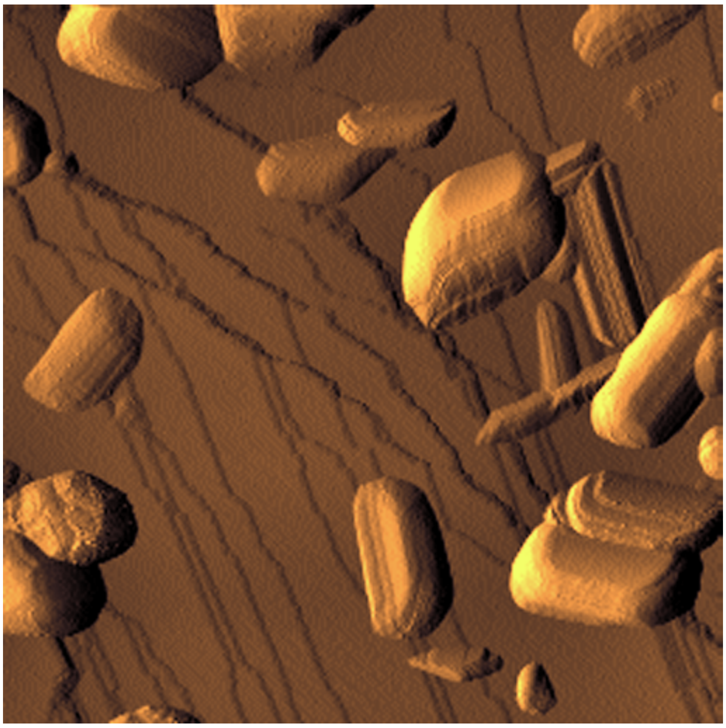
EUROPEAN
COMMISSION

Community Health and Consumer Protection

NANOTECHNOLOGIES: A PRELIMINARY RISK ANALYSIS ON THE BASIS OF A WORKSHOP ORGANIZED IN BRUSSELS ON 1–2 MARCH 2004 BY THE HEALTH AND CONSUMER PROTECTION DIRECTORATE GENERAL OF THE EUROPEAN COMMISSION



Cover page illustration: The picture on the cover page shows nanoparticles of titanium silicide embedded in silicon (3200Å × 3200Å × 291Å). (Courtesy of Professor Mark E. Welland, Cambridge University.)

The present report may be found under http://europa.eu.int/comm/health/ph_risk/events_risk_en.htm.

FOREWORD

Nanotechnologies refer to “technologies of the tiny”. They span domains as diverse as computing, material science, medicine, energy production and storage, etc., bring together fields as varied as physics, chemistry, genetics, information and communication technologies, and cognitive sciences, and should become virtually ubiquitous before long.

Nanotechnologies are with us already. Indeed, consumers are already being offered products manufactured with nanotechnologies including cosmetics, clothing, and sporting goods. But, while technology and market analysts alike expect the very small to become very big, nanotechnologies are still emerging.

Like other new technologies before them, nanotechnologies may not only present potential benefits, but also potential risks. Today therefore constitutes an appropriate time to establish a dialog on nanotechnologies involving scientists, consumers, workers, industrialists, and other stakeholders. Today also represents an opportune moment to reflect on the implications of these “technologies of the tiny” for public health, health and safety at work, and the environment. Today presents us with a unique chance to set nanotechnologies on a responsible development trajectory, one that will benefit both human and environmental health and global competitiveness.

The “Mapping out Nano Risks” workshop represents a modest first step—albeit an important one—towards analyzing the potential risks of nanotechnologies and what they may imply. Consequently, I should like to thank all the experts who took part in the workshop for contributing written statements prior to the workshop, for actively participating in the workshop, and for producing this timely report.

This report is available under http://europa.eu.int/comm/health/ph_risk/events_risk_en.htm.

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[to **EXECUTIVE SUMMARY**, to **INTRODUCTION**]

EXECUTIVE SUMMARY

The Health and Consumer Protection Directorate General of the European Commission convened a workshop in Brussels on 1–2 March 2004 entitled "Mapping out Nano Risks", inviting an international, interdisciplinary group of seventeen experts to examine the hazards, exposure, and risks to human and environmental health potentially associated with materials derived from nanotechnologies (NTs) within the next 3–5 years.

