPA, DoE, the Department of Health and Homeland Security²². There is a huge potential for civilian applications derived from this funding (e.g. biological sensor networks).

The nano-arms race has already started and is a separate market. It will lead to severe strategic and tactical upheavals, since the products will be widely disseminated, and deterrence will be impossible.

The search for first-strike weapons targeted on the enemy populations, plus maximum protection, coupled with special tools for increasing troops' sensory and locomotory abilities, allied with the calling into question of concepts derived from the nuclear deterrent, will ensure that arms race for weapons of mass destruction based on nanotechnologies will be almost boundless.²⁴

2 The risks created by nanotechnologies

For there to be a risk, in principle three factors must be present: a) a possibility of damage occurring, conventionally assigned a minus sign; b) a degree of probability of this damage actually occurring; c) a population of individuals that could potentially be affected by the damage and whose "utility" (or "satisfaction", or "ophelimity", etc.) serves as a standard for damage assessment. The debate on the "precautionary principle" has led to the introduction of an *epistemic* ranking, i.e. the type of knowledge that those involved either have or do not have on the probability of damage occurring, for example in the form of objective probabilities. The definition of risks is very restrictive, and it is evident that a new technology in general has effects that are not risks in this sense. When the National Science Foundation said of nanotechnologies that it is going "lead to a change in civilization", it would be very difficult to either ascribe a plus or a minus sign to this possibility, or to say anything about its probability or even assess the consequences by adding the differentials of "utility" across the entire population. Risk analysis is an important factor for the normative assessment of a new technology, but on its own, it does not represent the totality of this evaluation. There is a "risk of risk-analysis tyranny", to use the wording of the British Environment Agency²⁶. Our task force judged it essential to extend the ethical assessment of the nanotechnology programme, especially when considered within the framework of meta-convergence, far beyond that of risk analysis.

That being said, the standard risk assessment approach includes identification, management and assessment stages. There is an abundant literature on the subject and the institutions, at least in France and in the western world, have generally taken into account this aspect as far as it concerns them. Companies have also been obliged to include the financial aspects of industrial risks as a compulsory item in their annual accounts.

The insurance and re-insurance sector has itself for a long time invested in modelling, in order to calculate probabilities and amounts, in order to set the price of their premiums. One of the re-insurance groups that is very proactive in this field is the company Swiss Re, that poses the problems in these terms: to reduce the uncertainties associated with nanotechnologies, risk analysis and management and the options for acceptable risk transfer must be studied on a shared basis, between business, scientists, government authorities and insurers²⁷.

The health insurance field can serve as a countermodel, the disastrous macroeconomic effects of problems related to coal dust, asbestos and residues of diesel combustion, etc. being the result of the absence of such a consensual approach.

The relation of risk to responsibility is traditionally determined by the occurrence and demonstration of negligence, which implies a responsibility of a subjective nature. The risks posed by nanotechnologies open the way for debate on the conditions of the insurance cover for risks, which the *Conseil Economique et Social* (economic and social council) approached in these terms: the principle of subjective responsibility could be replaced by that of objective responsibility, making the risk, and not negligence, the foundation of responsibility.²⁸ The implications regarding the legitimacy and methods of government intervention are important, from recognition of the **nanoerror**, which characterises the concept of "no-fault" liability, to that of nano-terror,²⁹ which refers to a "major risk", which may or may not be related to a deliberate act.

a) Simple causality

The intuitive approach in terms of the risks posed by nanotechnologies consists of choosing whether to develop or limit them in terms of minimising costs or maximising benefits. This approach is by nature causal and focuses on still very recent and limited studies, on toxicology relating to the human body. The studies by Dr Vicky Colvin (Rice University, United States), supported by the NNI, are the world reference in this field.

This approach is absolutely essential and requires considerable development, in liaison with the chemical industry that has the necessary experience for assessing the risks relating to the production, coating, and dissemination of the final products (that include colorants, industrial perfumes, cosmetics, aerosols and pesticides that can come into everyday contact with living organisms). In this area, consumer pressure is a key factor for the setting up of suitable regulations, starting, for example, with the assignment of a new CAS number (*Chemical abstract safety registry number*) for manufactured nanoparticles.

However, such a simple causal approach, although essential, should be included within the wider perspective of ecotoxicology and especially that of the very special nature of the risks posed, directly or indirectly, by nanotechnologies.

The first version of the project Nanosafe lies between these two approaches. The European Union has attempted to relate the phenomena of simple causality and systemic analysis as from the 5th RTDFP, with the NANOSAFE project of the programme GROWTH. With a budget of 300 k€, it is entitled "*Risk assessment in production and use of nanoparticles with development of preventive measures and practice codes*" and reported its conclusions in June 2004. The main of these was calling for the creation of a single regulatory framework for the European Union in this field where the more the information is vague, the more it leads to fear and scepticism. The call for tenders of the 6th RTDFP was called "*Impact of nanoparticles on human health and the environment*".

b) The dynamic and systemic nature of risks in nanotechnologies

The first improvement to the simple causal approach consists in opting for a systemic understanding of the risks posed by nanoparticles and nanostructured products, using a methodological procedure that has been well defined in ecotoxicology studies. A synoptic representation of the environments surrounding the emission of nanoparticles, transport, exposure and the effects has been attempted by a working group of the European Commission's Health and consumer protection DG.³⁰ It highlighted the usefulness of a systemic approach to risks.

Government policies are increasingly involved in the management of environmental crises, which implies having quantitative and qualitative skills in the understanding of the nature of risks and impacts so as to optimise public intervention. Environmental risk assessment is conducted according to the following sequence "identification of the danger – exposure – the dose-effect relation – risk characterisation".

The ecotoxicological approach concentrates on nanoparticles and nanostructured materials that are free or bound, manufactured or released by a manufacturing process that is intended for other purposes, with or without a coating, and with a variable lifetime.

At this stage there is an expert consensus on the unpredictability of the properties of manufactured nanoparticles, or those occurring naturally in the environment over very long time periods (oxidation of dusts, volcanic ejecta, etc.), and nanostructured materials. In these conditions and in the absence of significant progress in this field, it is impossible to pretend to be able make any exhaustive risk assessment by a dose-response type approach or by recording exposure data.

Here again, the systemic approach is not limited to risks in the strict sense of the term, and must take into account the solutions that nanotechnologies are likely to provide for the major challenges facing sustainable development. Nanomaterials, because of their new properties, can lead to a reduction in environmental pollution, not only by improving our understanding of pollutants in the environment, but also by the use of functional filters or of nanoporous ceramics.

The short-term requirements for increasing knowledge on the ecotoxicity of nanoparticles are characterisation and classification, the preparation of standards, investment in nanometrology and instrumentation.

But beyond the systemic approach, another qualitative stage must be accomplished, if possible by highly inclusive international cooperation, that of the dynamic approach, which alone can take into account the spatio-temporal dimension, and lead to a *normative methodology for assessing the combination of risks, or meta-risks* posed by nanotechnologies.

The need for such a methodology is urgent. In its absence, there is already a rather sterile communications war between the promoters and the critics of nanotechnologies.

On one side, some people vaunt in hyperbolic terms the benefits for humanity of the current scientific and technical revolution. The report of the American National Science Foundation (NSF), which launched the nanotechnology programme under the title "Converging Technologies for Improving Human Performances" (2002), without doubt beats all the records. It promised no less than the eventual unification of science and technology, universal material and spiritual well-being, world peace, the pacific and mutually advantageous interaction between humans and intelligent machines, the complete disappearance of obstacles to universal communication, in particular those that result from the diversity of languages, etc.

However, research workers in the field easily see through this. If you overemphasize the "fabulous" positive consequences of the current revolution, you lay yourself open to no less "over-the-top" criticisms that endeavour to kill it before it is born.

The risk most frequently expounded by critics, and which has already been dramatised in book form and soon at the cinema³¹, is that of the uncontrolled self-replication of nano-robots following a programming accident or an act of terrorism. All or part of the biosphere would then be destroyed by the exhaustion of the carbon reserves needed for the self-reproduction of the nano-engines in question. The possibility of such nano-robots has been envisaged by Eric Drexler, the creator of the concept of nanotechnology and the founder of the Foresight Institute. Drexler himself has to some extent gone back on his ideas in an article published in June 2004 entitled "Safe exponential manufacturing"³². In any case, this risk can only bring fear to those who believe in the possibility of such machines. By simply denying the possibility, this pseudo-risk can be dismissed with a shrug of the shoulders.

Oscillating between such extremes, the debate on the risks of the nanotechnology programme has got off to a bad start. By attempting to weigh enormous, but very poorly defined, costs and benefits on a single set of scales, the normative assessment will never provide information conducive to decision-making. But before restating the problem, it is necessary to define what it is that makes emerging technologies so different with respect to the precautionary principle and why it is legitimate to talk of an entirely new form of risk.

The normal criticism that is made of any technological misuse, consists of lamenting that the dream of Descartes – "*se rendre comme maître et possesseur de la nature*" (to make oneself master and owner of nature), or the "Promethean" ambition of man, have turned out wrong. It appears urgent to once more to gain "control over control". It seems likely that this criticism is missing the point. The imaginary idea that underlies the nanobiotechnological programme, in particular, is bioengineering, and then eventually, the fabrication of life itself. And, those who want to create life cannot help themselves from wanting to reproduce its essential ability — that of creating in turn something radically new.

As John von Neumann already predicted, in his 1948 thought experiment on self-replicating automata, tomorrow's engineers will be at least as much explorers and experimenters as producers. Their success will be measured at least as much by the outlandishness of their creations, that will surprise even themselves, as by the conformity of their work to pre-established specifications. Disciplines such as artificial life, genetic algorithms, robotics and distributed artificial intelligence already fit in with this prediction. It is in this perspective, which tends to obliterate the normal distinctions between science and technology, discovery and invention and the scientist and the engineer, that the question of risks should be repositioned.

The popular media have had a field day with reports on the major scientific risks associated with biotechnologies and all the conflicts of opinion they have engendered (e.g. moratorium on genetically modified organisms, and the views of ethics committees on stem cell research). In contrast to what has happened in the United States and some countries in northern Europe, nanotechnologies have not yet been the subject of popular scientific reporting in France. The comments that have been made come mainly from economic affairs reporters, and report on the subject from a viewpoint of competitiveness and the involvement of various companies and other parties. But this situation is likely to change very quickly. The main stakeholders in the nanotechnology programme must be ready, which implies that they must organise means of holding debates and discussions without delay, using a methodology and rules that are mostly yet to be invented.

3 The ethical questions raised by nanotechnologies

We will deal in succession with the question of ethics going beyond risks, and then the cultural obstacles that confront this question.

a) Ethics beyond risk analysis

The task force revealed five main aspects by which the ethical questions raised by the nanotechnology programme can be identified. To dissociate this analysis from the problem of risks in the strict sense of the term, this discussion will refer to the *effects* of nanotechnologies. A distinction can be made between: 1) the effects on relations of domination; 2) the effects on the relation with nature; 3) the effects on the relation with knowledge; 4) the ethical effects; and 5) the metaphysical effects.

a1) The effects on relations of domination (the effects of power)

These are effects that affect opinion and explain most reasons for rejection. They range from the monopolisation by a small number of companies of the means of production and of reproducing life, to the domination that science and technology exert on the public, the vast majority of which does not have access to the scientific and technological culture. They also range from the humiliation that scientists feel when they have to resort to public relations exercises to gain "acceptance" that becomes increasingly tenuous, to the anger of people who feel that they no longer control what they find on their plates; from the deepening inequalities in the world to the new poverty caused by the monopoly that new technologies exert on acts or relations that hitherto had escaped from technology, etc.

a2) The effects on relations with nature (ontological effects)

The current debate on the transformation of the relations with nature provoked by new technology is generally presented as follows. On one side, radical ecologists consider nature to be an immutable model of equilibrium and harmony, and humans as irresponsible and dangerous predators. On the other, the modern humanists want to divorce humanity from nature and make it master and possessor of the world and of itself. In the first case the "transgression" is reviled, in the second it is hailed.

The debate that is therefore underway appears to the task force to be very unsatisfactory. Behind every scientific and technological "paradigm" there is what Karl Popper called a "metaphysical research programme" – all the non-testable propositions that are assumed to be correct with no attempt at questioning them, the theoretical framework that limits the type of questions that are asked but which also first inspire them. The metaphysical research programme of nanotechnologies, considered in the framework of meta-convergence, where the cognitive sciences play a very singular role, is based on two proposals that could at first sight seem to be contradictory:

- 1) The spirit and life must be naturalised so that they again find their place within nature, which gave rise to them.
- 2) This naturalisation involves mechanisation and artificialisation, not only of nature, but also of life and the spirit.

If nanotechnologies aim to pick up where nature and life have left off, it is only because they have completely redefined them in their image. The expression "artificial nature" is therefore no longer a contradiction in terms.

Once such a view of the world is accepted, one is only a step away from formulating the task of becoming master of these computational and algorithmic machines, first by simulating and reproducing them (the birth of intelligence, then of artificial life), then by changing them the way an engineer would (biotechnology, cognitive technology, nanobiotechnology, etc.). The problem is no longer to know up to which point one can or should "transgress" nature. The problem is that the very notion of transgression is on the point of losing all sense. But, there can be no ethics in a democratic society founded on science and technology without procedures that are freely consented by all citizens to set **the limits** of what can be done. A fundamental tension therefore shows itself here between the imaginary that governs technological advances and the very conditions of ethics. It is essential to show great lucidity on the subject of this tension, if violent rejection reactions are to be avoided in the long term.

It is obviously especially on the subject of itself and of its own nature, if it is recognized as having one, that humanity must decide its transformation thresholds, beyond which it should not go.

The Astronomer Royal, Sir Martin Rees summarised things as follows: "the most important novelty is that human beings themselves are henceforth capable of changing. In the last ten millennia, the character of humans and their physique have scarcely changed. But in the next hundred years, with targeted drugs, genetic modifications and possibly the implantation of microcomputers within the brain, human beings could start to change. This makes the current century even less predictable than the previous"³³.

The question of the bionic man is at the heart of the ethical question. The debate has already started with gene therapy, with a favourable conclusion when it is a question of repairing a deficient function, but an unfavourable one when the aim is to improve human sensory or motor performance. Nanobiotechnologies will certainly break down these oversimplified distinctions, which form the grounds for such contrasting conclusions.

a3) The effects on relations with knowledge (epistemic effects)

At the beginning of the 18th century, the Italian philosopher Jean-Baptiste Vico formulated in famous terms the postulate of what he called the "new science": "*Verum et factum convertuntur*" (the true and the made are interchangeable). We can only rationally know that of which we are the cause, that which we make. According to this criterion, in decreasing order of perfection of knowledge, mathematics comes in first place, followed not by the natural sciences, but by the moral and political sciences. However, the natural sciences themselves must, from the start, be oriented by the conviction that you can only know by making. The insistence on the "how" of processes rather than on "being" of things is thus explained, but also, in particular, the considerable role devoted to experimentation and modelling by science.

With nanotechnologies, this philosophy of science should find its final outcome. It is not only by conducting experiments on it, and it is not only by modelling it that humans will know nature. It is literally only by re-creating it. Yet, immediately, it will no longer be nature that they will know, but what they have made. Or rather, it is the very idea of nature, therefore information outside of oneself, that will appear to be outmoded. The very distinction between knowing and doing will tend to lose its meaning, as will that which still currently separates the scientist from the engineer. We can already see in biotechnologies alone that the distinction between discovery and invention, on which patent law is based, is increasingly difficult to discern, as witnessed by the debate on whether living organisms can actually be patented.

a4) The effects on the very possibility of ethics (ethical effects)

Nanotechnologies open an immense continent that humanity must be able to standardise if it wants to give it a sense and a purpose. The human subject must have recourse to a greater willingness and conscience for determining, not what he can do, but what he *should* do. To do this, an infinitely more demanding ethics is required that that which is currently being set up to contain the pace and possible misuses of biotechnology.

When we talk of "ethics", "conscience" or "willingness" we talk of triumph over the subject. But what does this triumph signify in a conception of the world that deals with nature, including humanity, as a computational machine or as an algorithm? This humanity that has thus become a machine, in the name of whom or what is it going to exert its immense power over nature and over itself? In the name of the mechanism with which it identifies itself? In the name of a meaning of which it pretends that it is only an appearance or phenomenon? Its willingness and its choices can only hang in the void. The unlimited enlargement of the field of ethics in the long term threatens the very possibility of ethics.

a5) The effects on categories (metaphysical effects)

It can be considered that the mechanistic and computational metaphors on which both the cognitive sciences and molecular biology are built are both scientifically and philosophically false and it can be conceded that they give us a power to act and have a radically new mastery over the natural and living world. If such is the case, the very success that the new technologies will achieve will make the mechanistic and computational representations of nature and of life incontestable and no one will be able to say that they are illusory. It is no exaggeration to talk of metaphysical effects.

The most worrying effect is without doubt the clouding of the categorical distinctions by means of which humanity has been able to place itself within the world, ever since humanity has existed. The non-living natural, the living and the artefact are about to fuse.

Each of the categories in this classification, here too succinctly sketched out³⁴, would be worthy of inclusion in the public research programme, including that of the CNRS human and social sciences department. The results could usefully enrich the debate of the various ethics committees. We repeat that this is an essential challenge, that of the limits that society, at a given time in its evolution, wishes to define to make the pathways of research and technology acceptable, and therefore effectively appropriable by the citizens that compose it.

b) Towards gradual institutional awareness

The European Ethics Committee included in its 2004 programme the ethical questions raised by the development of new means of communication and information technology and nanotechnologies. According to this committee, the change in the concept of the identity of human beings will be at the heart of the debates, by taking into account the prospects opened by new, non-invasive and biocompatible interfaces provided by nanotechnologies, between humans and the machine.

These preoccupations are in accordance with the call for tender priorities of the European Commission in the field of future concepts in the NEST programme. In addition to the complexity found in the science of synthetics and synthetic biology, this programme identifies a third priority that refers to the relation between cognitive sciences and technological progress, with this striking title "What does it mean to be human?" Noting the NNI and the financial support, especially by the DARPA, it attempts to stimulate research in this field while adopting a prudent approach when it involves the functioning of the brain in its relational and emotional aspects.

The calls for tenders of the 6th RTDFP in nanosciences/nanotechnologies require that the projects submitted include an "ethical" section. However, none of the people involved were able to satisfy this requirement, neither the designers nor the submitters or the assessors. There is therefore still considerable room for improvement in this field. It is very important that the choice of research supported by public funds should be made with full knowledge of the facts, on the basis of explicit assessment criteria, drawn up by all parties involved, on the basis of clearly defined ethic principles.

Because of the inherent limits of the methods of risk assessment and assessing social and ethical impacts, the international community has started to look for a means for discussing the responsible development in this field. The meeting that was held in Alexandria, on the initiative of the NSF in June 2004 on the subject of responsible international development of nanosciences and nanotechnologies, included in its programme a working group on the socio-economic and ethical aspects. (See part 3 of the report, below).

This group recognized that nanotechnologies have started to become the subject of discussions in society, that producing factual data, measuring perception and explicitly stating values are going to become an integral part of discussions between scientists, governments, business, representatives of the public at large, government policymakers, the media and any other stakeholders.

The ethical question posed by "increasing" human performances also came to light, as either being a choice that is freely consented to or not. For example, what should be done if a country decided to opt in favour of a particularly controversial technique or product? Would this would create pressure on other countries, either to opt in or opt out of this technique or product? Would pressures be exerted on those countries that decide to go ahead and what recourse would either side have on this question³⁵ ?

The position of Austria announced at the Competitiveness Council on 24 September 2004 is very clear on this question: "considering the preliminary results on the questions posed by the available nanotechnology in the fields of the impact on the public health, security, consumer protection and the environment, the research on safety must continue to be supported in Europe. Public access to the results and their active dissemination and their application are of the highest importance for preventing the mistakes that have been in other areas of research. A responsible dialogue with the parties concerned (research, industry, public sector, consumers and professional representatives) must be set up³⁶".

However this position is optimistic with respect to the nature and the quality of the available results, the observation tools are still very fragmented and therefore unsuitable, in their current state, for providing a satisfactory overview. Especially, it seems to make little of the lack of conceptualisation and suitable methodological tools for conducting an authentic normative assessment, along the lines described above.