This report comprises two parts. The first part consists of outcomes—a preliminary risk analysis as well as a general statement and a concept note on a hazard trigger algorithm as a potential prioritization tool for use by regulators, which follow up on work initiated during the workshop by two working groups. The second part contains documents produced and circulated prior to 1 March 2004, namely, a collection of short contributions by the invited experts, the terms of reference, and the agenda.

The "Mapping out Nano Risks" workshop

- pointed out the need for and offered **clarifications** about nanotechnologies terminology, establishing, above all, the need to **distinguish between nanotechnologies** and, specifically, to **distinguish between free and fixed nanoparticles (NPs)**, the latter being much less likely to raise concerns because of their immobilization (Subsection 1.1.1.1);

- reconfirmed the **serious concerns** that **unintentionally produced and released (waste) nanosized particles** created via conventional technology (e.g., airborne combustion by-products) continue to pose;

- highlighted that **some engineered nanoparticles** produced via nanotechnology may have the **potential to pose serious concerns**—the most significant ones relating to NTs within the next 3–5 years—and require further studies (Subsection 1.1.1.2);

- revealed that panel experts were of the unanimous opinion that **the adverse effects of NPs cannot be predicted (or derived) from the known toxicity of bulk material**;

- exposed the **limits** that preclude a complete risk assessment today, in particular, the present **scarcity of dose-response and exposure data** (Subsection 1.1.1.3);

- gave rise to twelve **recommendations** from the experts including developing a **nomenclature** for NPs, assigning **a new Chemical Abstract Service (CAS) Registry number to engineered NPs**, advancing **science**, developing **instruments**, developing risk assessment **methods**, promoting **good practices**, creating **institutions** to monitor nanotechnologies, establishing a **dialogue with the public and with industry**, developing guidelines and standards, revisiting existing **regulations** and, when appropriate, revising them, **containing** free engineered nanoparticles, **eliminating** whenever possible and otherwise **minimizing** the production and unintentional release of waste nanosized particles (Subsection 1.1.3); and

- led to the identification of policies **options** relating to R&D; norms, standards, guidelines, and recommendations; international cooperation; legislation; risk assessment; public understanding and shaping of nanotechnologies; international exchanges; privacy, security, and other aspects; and good practices (Subsection 1.2).

INTRODUCTION

The Health and Consumer Protection (SANCO) Directorate General (DG)[3] of the European Commission[4] convened a workshop in Brussels on 1–2 March 2004, inviting an international, interdisciplinary group of seventeen experts to examine the hazards, exposure, and risks to human and environmental health potentially associated with materials derived from nanotechnologies within the next 3–5 years.

Nanotechnologies refer to technologies of the very small, with dimensions in the range of nanometers. "*Nannos*" means "little old man", "dwarf" in Greek. Nano (n) refers to the SI unit prefix for 10^{-9} (= 0.000000001). Therefore, one nanometer (nm) is one billionth of a meter. As an illustration of the scale of interest, a chain of 5 to 10 atoms is about 1 nm long and a human hair, about 80 000 nm in diameter on average. Nanotechnologies exploit specific properties that arise from structuring matter at a length scale characterized by the interplay of classical physics and quantum mechanics. Nanotechnologies enable other technologies. As a result, they will mostly result in the production of intermediate goods. Because nanotechnologies connect disciplines as diverse as physics, chemistry, genetics, information and communication technologies (ICTs), and cognitive sciences, they offer the foundation of the so-called nano-bio-info-cogno (NBIC) "convergence". Technology analysts expect nanotechnologies to benefit computing, medicine, materials, and the environment. The US National Science Foundation (NSF) estimates the nano market at $700 billion by 2008 and more than $1 trillion by 2015.

This report comprises two parts. Part 1 consists of outcomes—a preliminary risk analysis as well as a general statement and a concept note on a hazard trigger algorithm as a potential prioritization tool for use by regulators. The two statements follow up on work initiated during the workshop by two working groups. The report presents a preliminary risk analysis by providing an overview of the workshop, listing a series of policy options identified during the discussions at the workshop, and summarizing recommendations from the experts formulated during the workshop. The report then presents options for future policies identified by Commission services on the basis of the expert recommendations.