In France, the *Comité Consultatif National d'Ethique* (CCNE, national consultative ethics committee) created a working group in 2004 specialising in nanotechnologies. Our task force on one hand has helped with this group to liaise with the *Réseau micro nanotechnologies* (RMNT, micro-nanotechnology network)³⁷, and also with the CNRS national ethics committee, but the initiatives again came up against the stumbling block of a lack of assessment methodology.

Research on risk assessment and toxicology/ecotoxicology studies are certainly welcome and useful, but they only contribute to a small extent to providing consumers and citizens with the proof of safety that they need to support the development of nanotechnologies, and the answers to the questions that it will inevitably pose on the meaning and purpose of the technological advances.

There is a major risk in denying the very existence of any risk under the false pretence that factual, measurable and interpretable information is not available. Although it is easy to maintain, public confidence is almost impossible rebuild within a generation once it has been abused. The ethical dimension therefore appears to be a fundamental factor not only for acceptability, but also for the orientation and forthcoming implementation of the advances coming from nanotechnologies.

In practice, manufacturers recognize that the health risks related to the production and use of carbon nanotubes have not been clearly established and could constitute a stumbling block that they wish to avoid. A coordination of the taking into account of these risks and appropriate communications are particularly necessary on this subject, estimated a representative of ATOFINA³⁸, a company that has a simulator capable of producing of 10 tonnes/day of carbon nanotubes at a cost price of less than 10 €/kg, i.e. 10 times less than the reference price of the company Nanoledge.

Institutions have recently become aware of the ethical issues through the question of limits. As the industrial risks become better known and we know how to assess them better, this awareness will progress. This will remain insufficient as long as the ethical issues that reach beyond risk analysis are not more clearly apprehended. In any case, some resistance, mainly of a cultural nature, is highly likely.

c) Cultural obstacles to dealing with ethical questions

There are currently major obstacles to introducing ethical arguments in the field of nanotechnologies. These obstacles are related to the fear of a breakdown in transatlantic relations, and the underlying industrial and cultural issues.

Not all countries allow the international public to openly scrutinize the underlying trends that structure their society. From this viewpoint, the United States tends to be more accessible to analysis than others. In this country, there are two positive trends that mutually reinforce each other and consequently accelerate the development of applications made possible by nanotechnologies, even if they show substantial differences in terms of communication.³⁹

Firstly, there is a trend that we will call the "enlightened progressive movement", which is involved in promoting progress in fields of general interest by adopting a responsible attitude to applications of discoveries and of their multidisciplinary combinations. These latter are presented in a positive historical-philosophical context: their breadth and shock waves will launch a new Renaissance. The promotion of the responsible attitude is accompanied by a minimal investment in toxicity and ecotoxicity studies, but does not consider the question of ethics in itself as being fundamental. The underlying assumption is that ethics will adapt, because it must do so, to the new state of affairs caused by the technology. Positive thinking outweighs the negative in an *almost* axiomatic manner.

The second, that we will call the "libertarian movement", aims at affirming the inalienable right of each individual to choose for him or herself whether to increase his sensory or motor performance, either singly or in a combined manner, reversibly or irreversibly, by means of a human-machine interface made commonplace by nanotechnologies — a view held by "transhumans"⁴⁰. According to this movement, all form of limit is illegal and therefore the question of ethics does not apply. The positive rights of the individual outweigh the collective and possibly negative approach, in an *absolutely* axiomatic manner. Or, more precisely, the ethical question resolves itself by the refusal to allow any government interference, that is seen anti-libertarian and therefore against the American constitution.

In the European Union, there is insufficient awareness of the ethical challenge, as shown by the project of the 6th RTDFP, entitled the "NanoRoadMap"⁴¹ over the period January 2004 - June 2006. This project dealt with the predictable applications of nanotechnologies in sectors as important as energy, materials, and medical technology, on account of their hoped-for contribution to competitiveness, growth and employment.

Any ethical issues are, however, absent from the specifications of this road map, as if society could do without them.

The eminently ethical question of the limits to the possibilities opened by nanotechnologies was not asked, or poorly put, the immediate consequence of this being the risk of a strong and short-term discrepancy between the perception of public opinion in the European Union and in the rest of the world, with very uncertain effects on the continued public support for scientific and technological developments in this field.

The question of the relation between ethics and social acceptance can be treated in very different ways. The realists and the cynics in any case point out that interests will always prevail, whether or not they lead to a violation of the ethical requirements strongly anchored in the collective conscience, because they think that this anchoring is contingent, and in part arbitrary and therefore not sustainable. However, history shows that when divergence is too great between technology and ethics, the resulting social tensions create damage and suffering that are sometimes irreversible. On this subject, ethical specialists evoke the principle of "tolerable divergence" between the facts and values. Consequently, even the realists should not try to bypass the question of ethics.

From this viewpoint, it is significant that Japan plans to open the debate on ethical aspects when it officially announces its national position in favour of nanotechnologies, which is currently being defined at interministerial level. Dr Kazuharu Shimizu, deputy director general of the science and technology policy council (*Cabinet Office*) wrote on 4 April 2004: "*by applying nanotechnology (...) these progresses may cause a drastic change of social systems, industrial structure and individual life. In order to be ready for such drastic change, innovation and education system, and effective measure in social scientific field such as economy, legal matter, ethic and culture, have to be discussed*"⁴².

Russia does not seem to want to become involved in such an approach in the short term. As for the official American position, as expressed by the Under Secretary of Commerce for Technology (Mr Philip J. Bond), it consists firstly of requiring a significant return on the investment made by the NNI, the priorities of the applications being given to Homeland Security and the fight against terrorism on the one hand, and the creation of qualified jobs within America on the other.

It should however be noted that 1% of the Federal money allocated to nanotechnology research must go to research on the social and ethical implications. Thanks to this money, universities such as Stanford and the University of South Carolina at Columbia, are in the process of setting up research institutes dedicated to these questions, in which eminent scientists in the human sciences and philosophy will participate. It can therefore be predicted that the USA will also take the lead in this field. The two signatories of this report will collaborate, in one way or another, in this American effort.

It can be said, however, that, as a general rule, in the race for competitiveness as in the arms race, the question of limits to nanotechnology applications remains the poor relation. It could be that this is only a short-term option, and that in the future a competitive advantage could be found in the capacity for *anticipation* and support for societal tolerance, and in the mechanisms of appropriation and means of expression.

We repeat that the effects of nanotechnology that interest us here are not only the effects of the technology in itself, but also the effects of the ideas that spur the development of technology, whether the technology comes to fruition or not.⁴³ The means of collective representation and the forces present in their evolution are here a major issue, whose scope justifies a structured and continuous attention by public authorities, even if this were only for understanding them better.

The difficulties mentioned in the correct consideration of the ethical dimension and its implementation in the face of geostrategic and of competitiveness challenges increase considerably if nanotechnology is considered in its natural biotope, namely in the heart of a process of industrial meta-convergence. The second part of the report will be devoted to the reality of this meta-convergence, to the differences of approach on either side of the Atlantic and to the potential consequences on innovation and exchanges.

PART 2: NANOTECHNOLOGIES AND META-CONVERGENCE

The problem of convergence is traditional in the field of information technology (between computer and telecommunications technologies), then between these two technologies with audiovisual technology and the passage to the mobility of goods and services. The combinations in question here are clearly more "counter-intuitive" to the extent that they henceforth transcend the scientific and technological sectors that are traditionally tightly partitioned, from conception to marketing.

The problem of meta-convergence was more of a future prospect in 2004 than a reality. However, combinations of inputs coming from at least two distinct sectors are starting to appear, at very different rates. The aim of this part is to briefly describe potential opportunities and their economic interest when they result from the convergence of technologies characterised by their ability to stimulate the rest of the economy.

Our task force estimated that **the convergence of transformative technologies will create previously unequalled opportunities, for which the voluntarist acquisition of a favourable international specialisation is justified.**

1. The place of nanotechnologies in the next technological wave

We will deal with convergence firstly in two-by-two combinations, then in multiple combinations, and finally in cases involving the cognitive dimension as playing a specific role.

a) Convergence by simple combinations refers to products obtained from combining nanotechnology with information and communications technology (ICT), or mainly biotechnology, or else the coming together of biology and ITC at the submicron scale.

The miniaturisation of electronic components has already reached the nanometre scale and there has been a consensus view of the rate of decrease in size: 90 nanometres for a DRAM memory in 2004, 32 nanometres announced in 2013, for example, by the ITRS international road map. The integration capacity of a component will increase from 1 billion transistors to 16 times more in 6 years. The reduction in costs and size opens the way to uses affecting all of society, and to new perspectives for developing so-called intelligent environment services (virtual reality, enhanced reality, targeted dissemination of relevant information, the use of artefacts and avatars, etc.).

Bottlenecks have however appeared in terms of the qualifications available for quantum engineering, or the production capacities based on self-organisation and molecular computing (bottom up, using DNA, etc.). Spintronics manipulates the spin currents in nanostructures combining magnetic and non-magnetic materials. Major research is underway in two fields: the field of spin transfer, by means of which the direction of magnetisation in a ferromagnetic component can be reversed *without the application of a magnetic field*, by the transfusion of spins carried by an electrical current, and the field of nanospintronics. This is evolving toward nanoparticles, quantum boxes and quantum computing. The injection of spin into nanoparticles is one axes, as "the life time of the spin is longer, the smaller the size of the particle"⁴⁴.

Optical connections by photonic crystals, that are essential for miniaturisation, depend closely on progress in nanotechnology. A photonic crystal with a wavelength in the near-infrared is formed of elements about 100 nanometres in size, and the precision needed to produce efficient components is equal to or less than 10 nanometres, i.e. the scale of precision of silicon microelectronics. The manufacture of three-dimensional photonic crystals is now possible, bringing us closer to an area of dreams: "manipulating the flow of light in the three spatial directions and ultimately controlling the spontaneous emission of light".⁴⁵

The combination of nanotechnology and biology is also underway. It mainly deals with the techniques of compressing and enriching DNA, proteomics, living organisms manufactured from synthetic nanoelements (in particular viruses) and the production of extremely small living organisms. There are increasingly great expectations of applications in medical technology, that need to be seen in the light of a risk of a hostile public attitude with respect to possible misuse, which seem to be more of a purposeful nature than accidental. High-density biochips are the subject of fierce competition at the world scale.

b. Convergence by multiple combinations expresses the reality of industrial meta-convergence.

Two-by-two combinations do not by themselves describe industrial realities. You have to combine at least three sectors to identify the applications with the highest added-value.

For example, the combination of nanotechnology, biotechnology and ICT, which requires a new multidisciplinary know-how is favoured by shared instrumentation and equipment. Biological sensors organised into networks are very reliable when used on production lines. Advanced systems for targeted administration for the detection and destruction of cancer cells, or for remote monitoring in health applications, offer significant market prospects, as well as cost savings for health services. In a more distant perspective, reference can be made to "active skin" systems using remote perception or the sensation of perception of touch (one of the elements of what could be called remote presence perception).

c) The particular position of cognitive science and neurotechnologies

Cognitive sciences are not limited to knowledge, but cover the entire field of scientific psychology and its counterparts in philosophy, logic and human sciences in general.

Whereas the information technology community considers information as data, cognitive science searches for the conditions by means of which an agent acquires, holds, loses, transforms and communicates information, i.e. all the skills and representations of which knowledge is only the perceptible part.⁴⁶ This is a multidisciplinary field that attempts to understand how the human brain is capable of learning, of using a language, of reasoning, thinking, having emotions, acting, having social relations and behaving.

The decoding of information in neural networks to transform it into command signals for controlling, by thought, external devices such as robots or computers, is a key challenge for the applications of meta-convergence including cognitive science and neurotechnologies. The latter are materialised by a series of tools capable of influencing the central nervous system. The future of research consists of the transition from *in vitro* technology using tri-dimensional electrodes (points) to *in vivo* technology based on the implantation of batteries of flexible electrodes. The test of the latter and the speed of their development partly depend on the attitude of society with respect to stem cell research and the cloning of living organisms, understood to be an accelerator.

The industrial applications of the convergence of cognitive sciences with the transformative technologies such as nanotechnology, ICT and biotechnology are extremely useful in the fields of repairing damaged vital functions (e.g. Parkinson's, and Alzheimer's diseases and paralysis caused by cerebrovascular accident) whatever the causes (violent for the armed forces, accidental or caused by age for others). They also open the way to increasing capacities, and thereby, to changing productivity, creativity, attitude, or even personality. They are therefore more likely than other applications to be subjected to the question of limits.

Education in the information society is itself likely to benefit from meta-convergence centred on the methodology of cognitive walkthrough. This selects semantic spaces adapted to the audience in question on the basis of latent semantic analysis rather than on that of subjective assessors, thereby increasing the effectiveness of learning. Included in a personal assistant that can be remotely controlled at will, it suggests many multiple applications in the education, vocational training and in professional practices in a multicultural and multilingual environment.

2. The differences between the NBIC and CTs approaches

In 2004 a response was produced to the report of the National Science Foundation on NBIC Convergence, by a group of experts brought together by the European Commission. In this sub-section we will describe the specific details of the NSF report in terms of ethics and meta-convergence and for the purpose of comparison we will present the originality of the European approach, which is reflected by different concepts from those underlying the acronym NBIC, this difference referring to distinct purposes. We will complete this description by a brief review of dual technology issues and an examination of the potential consequences that these different approaches may have on competitiveness and social cohesion.

a) The NSF on the issue of increasing performance

The subject of increasing human performance was welcomed as one of the subjects liable to ensure the promotion of the NNI initiative, by providing, at least in popular media accounts, a completely safe "new dream world". Although this area held the limelight, reality was otherwise. The American NNI devotes 45% of its budgetary resources to research on synthetic nanostructures (physical, biological, electronic, optic and magnetic), and 20% to systems architecture (interconnection, integration). Nanoelectronics, optoelectronics and magnetic electronics account for 39% of the programmes identified as representing major challenges, to which are added nanostructured materials accounting for 22%. In contrast, research on biosystems at the nanometre scale only accounts for 14% of the NNI's expenditure.

The miniaturisation of products and services derived from the electronics sector therefore remains the current and future core business of the international specialisation of the United States in the advanced technologies of the information society. The strategic defence options against the effects of electromagnetic arms, which can be designated by the term of electronic warfare, also lie just beneath the surface in the orientation of fundamental research.

Help in coming to market also occurs as early as the process of public support for research, with an allocation devoted to the process of manufacturing at the nanometre scale and investment in instrumentation and metrology.

The new paradigm inaugurated by the 21st century will result from the NBIC convergence, according to a pattern proposed by Roco and Bainbridge in their 2001 and 2003 works cited in the appendix. A complete understanding of reality or of nature (understood as an algorithm on which man can exert his control), an objective against which all former paradigms came to a standstill, will be made accessible for the first time by the convergence, "with the help of a human-computer interface which will allow humans to learn to design and produce machines and information systems capable of helping them use their potential to the maximum".

The artificialisation of nature and the naturalisation of man are treated as *fait accompli* by the American NSF approach, with the reservation that there is risk assessment in terms of simple causality or possibly in the systemic terms of ecotoxicology. The path is therefore open to fast progress in all the fields of transformative technology and in their convergence. The role of the authorities is to establish a series of conditions favourable for private initiative while guaranteeing acceptability by public opinion.

b. The report of the European Commission experts and the question of end-purpose

The European Commission held a series of meetings of multidisciplinary experts from October 2003 to September 2004 to establish a European reference system on the issues evoked by the NSF NBIC report, by proposing other options than the latter, in an exercise consisting of forecasting converging technologies for the year 2020. The signatories of this report participated in this group of experts and produced, under the individual responsibility of the authors, the targeted contributions cited in the appendix. The results of this group do not represent the views of the European Commission. However, in the opinion of Theodius Lennon, director of foresight at the Research DG, the results are intended to be incorporated in the process of revision of the Lisbon agenda and to provide elements for orienting Community public policies on the information society.

The economic effects of converging technologies, which was not the core of the works, were nevertheless included at our request on the basis of scenarios in a specific document ⁴⁷, prepared in terms of its main recommendations on the basis of works piloted by one of the two authors of the present report⁴⁸. The final document retained a strong societal connotation in the context of the historical analysis of the appropriation of technology.

The models of societies, with their values, the objectives that they provide themselves with and the priorities and limits that they set for themselves, are vulnerable to the gain in power of the industrial metaconvergence that is forecast for the next half century.

The artificialisation of nature has shown the limits of its acceptability with the sometimes violent reactions against GMOs. What can we say of the process of the naturalisation of mankind if by it we mean that "we are natural to the exact extent that we can become artifices, scientific products, that we can be transformed, improved, economised and exploited by using the laws of nature"⁴⁹?

The combination of biocompatible nano-implants, related to the possibility of creating, by bioengineering neural connections and remotely influencing the working of the brain, provides technologists with tools for operating on the "conscience", seen as the globalisation of memory, the perception of presence and the purpose of the act and of willingness. For the time being, the scientific community confines itself to repairing activities (they are not going to change thought but only short-circuit the bits that aren't working properly). But what about societal intentions?

The European group of experts mainly differed from the NSF report on one point, that of the **end-purpose** pursued in the orientation of fundamental and applied research.

The group judged that, because of the structural cultural mosaic of the European Union, the contribution of industrial meta-convergence should be used by government authorities to serve humanity. Rightly or wrongly, it interpreted the end-purpose of the NSF approach as giving priority to the service of economic competitiveness, to the possible detriment of mankind, its values and fundamental rights.

If there is a possible conciliation between the American and European approaches, it still needs to be built from scratch.

The group also considered that the rate of discovery was so fast that it now exceeded the ability to assess the technology *before* it became disseminated, therefore implicitly meaning that there is a duty of collective vigilance. It expressed the desire for surveillance of the forward march of nanotechnologies at the same rate as its development and if possible, in advance, by impact studies and permanent monitoring, no less multidisciplinary than the nanosciences themselves. This would be sort of real-time reflex action to scientific and technological changes, which would thus be the first in the history of humanity. It is without doubt made inevitable by the speed of change.

c) The open question of dual technologies and the quality of competition

The civilian and military markets are distinct in terms of specifications and segmentation. Innovations designed for one can sometimes be transferred to the other at a lower cost. As far as defence is concerned, the contribution of nanotechnologies is expected in many fields⁵⁰, including: energetic nanomaterials, soldier protection, the information detection and transmission and communications management, remote-controlled actions, aeronautic and space avionics equipment and energy supply.

The transformative capacity of converging technologies is potentially propelled by the search for lower costs in ICT. According to a *prospective* view, between now and the year 2024, a PC will become 8000 times more powerful than those of 2004, but for the same power as those available in 2004 it will only cost 20 cents and will be about the size of a shirt button⁵¹. However, it is also necessary to estimate the approximate cost of a manufacturing line for transistors on grid of 7 nm, forecast in 2018, by the 2003 version of the ITRS road map, which would in principle be more expensive than the current cost (2.5 G\$). For comparison, the investment in Crolles II is estimated to be 3.5 billion euros.

Nanotechnologies are already used create networks of sensors that can detect and identify chemical pollutants or bacteriological agents almost as soon as they appear in a given environment. Although this technology is firstly being used for military defence, it could be adapted to medical technology in a few years.

The industrial processes intended for civilian applications and based on molecular manufacturing will have, according to Chris Phoenix and Eric Drexler, a sufficient potential to profoundly disorganise the economy and international relations. These authors estimate that a country that makes full use of this potential would see its multiplied by a factor of 10 or more each year, obliging government policymakers to come to terms with the considerable and fast changes in the production of riches and resources.

Similarly, Bill Joy, one of the leading American computer scientists, inventor of the Java program and cofounder of Sun Microsystems, has evaluated that the combination of ICT and physical use of nanotechnologies would create in the 21st century a fortune worth a million billion dollars, i.e. the equivalent of 100 times the economy of the United States in the world market.

The duality of nanotechnologies in the industrial meta-convergence poses the question of the competitive advantage produced by the military funding of civilian outlets. Other than the absolute protection of scientific advances and prohibition on the publication of information that would be liable to adversely affect national security, and targeted technology transfers that this would permit, this competitive advantage is coupled with a potentially strong orientation of the purposes of research, including their societal impact.