DG SANCO asked the experts who accepted the invitation to the workshop to produce short position statements in preparation to the meeting. Therefore, Part 2 contains these contributions, which DG SANCO collected and circulated prior to 1 March 2004, as well as the terms of reference and the agenda of the "Mapping out Nano Risks" workshop.

[3] http://europa.eu.int/comm/dgs/health_consumer/index_en.htm
[4] http://europa.eu.int/comm/index_en.htm

PART 1: WORKSHOP OUTCOMES

1. PRELIMINARY RISK ANALYSIS

1.1. Overview

During the workshop hazards were identified (Subsection 1.1.1). With the objectives of the Commission and of DG SANCO in mind, the experts explored a series of policy options (Subsection 1.1.2) and formulated recommendations (Subsection 1.1.3).

1.1.1 Hazard identification

The "Mapping out Nano Risks" workshop organized by SANCO.C.07 in Brussels on 1–2 March 2004

- offered **clarifications** about nanotechnologies terminology, establishing, above all, the need to distinguish between free and fixed NPs, the latter being much less likely to raise concerns because of their immobilization (Subsection 1.1.1.1);

- reconfirmed the **serious concerns** that **unintentionally produced and released (waste) nanosized particles**[5] created via conventional technology (e.g., airborne combustion by-products) continue to pose;

- highlighted that **some engineered nanoparticles (NPs)** produced via nanotechnology may have the **potential to pose serious concerns**—the most significant ones relating to nanotechnologies within the next 3–5 years—and require further studies (Subsection 1.1.1.2);

- exposed the **limits** that preclude a complete risk assessment today, pointing out, in particular, the present scarcity of dose-response and exposure data (Subsection 1.1.1.3).

1.1.1.1 Clarifications

Although there is presently no international consensus on the definition of terms, the experts highlighted the need to establish a clear difference between the diverse foci of nanosciences and to discriminating between the different kinds of nanotechnologies (medical applications, information technologies, energy production and storage, materials science, manufacturing, instrumentation, food, water and environmental, security, etc.) and to agree on a common vocabulary. They made the following distinctions

- "**nanoparticles**" and "**nanotechnologies**": "Nanoparticles" are elements with dimensions less than 1 micrometer (< 0.000001 m); in practice, to provide a "ball park" figure, and without making this a formal threshold, designed and manufactured nanoparticles tend to have dimensions less than 100 nanometers (< 0.0000001 nm).

  "Nanotechnologies" refer to technological fields concerning the controlled manufacturing of functional nanosystems or the deliberate creation of nanostructures that results in the production of entities with at least one dimension on the order of the above-mentioned 100 nm length scale.

[5] The "Preliminary Risk Analysis" Section of this report distinguishes between unwanted waste and engineering products by using the phrase "nanosized particles" when referring to unwanted waste and "nanoparticles" or "NPs" when referring to engineering products.

This production therefore includes the fabrication of

- nanotextured surfaces (one dimension on the order of the 100 nm length scale);
- engineered nanotubes (two dimensions on the order of the 100 nm length scale);
- spherical engineered nanoparticles (three dimensions on the order of the 100 nm length scale);
- and, probably beyond the next 3–5 years, engineered nanomachines;

– "**engineered nanoparticles**" such as catalysts and "**unwanted or unintentionally produced and released nanosized particles**" such as soot particles produced as a by-product of combustion;

– "**free nanoparticles**" that can enter the human body, move in it, and bioaccumulate in some target organs or disperse in the environment and "**fixed nanoparticles**" that are embedded in a matrix and cannot move: Experts emphasized the importance of establishing this difference because it has a direct incidence on exposure;

– "**nanostructured materials**" that are constructed atom by atom or molecule by molecule and "**nanostructured surfaces**" that start with a substrate and use techniques such as photolithography, scanning probe methods, and soft lithography to create nano-sized features on the surface;

– "**coated engineered nanoparticles**" and "**uncoated engineered nanoparticles**": From a toxicological or ecotoxicological standpoint, coating is all important because coating would render an engineered nanoparticle inert as long as the coating lasts, which will depend on the characteristics of the particle, the properties of the coating, the environment of the nanoparticle, etc.;

– "**short-lived engineered nanoparticles**" and "**long-lived/durable engineered nanoparticles**": This difference will acquire special importance in the case of drug delivery devices; indeed, once the drug has been delivered and in order for the device not to become a hazard, it should be either excreted by the body or disintegrate once it has fulfilled its mission.

1.1.1.2 Concerns

1.1.1.1.1 Toxicology and ecotoxicology[6]

The workshop discussed the hazardous nature of some manufactured nanomaterials and products of nanotechnologies, in particular spherical engineered nanoparticles (NPs) and engineered nanotubes. The workshop reconfirmed the well-known health threats associate

[6] Note that there are several ongoing R&D activities in the field of health, safety and environmental aspects of nanotechnology at both EU and national level. Within the scope of the EU's 5th Framework Programmes, examples of ongoing projects include Nanopathology "The role of nano-particles in biomaterial-induced pathologies" (QLK4-CT-2001-00147); Nanoderm "Quality of skin as a barrier to ultra-fine particles" (QLK4-CT-2002-02678); Nanosafe "Risk assessment in production and use of nano-particles with development of preventive measures and practice codes" (G1MA-CT-2002-00020). Specific initiatives are also being launched as part of the 6th Framework Programmes together with the inclusion of such studies within Integrated Projects, where relevant. Additional information on these and other initiatives can be found under the Cordis web pages (www.cordis.lu/nanotechnology).

with unintentionally produced and released nanosized particles resulting, e.g., from fossil fuel combustion.

The workshop highlighted the potentially hazardous nature of some free, engineered NPs—the most significant one relating to nanotechnologies within the next 3–5 years. NPs are invisible to the unaided human eye. While surface coating also has to be taken into account, studies suggest that the biological activity of NPs—including potential adverse as well as beneficial effects—tends to increase as their size decreases.

NPs can enter the body via the digestive tract by ingestion, via the respiratory tract by inhalation, and possibly via the skin through direct exposure. Injection of NPs in the body for medical purposes could constitute another (chosen) exposure route. Once in the body, NPs can translocate to organs or tissues of the body distant from the portal of entry. Such translocation is facilitated by the propensity of NPs to enter cells, to cross cell membranes, and to move along the axons and dendrites that connect neurons. Notably, under certain conditions, some NP can cross the blood/brain barrier (cf., e.g., Kreuter et al., 2002)—which opens therapeutic possibilities as well as radically novel health concerns—and were found to enter the brain via the *Nervus olfactorius* after deposition on the olfactory mucosa of the nose following instillation or inhalation.

Durable, biopersistent NPs may also bioaccumulate in the body, in particular in the lungs, the brain (Bodian and Howe, 1941; De Lorenzo, 1970; G. Oberdörster et al., in press), and the liver (G. Oberdörster et al., 2002; Kreyling et al., 2003).

Some *in vivo* inhalation studies with rats employ nanosized particles in the form of polymer fumes. These studies show that estimated doses as low as 60 ng cause severe lung damage within hours, resulting in the death of most rats (G. Oberdörster et al., 1995). Even so, the nanosized particles used in these experiments should not be considered "engineered" and there is probably no justification to extrapolate these results obtained with rats to humans.

In the environment, natural enzymes can change the surface properties of NPs such as fullerenes—the C_{60} molecule consisting of 60 carbon atoms bonded in a nearly spherical configuration also nicknamed "buckyballs". Fullerenes can form aqueous suspended colloids (from the Greek *collodion* "resembling glue or jelly") termed nC_{60} and become re-suspended after evaporation. In their native form, the small size, colloidal characteristics, and reactive surfaces of colloidal fullerenes make them ideally suited to carry toxic material over long distances. Thus, potentially, colloidal fullerenes could pollute aquifers. (On this same topic of fullerenes in the environment, environmental toxicologist Eva Oberdörster of Southern Methodist University in Dallas, TX, USA, published an article shortly after the workshop took place. In her paper, E. Oberdörster (2004, p. 15) states that "manufactured nanomaterials can have adverse impacts on aquatic organisms, and it is possible that effects in fish may also predict potential effects in humans".) During the workshop, experts suggested that simple remediation treatments can oxidize the fullerene cage. These treatments should render the fullerene cage chemically inert as long as the treatment lasts, thereby reducing the overall potential biological activity of the treated nanoparticles.

1.1.1.1.2 Ethics

The main ethics issues associated with nanotechnologies at large, i.e., beyond nanoparticles, relate to **processes**, **procedures**, and **substance**.