For example, in 2004 the DARPA had a budget of 445 M\$ for supporting nanomaterials, nanosciences and associated technologies, with a strong emphasis on the NBIC convergence. The LifeLog programme of this agency, officially renamed since then for reasons of controversy in public opinion, had the role of designing a new generation of cognitive systems in the form of personal assistants.

3. The risks weighing on innovation and exchanges

Investment needs transparency, clearly identified rule games and confidence in the behaviour of its actors for it to be conducted. Innovation and exchanges are certainly worthy of being encouraged by government policies to ensure that nanotechnologies take off. It is therefore essential to identify the limitations to investment in order to propose the most appropriate public actions. Our task force did not produce an exhaustive overview, however it can, with reasonable insurance, put forward two pathways: on one hand the unsuitability of the law, and on the other hand the difficulty relating to patents and to the protection of intellectual property rights.

a) The need to change the regulatory framework

The market needs a stable and as predictable as possible framework for lasting development, unless highly speculative behaviours are to be favoured. The constraints in terms of safety and of industrial risk prevention are expensive to comply with, especially when they occur with the processes already in place. It is more economic to design and install safety systems at the same time as the processes themselves whenever possible. However, we collectively come up against the problem of the non-availability of the results of impact studies, on the absence of risk characterisation, on the difficulty of determining their nature, their adverse financial, insurance and legal implications, and on the flagrant deficit of adequate conceptualisation.

The practical, legal implications of nanotechnologies are as yet completely unknown. The same is true, but even more so, for those of industrial meta-convergence. Within the European Union, companies must comply with the obligation to publish an annual report, with the presentation of the accounts and estimates of the costs that would have to be met by the company if there was environmental damage resulting from their activity.

Investors seek the avoidance of uncertainty. How can you interest the stock markets, or, before flotation on the stock markets, the investment of risk-capital needed for applied research and for the creation of startup companies? Groupings such as Sofinnova Partners, CdC-PME or BioMérieux are within their right to know with precision what government regulations will apply to the products for which they hope to obtain a fair return on investment.

To do this it seems necessary to cooperate in European and international plans to determine the components of a regulatory framework that is likely to govern nanotechnology development and that will gain the confidence of all, with monitoring procedures and sanctions to be determined in consultation with all stakeholders. Although over-regulation has a negative effect on innovation, the absence of regulation has direct adverse effects on the market. A balance must therefore be actively sought and found, in a spirit of cooperation, in the general interest.

b) The crucial question of standards and intellectual property rights

Because of the importance of the potential market opened by nanotechnologies, the basis of appropriate standards must be set up to ensure that the organisation responsible for marketing in Europe can benefit fully from this evolution as soon as the thresholds of profitability are reached. From the viewpoint of the establishment of standards, nanotechnologies are by nature considered to be cross-disciplinary, encompassing and combining relevant sectors such as chemical, physical, biological and information technologies.

In the framework of the European Committee for Standardisation (CEN), the relevant fields identified are the standardisation of basic metrology that supports nanotechnology, the determination of the physical properties, the characterisation of structures and biological properties and evaluation, at the nanometre scale.

Terminology and classification are included among the working orientations explored by WG 166, a new European working group of the CEN on nanotechnologies. This group has produced a questionnaire for evaluating the interest expressed by its subject among parties potentially involved in the process. However, until nanotechnologies are strongly embedded in industrial practices, it is unlikely that a European technical standardisation committee will be able to steer and control this work based on private funding alone. Public financial support for classification and standardisation will therefore probably be needed to ensure that no delay occurs.

At the same time, reflecting an emerging consensus and encouraged by the Federal Administration, the American National Standards Institute (ANSI) Nanotechnology Terminology Steering Panel held its first meeting in September 2004 in the United States. According to Dr Peter Hatto, UK observer at the CEN, a fairly broad consensus has been obtained that proposes going directly toward international standardisation under the auspices of the ISO, with an American secretariat. The joint delegations then intervened among a number of speakers so that at least a structure could be envisaged for a joint US-UE secretariat, a position that was adopted, *in extremis*, during the meeting of the CEN working group in early October 2004. This position will rely on the so-called "Vienna agreements", which will enable ISO/CEN initiatives to be coordinated and managed⁵².

The *Association Française de Normalisation* (AFNOR, French standards association) has played an active role that should be encouraged by the French government authorities, by establishing a panel of bodies liable to contribute practically to drawing up of standards, by stating its positions within the CEN, and sending out the first questionnaire specific to nanotechnologies⁵³. It did, however, encounter difficulties relating to the both emerging and cross-disciplinary nature of nanotechnologies, which lie at the interface between "standardisation territories" with well-established boundaries.

Despite these difficulties, all slowing down in the process that is underway must be avoided, the greatest risk being the uncoupling of the international dimension, toward which the standardisation in the field of nanotechnology has been heading from the outset.

AFNOR has also since March 2004 been steering the European and national working groups on risk assessment (CEN WG 160 "*Risk assessment*", and the CNRISQUE, or national "risk assessment" commission).

It is desirable that "industrial risk" dimension of nanotechnologies be taken into account in one way or another by the standardisation authorities, and that their results be used without delay in international discussions. Other points of entry into this subject area have been opened or are to be created (health and safety at work, orientation of INRS action programmes for the prevention of industrial accidents and occupational diseases, of the *Institut National de Recherche et de Sécurité* (INERIS national research and security institute) and the *Institut de Veille Sanitaire* (IFVS public health vigilance institute) in particular, as from 2005).

Intellectual property rights are a source of remuneration for investments made in design and innovation. Their protection is therefore a strong condition for the mobilisation of funding. In terms of nanotechnology, **patents** are accepted by the national offices without a detailed classification in place that would allow observers to isolate what really belongs to nanotechnology. The classification of patents that have been submitted has been done under traditional headings. Because of the growing patent submissions incorporating nanotechnologies, the USA decided in October 2004 to study the definition of a new class of patents meeting the combined criteria of nanotechnology and innovation. A similar EPO classification for Community patents should be envisaged without delay.

The USPTO and EPO statistics show that the scientific origin of nanotechnology patents is dispersed throughout several sciences, none of which is dominant. The three most important sources are chemicals (21% of patents), the multidisciplinary category, clearly reflecting convergence (16%) and applied physics. Materials science accounts for 4% of patents. The major American groups such as DuPont de Nemours, Dow Chemical, Procter and Gamble and IBM all have a portfolio of patents that they are perfecting. L'Oreal also has patents in its field.

Whether or not something can be patented is an ethical question that has not yet been clearly stated in the nanotechnology field and that of its meta-convergence, in particular when living materials come into play. Many legal questions, that follow on from ethical considerations, will be raised as products come onto the market, if a regulatory framework making investments safe (a patent is applied for hallmarks an investment) is not defined quickly. The fields situated at the interface of nano, neuro and information technologies could see their expansion suddenly halted by a lack of transparency in the game rules.

On the other hand, if patentability is implicitly allowed, without "limits", in the neurosciences field, for example, it could block the development of medical technology applications with a high social utility, if there were to be a voluntary restriction of use or of price, such that an economic divide were to occur.

In practice, companies specialising in patent portfolio management have been set up to facilitate the coming to market, especially in Switzerland. A special feature of structures that include nano-manufacture is that they gather blocks of intellectual property rights on the same physical support. As a result, special skills are needed in the legal management of this collection of intellectual property to prevent legal disputes. Furthermore, sufficient areas should be allowed in the *generic* public domain, open to all those who wish, if entire areas of innovation are not be blocked to the detriment of wider society.

As a general rule, an area of dialogue⁵⁴ should be created to allow scientists to clearly express the new possibilities or what is "within arms' reach" in the near future, including when they will require in vivo tests as part of convergence, so as to allow industrialists, economists, jurists, ethical experts, members of parliament and government authorities to better understand what it is about before expressing either an opinion, a recommendation, a standard, a regulatory framework or a code of good practices.

As a conclusion of this second part, we will cite the strong signal given by MEDEA+, to amplify it for measuring the breadth of the industrial meta-convergence: starting from the finding that the European success in the microelectronics sector is measured in terms of leadership acquired the fields of mobile phone services, and services provided by chip and pin cards to make financial transactions secure, MEDEA+ estimates that to maintain *leadership*, the powerful existing European industrial base must evolve from microelectronic to nanoelectronics. But, although the results have been impressive, the future of the (nano)electronics industry in Europe is far from guaranteed⁵⁵, which opens the question of the responsibility of public and private players in the creation of a favourable context.

PART 3: PERSPECTIVES AND SUBSIDIARITY OF NANOTECHNOLOGIES IN METACONVERGENCE: WHAT PUBLIC POLICY?

At this time, when public-private partnerships are becoming the norm, it is necessary to give some thought to the principle of subsidiarity in public responsibilities before going on to the definition of government policy.

From regional economic development, where the legitimate concerns about efficiency and land-use planning are constantly trying to find a better balance, to government leaders acting on the world stage, to industrialists, or simply representatives of special interest groups acting as simple citizens, nanotechnologies and their insertion in transformative technologies merit an exhaustive examination, on the basis of the concept of subsidiarity.

In this part we have adopted an approach ranging from the local to global, by including information currently available on 1 November 2004. We will then deal in succession with the local, regional and European levels, and finally the emerging international dialogue, that is searching for the ideal balance between cooperation and competition.

The section ends by a series of operational recommendations that wish to be in harmony with the levers of government policy available in France for institutional industrial intelligence.

1 The question of public responsibility

Being responsible can be defined as the fact of accepting and submitting oneself to the possible adverse consequences of ones' own actions. In contrast to responsibility, the "game" of "actors" could be considered to be an activity "without seriousness", that does not bear any consequences, that does not harm, directly or indirectly. In the case of nanotechnologies, the properties of "building blocks" are still largely unknown from the outset, and therefore even more so when combined, or disseminated throughout their life cycle. The public awareness of the "risk" factor is therefore absolutely essential, in a context marked by an explicit demand for a moratorium on the basis of an argument inspired by that of the opponents of GMOs.

The societal and industrial challenges are much too important for this question to be treated "as an emergency", with the sole resources of what can be called "communications", in a more or less panic context after something has gone wrong. This must never happen, but it still could possibly occur.