First, an important element of the **process** is the public dialogue because the various stakeholders have different perspectives and the risks and benefits of nanotechnologies are difficult to estimate and compare. This dialogue has to be a two-way process—i.e., not telling the public what to do or think—if something has been learnt from the debate over genetically-modified (GM) food. Other stakeholders including scientists, industrialists, and public servants have to understand the concerns of the general public—what they are and why the public has these concerns—through this two way process. The political and social resistance to GM food is not only an information problem. Concerned stakeholders should set the agenda.

Second, relevant **procedures** include procedures for allocating money to research on nanotechnologies, for evaluating research proposals, and for monitoring the research itself. R&D on nanotechnologies covers a vast field, funded by both private and public funding agencies and carried out at national as well as international levels. These differences have to be taken into account when procedures are worked out.

Third and finally, some agreement on issues of **substance**, including ethical principles on which there is a fair amount of agreement in our culture, should be the starting point for the discussion. Such principles include human dignity (or integrity), autonomy, obligation not to harm and to do good, especially in the area of health care, as well as fairness and justice. Protection of values for civilian society is enshrined in a number of documents. In a European context, the Charter of fundamental rights of European citizens[7] and the proposed new constitution are particularly relevant. Our legacy to future generations is an important issue. A number of values and ethical concerns are all relevant in this context, in particular privacy, informed consent, and possible changes to the definition "humanity" because nanotechnologies enable "human enhancement" by establishing bridges with information and communication technology, biotechnology, and cognitive science. Notably, there can be tensions between values, e.g., competitiveness vs. health and safety at work. The competitiveness of European nanotechnologies is a legitimate interest but so are the concerns for health, safety, privacy, and the environment. One way of handling such tensions is to make them explicit and to promote a dialogue on the ranking order of different values at stake, which, as pointed out, while relevant, may clash. Different ranking orders imply different restrictions for the values at the bottom of the hierarchy. No value or normative principle has unlimited validity: values and principles will have to be balanced against each other and against other valid concerns and interests.

1.1.1.1.3 Security

Nanotechnologies have potential, like every other technology, to be used irresponsibly. However within the 3-5 years time frame, no marked influence on security is to be expected. Later, nanotechnologies could lead to better and smaller sensors that could increase security. The expert who provided an overview of the security issue to kick off the session stated that potential military uses of nanotechnologies should not be ignored. Rather, he argued that the dangerous applications (under several criteria) of nanotechnologies should be limited preventively. In the longer term, concerns could include nano/bio-terrorism, the misuse of unmanned devices incorporating nanotechnologies, and possible social effects regarding implants, either for performance enhancement or as a human state monitor, and their acceptance—the military acting as a technological and social precursor (Altmann, in press).

[7] http://www.europarl.eu.int/charter/default_en.htm

1.1.1.3 Limits

Present scientific knowledge about substances and devices produced with nanotechnologies precludes going further than identifying hazards—the first step of risk assessment—and providing some elements of hazard characterization—the second step of risk assessment. Indeed, there is little data on exposure and dose responses to engineered nanomaterials. Figure 1 provides a visual rendition of the three interconnected components of risk analysis—risk assessment, risk management, and risk communication—identified and defined by the so-called "Food Law". Figure 1 also highlights hazard identification as the first step in risk assessment.

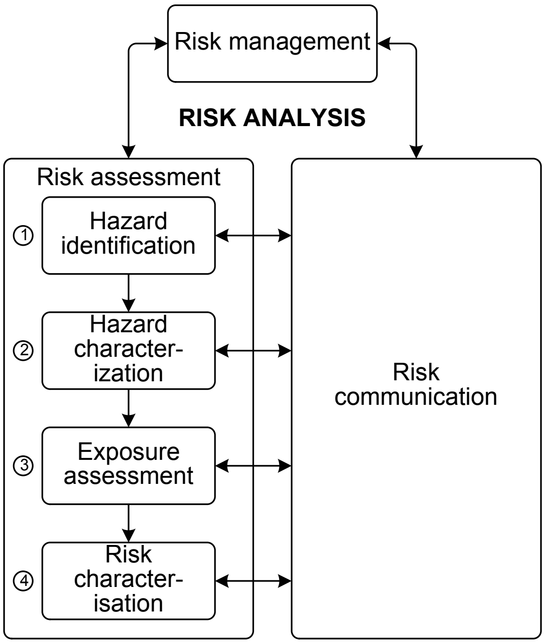

Figure 1: The three interconnected components of risk analysis—risk assessment, risk management, and risk communication—identified and defined by European Community (EC) Regulation No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety[8]

While exposure data are unavailable at present, one can safely predict that some degree of exposure will occur at least for segments of the population—in particular researchers and workers—and for the environment.