The procedure proposed in this report is new to the extent that it proposes *basing* the social consensus around public support for nanotechnologies on a sufficiently prior inclusive ethical thinking before there is a massive arrival in the market place. This leads us to think about the role of the actors in the process, knowing that very quickly, the ethical dimension could bring into play a whole battery of observation, intervention and communications tools.

Public responsibility is implicated in the drawing up and maintenance of the social consensus and also in protecting the general population and people in working situations from the scientific and industrial risks. Experience has shown that in terms of major risks (e.g. ionising radiation and asbestos whose public health costs will amount to 1 billion euros in 2005), it is the State that is answerable *in the last resort*. There is therefore a very great interest that the limits, and therefore the responsibilities, should be more precisely and more justly distributed as the properties of nanoparticles or nanostructures gradually become identified, characterised and modelled for their industrial uses.

We will deal in succession with the observational limits to national and regional plans, the possible choices in the field of the regulatory framework, and finally the application of the accountability principle in public action relating to nanotechnologies.

a. Observing and understanding at national and regional levels

The aim of setting up of the programme of five major technology centres specialising in nanotechnologies will be continued, according to methods currently being defined, by the regional competitiveness centres decided by the *Comité Interministériel d'Aménagement du Territoire* (CIADT, interministerial land use planning committee) in September 2004, without us currently being able to determine whether the logic behind territorial divisions and excellence will work together or against one another. It would be desirable if the criterion of critical size for European or even global partnerships were considered to be the determining factor in this dialectic.

Up till now the technology centres in question have been awarded 140 M€ of funding over three years, of which 100 from the ministry of research and 40 from the CNRS and CEA. They are situated at:

- Lille: IEMN – Université de Lille (fast micro and nano optoelectronics, microsystems).
- Besançon: FEMTO ST (microsystems and microelectronics).
- Paris-sud: IEF / LPN (nanophotonics, nanoelectronics and nanophysics).
- Toulouse: LAAS (power electronics, nano and microsystems).
- Grenoble: the Minatec centre for nanosciences, micro and nanotechnology: eventually 4000 people, including 2000 research and teaching staff, 1000 students, 1000 jobs in partner R&D firms; situated in an industrial area 16 600 employing 16 600 people including 3500 in research. 30 multinational companies are present, plus 30 high-potential young enterprises. The CEA, INP Grenoble and the Université Joseph Fourier are associated with the CNRS on the site.

A foundation project supporting the future cancer centre at Toulouse could include a bio-nanotechnology unit, as was announced by the French prime minister in April 2004.

The national research agency should strengthen the public resources for action in favour of nanotechnologies, and in particular the forging of relations with the major technology centres and their European and international partners, which have been unable to develop because of a shortage of budgetary resources. It is important that on the creation of this GIP, there is no budgetary break imposed on the RMNT, whose field of application covers meta-convergence.⁵⁶

A factor of conflict between the managers of these centres benefiting from public resources results from the success of the formula: SMEs and startup firms perceive this to be rationing in terms of the opportunities compared to the time which they need. The decision-makers responsible for the centres estimate that they must reserve themselves 70% of the time using the centres and that 50% of the time for other involved parties would be the absolute ceiling after which they give up.

An observation tool has been created in France, on the initiative of the CEA/Leti and the CNRS.

The aim of the *Observatoire des micros et nanotechnologies* (OMNT, micro and nanotechnology monitoring unit) is to detect weak signals that may herald breakthroughs in technology. This tool is an example of a successful public-private partnership, that has stayed within the limits of the precise objectives defined at the outset. The success of the OMNT's annual conference demonstrates the increasing interest from industrials, scientists and other risk-capital-risk players in learning about the scientific state of art, and its progress from one year to another. This is a light structure, a network of 150 scientific and technical experts, that has demonstrated its efficacy. In 2003, the CNES, the DGA and the Department Military Applications of the French Ministry of Defence brought together the subscribing members of this network.⁵⁷

In the short term the OMNT plans to develop a technology watch in four directions: energy microsources, biotechnology, molecular electronics and nanotechnologies. One dimension remains unexplored from the viewpoint of public decision-makers, this is societal, human sciences and social monitoring applied to emerging technologies.

Another monitoring tool coming before the orientation of government policies is the industrial association of microelectronics and microtechnologies in France (JEMI), whose skills would be usefully refined and completed by a knowledge of the emerging industrial activities in nanotechnology.

The harmonisation of the monitoring tools used in the member States of the European Union could be usefully "pulled together" by a specific European programme, as a nanotechnology societal monitoring unit and its insertion into transformative technologies, whose specifications would be defined in function of the needs of the stakeholders, public and private decision makers, taking into account the subsidiarity of the various players.

b. Choosing "laissez-faire" or regulation

Although this choice is naturally constrained at any given time by external European and international regulations, it is not necessarily affected if the anticipation and mobilisation of players involved is effective. There is always a margin for interpretation in national and regional implementation.

The French public powers have solid regulations and procedures for controlling industrial risks (e.g. by SEVESO class establishments and actions of the *Directions Régionales de l'Industrie et de la Recherche* (DRIRE, regional Directorates for Industry, Research and the Environment). In the field of preventing toxicological and ecotoxicological risks from synthetic nanoparticles, it is therefore more of a question of awareness and orienting action programmes than creating new tools. The budgetary allocations should be adjusted to emerging needs in terms of risk identification.

On the other hand, it is important that public powers accept and are aware of the consequences and the uncertainties specific to nanotechnologies⁵⁸ and to the meta-risk caused by meta-convergence: doubt and prudence are needed in the face of these phenomena, where it would be best to build communications that take account of this situation to better ensure the cooperation of all the parties involved; but a strict conceptual effort is also needed, that can overcome some of the over-simplifications that are inherent in the "precautionary principle".

The future of nanotechnologies depends on the way that society will react to the anticipations that are made on the subject. These anticipations themselves depend in turn on images and representations that are broadcast, and these are already being addressed to the youngest members of society (see the model that is suggested of the *obedient ant*⁵⁹).

Laissez-faire is necessary up to the point of allowing the freedom to conduct business, innovate and experiment, but must at all times be accompanied, if we wish to contribute to the construction of a sufficiently positive, optimistic and credible image of nanotechnologies, by the proof that they merit the confidence conceded at the outset. To do this, our task force is of the opinion, on the basis of the works of Alexei Grinbaum and J-P. Dupuy⁶⁰, that designing a radically new assessment methodology, called ongoing normative assessment, by means of which each new item of information on the properties discovered at the nanometre scale should be used to adapt the assessment and orient public action, without delay. This idea is both original and fundamental: original because it is not entrapped by any scenario, it takes account at each stage the scientific and industrial realities, and sets up a virtuous feedback loop for the service of the greatest number; fundamental because probably it contains the key to long-term informed confidence.

Molecular manufacturing and the use of clusters of atoms, are now possible and the debate between Eric Drexler and Richard Smalley (Nobel Prize for Chemistry, discoverer of fullerenes) is now to some extent behind us. In the face of potential risks, government responsibility consists of ensuring that the dividing line between the laissez-faire and regulation is defined in an enlightened way that can be changed in time if need be. In the short term, the existing regulations or those that are in the course of being adopted must apply, included among which are the international treaties signed by France (Carthagena Protocol) for bio-nanotechnology, and the future Community REACH regulations, under the reservation that they can be adapted to nanometric components or nanostructures.

c. Applying the accountability principle

As it involves public money, the accountability principle must apply to activities supported by taxpayers as from the first euro, as is stated on the motto of the French *Cour des Comptes* that scrutinises public expenditure. In addition to the budgetary aspect, which has its own importance, the accountability principle applies in different ways to civilian and military areas. Some public actions can, because of the recognition of a mutual interest, be conceived in partnership between the civilian and military spheres.

However the identification of responsibilities, of the degree of transparency and the means of transmitting information between legislative, executive and judiciary authorities raise such problems that it tends to discourage these partnerships (e.g. clinical trials conducted by the public and/or military health services), unless ad hoc contractual formulae can be found (case of the Armed Forces Nanotechnology Institute at MIT, which developed its programme in collaboration with civilian hospitals).

The accountability principle has also been useful in the industrial and commercial spheres, if only to avoid any phenomenon of consumer defiance, whose ultimate manifestation is the call for a boycott. The professional codes of good practice are interesting, motivating approaches that are of use to all parties involved. They tend to prove that those parties providing the goods or services are doing their utmost, within the competitive framework, to reconcile their interests with those of public preferences (in particular health and safety and sustainable development).

They have the effect of increasing the quantity of information accessible to the public, but the quality cannot be measured. They differ from scientific precision in the sense that they represent communications tools. It is up to the courts to judge, if necessary, whether the communications are true and to set the amount of damages. Sonia Miller, president of the Converging technologies Bar Association, New-York barrister, has published the following: "*As products incorporate more complex and multidisciplinary technologies integrated at the nanoscale, greater precautions **and proactive measures must be incorporated before nanomaterials enter the market place and appear before the court***".⁶¹

Noting the recommendation of the European Commission to proceed toward a code of conduct in terms of responsible development of nanotechnologies, we nevertheless consider that, however useful and desirable, it only constitutes one of the vectors of accountability, and is insufficient on its own to clarify and partition responsibilities. It should therefore, when the time comes, be accompanied by precise regulatory texts guaranteeing rigour, efficacy and the means of control.

Observing, orienting, deciding, acting and assessing are the sequential acts in the same operational chain. In a world context of research, manufacture and exchanges, it is essential to think of these sequences globally and, if possible, to influence them in accordance with democratically expressed collective preferences. Our relevant "homeland" is henceforth that of the European Union with twenty-five member States.

2 Inspiring the European Union's position with respect to Community regulations

The Union's competition and commercial policies being destined to remain instruments belonging to the European Commission, with or without a constitutional treaty, questions should be asked as to what forces we can bring to bear from France on the Community institutions (mainly the Council, European Parliament and the Commission). But to be in a situation of inspiring the European Union's position, it would be preferable to talk with a single voice, reflecting if possible the national consensus.

a) Some prerequisites for a clear French position with respect to European institutions

We have seen that up to now, the French position has been formulated by the natural leader acting in scientific fields, namely the minister of research. This situation, that was effective within the framework of preparing the 5th and 6th RTDFP, could be less efficient as from 2005 for two reasons. The first is because of the increasing number of people having a word to say on nanotechnology within the Commission, the Research DG is no longer the sole entity to deal with this subject, because of meta-convergence. The second reason is that laboratories are no longer the sole organisations concerned, many industries supplying goods and services, the insurance and risk-capital sector, international trade and many fields of public action (particularly justice, industry, transport, defence, ecology and sustainable development, education and customs and excise) are also involved.

A **permanent interministerial coordinating team**, reporting directly to the prime minister, capable of supporting the development of nanotechnologies as an emerging transformation economic sector and of ensuring the quality of the interaction with all the stakeholders is essential as of now. This function, which remains to be created, should be able to rely on an **operational reviewing body**, in charge of the actual implementation of government policy in terms of nanotechnologies, a recommendation sketched out in the report of the *French Académie des sciences* and *Académie des technologies*.

b) Obtaining consistency between government policy on nanotechnologies and other major areas of public action in the European Union

From long-term prospective studies to assessment, there are many ways of interacting with and influencing Community action. A series of more concrete proposals could be formulated in this field by the operational review body that we have identified above.

Among the important and predictable means of incorporating nanotechnologies in existing trends, for which a clear French attitude is desirable, we can mention:

- The participation in the orientation of the method and the prospective horizontal or targeted subjects and the impact on the work programme of the Joint Research Centre, JRC, and *Institut de Prospection Technologique* (IPTS, the Institute for Prospective Technological Studies). This action is essential in the construction of a consensus view, and therefore sufficiently positive anticipation to confirm the willingness, or even the priority for action, even if the results will only be obtained over a long period of time.
- The participation in the drawing up of the 7th RTDFP in **all** the fields involved in nanotechnologies, the first among which are information and communications technologies (and not only of the Research DG programme on nanosciences) and the assessment of the results of the 6th RTDFP in a feedback perspective. Special effort should be given to the field of technological convergence because this will be a focal point of competitiveness in the future, all going together with the definition of ethical assessment criteria for projects.
- Participation in the European Commission's high working groups in the field of the four converging technologies (bio, info, nano, cogno) and the proposal to create such groups when they do not exist, all having as common thread for the future, meta-convergence.

- Participation in seminars specialising in the perspective for 10 years time in all the sectors liable to include nanomaterials in their manufacturing processes or in their products.
- The active support of the Community policy of the SANCO DG SANCO for the creation of a network of bodies responsible for toxicology and ecotoxicology studies.
- The promotion of the ethical aspects of nanotechnologies within the STOA (European Parliament's Scientific and Technological Options Assessment unit).
- The promotion of European financial instruments in favour of startup businesses and SMEs in this field.

Lastly, interest should be taken in the European Union's international cooperation programmes in the field of nanotechnology, in particular with the United States and China. A proactive French participation in enhancing responsible international dialogue in the field of nanotechnology was initiated in the first half of 2004. It is essential that this opportunity does not simply cease.

3 Taking part in responsible international dialogue

The initiative for a responsible international dialogue came from the coordinator of the American NNI, M.C. Roco⁶². It is based on the absolute need to be accountable to the American legislature that the precautionary principle is being applied in the federal public funding of nanosciences and nanotechnologies. The intuition of Mr Roco, as briefly expressed during the Euronanoforum of December 2003 at Trieste, was that it would be a good idea to get the countries interested in working on finding a shared code of conduct, allowing the necessary confidence building for making investment attractive (public and private), while avoiding introducing any binding provisions. This initiative led to the start of the "Alexandria process".

a) The nature and future of responsible international dialogue

A first informal meeting was held at Alexandria (VA) on 17 and 18 June 2004, at the invitation of the NSF. There was a large attendance at this meeting, whose aim was to express an interest for an international dialogue on "responsible" nanotechnology (25 countries, plus the European Commission-Research DG), which was varied both in terms of geographical distribution and level of development (United States, Japan, Canada, Mexico, Brazil, Argentina, India, France, Germany, United Kingdom, Netherlands, Austria, Belgium, Czech Republic, Romania, Switzerland, Israel, Russia, South Korea, Taiwan, Australia, New-Zealand and South Africa).

It provided a better awareness of the benefits and anxieties caused by the emergence of nanotechnologies in the public at large. During the concluding session, it was clearly established that the participants were agreed that there was the need for the international community to urgently set up an ongoing dialogue, cooperation and coordination in the field of nanosciences and nanotechnologies. It was decided to agree on the terms of reference that an informal *preparatory group* could be given and which would be responsible for establishing the bases of an international dialogue and cooperation.

It is clear that the nature of this group is not yet definitive. Several options are open at this stage in creating a driving force to carry through this process: an independent scientific association or a group belonging to an existing entity such as the ICSU; a forum within the OECD (but not all countries belong to this organisation) or a United Nations Task Force — the options are open, since there are no treaties that foresee a "natural" diplomatic device in this emerging field. The ETC group, a non-governmental organisation promoting biodiversity and human rights, is favourable to launching the Alexandria process, referring to it as an important first step⁶³ in bringing governments to recognise the global impacts of nanotechnologies. It has pronounced itself in favour of an instrument that would operate under the auspices of the United Nations. The OECD representative at Alexandria, Mr Stefan Michalowski (executive secretary, Global Science Forum) said that an interesting precedent existed in IPCC (Intergovernmental Panel on Climate Change), that was created by World Meteorological Organisation and the United Nations Environmental Programme.

According to the conclusions of the Alexandria meeting, this group should explore the various possibilities of structuring the dialogue by actions, mechanisms, a timetable, the most appropriate institutional frameworks and the principles of this dialogue and cooperation, that could be accepted by all countries and all continents. It should prepare a proposed action plan for a continuous dialogue and cooperation, and a joint declaration accompanied by a procedure for their adoption. It was also planned that other interested countries could join the 25 participating countries.

The position upheld by the representatives of the member States of the European Union (in particular France and Germany) according to which in the future this dialogue should become as inclusive as possible, in particular with respect to China, was constantly upheld by the representatives of the European Commission. This position was confirmed by the conclusions of the Competitiveness Council on 24 September 2004.

b) The need to define responsible international dialogue and the continuation of the processes.

This meeting was reported on in detail by diplomatic correspondence on 23 June 2004. The French representatives organised an interministerial information meeting at Paris⁶⁴ on 29 June 2004, at which representatives of the CEA, the *Secrétariat Général de la Défense Nationale* (SGDN, general secretary for national defence) and Ministry of Ecology and sustainable development in particular participated. The dossier was circulated widely to the *Conseil Général des Mines* (CGM, general council for mine engineering), the *Conseil Général des Technologies de l'Information* (CGTI, general council for IT), the prime minister's cabinet office, the *Secrétariat Général du Comité Interministériel pour les questions de Coopération Economique Européenne* (SGCI, general secretariat of the interministerial committee for European economic cooperation affairs), the foreign ministry, the ministry for research (cabinet and services), the ministry of industry (cabinet and the *Direction Générale de l'Industrie des Technologies de l'Information et des Postes* (DiGITIP, general directorate for industry, information, technologies and the postal office)), the economic intelligence department of the *Haut Fonctionnaire de Défense* (HFD Defence High Official) / MiNEFI and to the scientific services of the French Embassy in Washington.

The most probable developments in the short term are the setting up of an informal steering structure for a first implementation task force, which Mr Roco suggests should come first without waiting for the "preparatory group", which could take some time to form.

This first working group is provisionally called the "*International Working group on Databases, Norms and methodologies for risk assessment in Nanotechnology*". Its prospective joint chairmen are American, (Environment Protection Agency), Japanese (Council for Science and Technology Policy), French (member of the *Conseil Général des Technologies de l'Information* (CGTI, general council for IT)) and Formosan (Advisor, Ministry of Education for Nanotechnology).

The road map for this group has been drafted consisting of four points: the promotion of exchanges of information, the harmonisation of the various trends, the organisation of an annual meeting and the identification of priorities for cooperation.

It remains to quickly define the means of implementation for France, knowing that the interests to be pursued have been clearly expressed by France in these terms: "The dialogue has started (see the Alexandria conference). It is therefore a matter of extending and continuing the dialogue with all the countries involved in the process of developing nanotechnology (in particular with China, a notable absentee at this conference" (SGCI 23 September 2004). As it is a dialogue between countries, and therefore of responsibilities and government policies, it is desirable that the process be supported by the French diplomatic services.

CONCLUSION

At the end of this report, we wish to emphasize the originality of the line of approach that we have chosen. It has a double comparative advantage for the strategic orientation of government action in favour of the development of nanotechnologies and their industrial convergence with biotechnology, information technology and the cognitive sciences, in that it proposes:

- basing a reasonable and sustainable social consensus on ethics, in France, in terms of nanotechnologies;
- orienting the responsible international dialogue by an active contribution to the definition of ongoing normative assessment tools that are effectively adapted to the growing reality of industrial meta-convergence.

To do this, a strengthening and a coming into play of the public orientation and operational implementation arrangements should be conducted in very short term, centered on nanotechnologies. A means of continuation and support should be actively sought in the action of the European Union, in particular by funding a unit to monitor the societal implications of nanotechnologies, in a network with strengthened monitoring capacities in each member State.

The task force's recommendations, most already stated in the report, are summarised below.

13 RECOMMENDATIONS FOR ACTION

- **Rec. 1: Design and implement in the very short term a permanent interministerial coordinating function**, capable of supporting the convergence of highly transformative technologies, starting with nanotechnologies.
- **Rec. 2:** Support AFNOR's **standardisation** effort within the framework of WG 166 of the European for Standardisation Centre, including the need for a joint EU/US secretariat at ISO, by inciting industry to participate in it.
- **Rec. 3:** Create a **technological network** for nano-bio- info- cogno meta-convergence, as a complement to nano-, micro- technologies network (RMNT), French network on software technology (RNTL), national telecommunications network (RNRT), international multimedia conference (RIAM), and (RNTS) national health technology network (RNTS) networks liable to favour, in particular, the French proposals for the calls for tenders of the 7th RTDFP.
- **Rec. 4:** Support the recommendation of the European Commission's high-level expert group on the perspectives for the new technological wave (NTW) aiming to create a **European societal monitoring unit** for converging technologies.
- **Rec. 5:** Promote **the monitoring of nanotechnologies in France**, in all their scientific, technological and societal dimensions, by providing public support for the adaptation and institutionalisation of the functions fulfilled by the OMNT, and based on the results, build a constructive dialogue between all stakeholders.
- **Rec. 6:** Mobilise the human and budgetary resources needed **to prepare ongoing normative assessment criteria** for the national and international community, for their presentation and implementation of the corresponding methodology (*relevant criteria for peer-review*).