Concerning engineered nanoparticles, which raise the greatest concerns relating to nanotechnologies within the next 3–5 years, Figure 2 presents a paradigm for their risk assessment and risk management. (Also, note that Figure 2 can be mapped onto Figure 1.)

In closing, it should be pointed out that implementing Figures 1 and 2 could pose problems. Exposure assessment cannot presently be conduct since it is not known yet how pervasive nanoparticles will become, which may depend in part on how industry and society responds to the warnings issued by this (and similar) report(s). Therefore, there is an urgent need for exposure assessments and risk analyses for at least those settings where there might already be relevant exposure levels, that is, where nano-particles are produced. (Such assessments and analyses would also avoid having to set exposure levels for which no data is available to

[8] Official Journal of the European Union L, 031, 01/02/2002, pp. L31/0001–L31/0024.

"high" by default.) In addition, the quantitative determination of risk necessitates launching an incremental monitoring process for real-time technology assessment to go beyond our presently limited risk calculation capabilities.

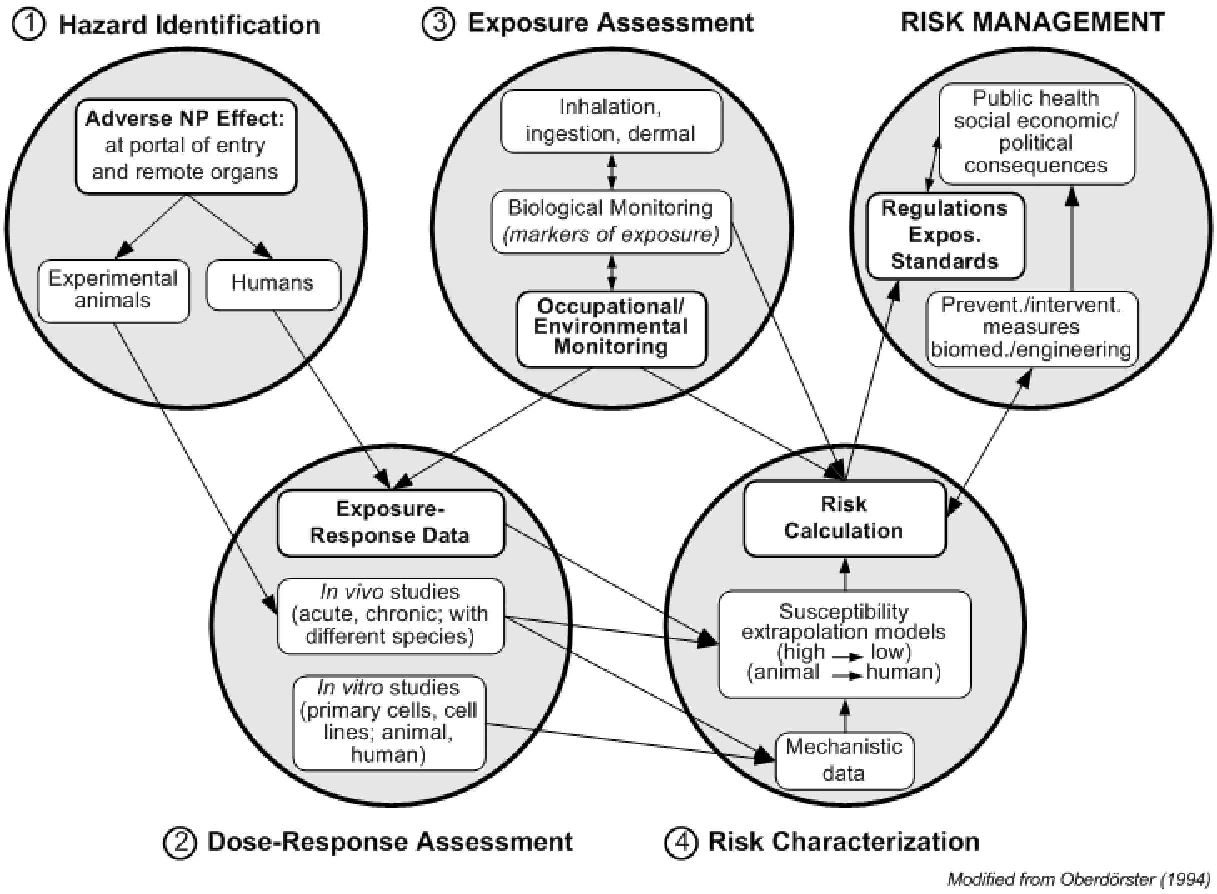

Figure 2: The four steps of risk assessment leading to risk management: a risk assessment and risk management paradigm for engineered nanoparticles (NPs) (modified from G. Oberdörster, 1994)

1.1.2 Policy options evoked during the meeting

Treaty Articles 152 and 153 respectively require that a "high level of human health protection […] be ensured in the definition and implementation of all Community policies and activities" and that "consumer protection requirements […] be taken into account in defining and implementing other Community policies and activities." To meet this high level of human health and consumer protection objective in mind, options identified during the meeting include

(1) adopting a "**laisser-faire**" attitude;

(2) decreeing a **moratorium** on nanotechnologies R&D and/or commercialization;

(3) relying on **voluntary measures**;

(4) launching a **comprehensive, in-depth regulatory process** specific to nanotechnologies;

(5) launching an **incremental process** using existing legislative structures—e.g., dangerous substances legislation, classification and labeling, cosmetic legislation, etc.—to the maximum, revisiting them, and, when appropriate only, amending them.

Concerning the latter, fifth option, would have to be supplemented by

- issuing **recommendations** (esp., regarding nomenclature and the classification of products of nanotechnologies, industrial production standards, *ex ante* evaluation and risk assessment guidelines, and guidelines concerning health and safety on the workplace);
- commissioning **studies** (esp. on exposure, dose-response, toxicology, and ecotoxicology);