- **Rec. 7:** Start a research programme on **new regulations and subsidiarity for converging technologies**, including those applicable to international trade and customs problems.
 - **Rec. 8:** Make young people aware of the value of multidisciplinary **education and training** and improve the image of nanotechnology and emerging technologies in the secondary school curricula by quickly updating teacher training and educational materials in technological subjects in secondary schools.
 - **Rec. 9:** Mobilise the national institute for research and security (INRS), the *Institut National de l'Environnement Industriel et des Risques* INERIS, the national institute of the industrial environment and risks (INERIS), and INVS, the organisations responsible for health and consumer protection in terms of **preventing physical and social risks**, starting by a classification of products and a database.
 - **Rec. 10:** Include in the **role of the DRIRE** the local monitoring of any facilities dealing with nanoparticles and nanomaterials, while ensuring interaction with the national and European regulatory authorities.
 - **Rec. 11:** Ensure that the *Comité consultatif national d'éthique* (CCNE, national ethics consultative council) for life sciences has the necessary means for fulfilling its mission with respect to nanotechnologies and meta-convergence, and for participating in international exchanges on these crucial aspects, in liaison especially with the national ethical committee of the CNRS.
- Rec. 12:** Encourage major research organisations, starting with the CNRS and INSERM, in creating **research platforms on the ethical and societal implications of nanotechnologies**, considered from the viewpoint of meta-convergence.

- **Rec. 13:** Define an **operational review board** responsible for implementing government policy on nanotechnologies, as a continuation of the proposals sketched out in the report of the French *Académie des Sciences* and the *Académie des Technologies*.

Paris, 8 November 2004

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and Telecommunications

END OF REPORT NOTES

- 1 Report rst No. 18 – April 2004, "Nanosciences Nanotechnologies", Editions Tec & Doc, p.11
- 2 "Les nano-matériaux, au cœur de la galaxie nano". Gilles Le MAROIS, Réalités Industrielles, February 2004 No., Les Annales des Mines, p. 64.
- 3 "Quantum grains for light-emitting diodes".
- 4 JOACHIM Christian "Nanoelectronics, the Bottom-Up Nano-Calculator", CNRS, in Emerging Technologies. Empowering People in the Information Society. Issue 21, September 2004.
- 5 DUPUY Jean-Pierre "Impact du développement futur des nanotechnologies sur l'économie, la société, la culture et la paix économique mondiale". Working document of the section "Innovation and enterprise".
- 6 Statement by Thierry GAUDIN, Joint meeting of the CGM-CGTI and the European Commission/ DG RDT/Unite K Foresight, 9 February 2004.
- 7 "Vers une stratégie européenne en faveur des nanotechnologies". Commission Communication COM (2004) 338 final, p.3.
- 8 The following figures are derived from the sources cited in ROURE F. "Economie internationale des nanotechnologies et initiatives publiques". Revue Réalités industrielles, February 2004, pp. 5 to 11.
- 9 "Les nanomatériaux", Gilles Le MAROIS, DIGITIP/ MINEFI, 12 July 2004.
- 10 <http://www.nanomatériaux.org>
- 11 Seminar organised by the DiGITIP / MINEFI on 22 October 2004, with the support of the German BMBF and The Austrian BIT.
- 12 SGCI note of 23 September 2004 on point 12 of the Competitiveness Council of 24 September 2004, fixing the basis of the French wording.
- 13 2nd Shanghai international nanotechnology cooperation Symposium, Asia Pacific Nanotechnology annual conference <http://www.anpf.org>
- 14 In Yole Development Study for the DiGITIP, "Nanotechnologies, environnement international", September 2003.
- 15 HAGEGE S. ROURE F. "Contribution to the National Science Foundation international dialogue on nanotechnologies", Alexandria (VA), June 2004.
- 16 See Appendix 4, tables and graphs No. 1.
- 17 Speech by M. François d'AUBERT, 12 October 2004 in <http://www.recherche.gouv.fr/budget/2005/priorite2.pdf>
- 18 Solution recommended by the CSTI in <http://www.csti.pm.gouv.fr>
- 19 See in particular the Fogale Nanotech company, <http://www.fogale.com>
- 20 Jeol News, in <http://www.jeoleuro.com>
- 21 See Appendix 4, tables and graphs No. 4.
- 22 See Tables and graphs No. 5, Appendix 4.
- 26 *See-through Science*, James Wilsdon and Rebecca Willis, with a preface of Barbara Young, Director of UK Environment Agency, Demos, London, 2004.
- 27 "Small size – large impact?" Invitation to Conference on nanotechnology, Swiss Re.
Centre de traduction Minéfi - Dossier n°2392-05 - 12/01/2006 - Traduction pour le Conseil stratégique des technologies de l'information **64**
<http://www.csti.pm.gouv.fr>

28 FITERMAN C., Conseil économique et social, 11 May 2003.

29 With reference to "scénarios catastrophiques de Sir Martin Rees, le Pari à 1 million de morts", in *Le Monde* 2, 2 October 2004. See his book *Our Final Hour. A Scientist's Warning: How Terror, Error, and Environmental Disaster Threaten Humankind's Future in this Century – on Earth and Beyond*, Basic Books, New York, 2003.

30 "Mapping out nano risks" Ad hoc working group of the European Commission SANCO DG 1-2 March 2004. Appendix No. 4. Tables and graphs No. 2.

31 See Michael Crichton's novel *Prey*.

32 DREXLER Eric, PHOENIX Chris. "Safe exponential manufacturing" Institute of Physics Publishing Nanotechnology 15 (2004) 869-872.

33 Sir Martin REES, *Our Final Hour*, op. cit.

34 See however the accompanying documents in the Appendix.

35 Report of the international dialogue on responsible research and development technology. August 2004, The Meridian Institute/ NSF, 52 p. in <http://www.nanodialogues.org/international>

36 <http://www.bmbwk.gv.at> "Austrian comments on the questions for the public debate on nanotechnologies".

37 ROURE F. Ethique et nanotechnologies", Talk at the Micro-Nanotechnologies Network (steering committee). June 2004-09-30.

38 DiGITIP note 5 May 2004, ATOFINA activities in the field des nano-materials, 2 p.

39 "La convergence des nanotechnologies, des biotechnologies, des technologies de l'information et des sciences cognitive, pour une augmentation des performances humaines". Françoise Roure. Proceedings of the NBIC Conference., New York February 2004.

40 See Center for cognitive liberty and ethics. United States.

41 <http://www.nanoroadmap.it/project/project.htm>

42 Official Japanese contribution to the NSF and Meridian Institute questionnaire about International dialogue on responsible R&D of nanotechnology. 4th Paris 2004.

43 DUPUY Jean-Pierre "Do we shape technologies or do they shape us?" Proceedings of the Conference "Converging technologies for a diverse Europe", September 2004, European Commission, Brussels.

44 FERT Alain, joint CNRS Physics unit/ Thalès and Université de Paris-Sud Orsay unit, in 5th meeting of the RMNT, 13 October 2004.

45 Ditto LOURTIOZ Jean-Michel, Institut d'électronique fondamentale, CNRS Université Paris-Sud Orsay.

46 ANDLER Daniel, professor of philosophy, Université de Paris Sorbonne, 19 September 2003. "What does C stand for in the NBIC acronym". Working paper, 2 p.

47 ROURE F.HLEG Foresighting the new technology wave. "Economic and social effects of converging transformational technologies (CTTs)", report on Madrid meeting, 21 May 2004. F. Roure.

48 ROURE F. "The main economic focus of converging transformational technologies (CTTs)". High Level expert group Foresighting the New Technology Wave, European Commission / DG RDT, unit K Foresight. Special interest group meeting 21 May 2004, Madrid.

49 Cf DUPUY Jean-Pierre "Do we shape technologies or do they shape us?", loc. cit.

50 BOILEAU Jacques: "Les aspects duaux des nanotechnologies. Peut-on envisager une initiative nanotechnologique nationale (INN) ?". In *Réalités industrielles* February 2004, p. 76.

51 BAINBRIDGE W.S, ditto, p. XXXV.

52 According to Pascal GAUTIER, head of the AFNOR project for nanotechnology.

53 See tables and graphs p. 8, Appendix 4.

54 Wish expressed by the American Association for the Advancement of Science, Report "Neuroscience and the Law: brain, mind and the scale of justice", Sept. 2004, Dana Press, summary report, 29 p.

55 Arthur Van der Poel, MEDEA+ Chairman of the board, 19 October 2004.

56 See tables and graphs No. 9, Appendix 4.

57 2003 annual report of the CEA- Leti, p. 45.

58 "Complexity and uncertainty, a prudential approach to nanotechnology", Jean-Pierre Dupuy, Proceedings of the meeting "Mapping out nano risks", March 2004, DG Health and Consumer protection. European Commission, 32 p.

59 "Bienvenue dans le nanomonde", OKAPI Nov. 2003 p.10 in tables and graphs No. 7, Appendix 4.

60 Jean-Pierre Dupuy and Alexei Grinbaum, "Living With Uncertainty: Toward a Normative Assessment of Nanotechnology", *Hyle/Techne*, in press.

61 MILLER, Sonia: "A matter of Torts: why nanotechnology must develop processes of risk analysis", New York Law Journal vol. 232-N°. 67, 10-05-2004.

62 Mihail Roco, *senior advisor on nanotechnology for the National Science Foundation (NSF), Chairman of the Subcommittee on Nanoscale Science, Engineering and Technology (NSET) of the U.S. National Science and Technology Council.*

63 "26 governments tiptoe toward global nano governance: grey governance?" June 30, 2004-10-22.

64 See Appendix Table of contents dossier for the interministerial information meeting of 29 June 2004