- promoting **risk assessment** throughout the life cycle of a nanotechnology including conception, R&D, manufacturing, distribution, use, and disposal—not only at the macro, ecological level but also within the human body, as in the case of drug delivery devices;
- encouraging **actions** of existing institutions;
- supporting the setting up an **observatory of nanotechnologies** to monitor the scientific, technological, economic, and social development of nanotechnologies; and
- initiating a **minimalist, appropriate and proportionate regulatory intervention** (esp. revisiting thresholds in risk assessment protocols and for the registration and documentation of manufactured and imported products and making sure that regulations characterize engineered nanoproducts in a toxicologically and ecotoxicologically-relevant manner).

Option 1 ("laisser-faire") seems unwise because

- **scientific evidence highlights hazards** associated with nanotechnologies, even if evidence remains, at present, insufficient to complete the other three steps that follow "hazard identification" in the risk assessment sequence, namely, "hazard characterization"—including the determination of dose-responses, "exposure assessment", and "risk characterization"; and
- the Community intends to ensure a **high level of protection** of human, animal and plant health and of the environment.

Given the protection imperative, several experts argued in favor of following the "Precautionary Principle"[9] upheld in international treaties and agreements within the EU and

[9] Communication from the Commission on the precautionary principle (COM (2000)1 final). In order to avoid misunderstanding regarding the "Precautionary Principle" within the context of European Community legislation, it seems important to point out in particular that "the Commission stresses that the precautionary principle may only be invoked in the event of a potential risk and that it can never justify arbitrary decisions. Hence the precautionary principle may only be invoked when the three preliminary conditions are met—identification of potentially adverse effects, evaluation of the scientific data available and the extent of scientific uncertainty." (Art. 6 of COM (2000)1 final). Moreover, "as regards the measures resulting from use of the precautionary principle, they may take the form of a decision to act or not to act. The response depends on a political decision and is a function of the level of risk considered 'acceptable' by the society on which the risk is imposed." (Art. 7). Finally, "when action without awaiting further scientific information seems to be the appropriate response to the risk in application of the precautionary principle, a decision still has to be taken as to the nature of this action. Besides the adoption of legal instruments subject to review by the courts, there is a whole raft of measures for decision-makers to choose from (funding of a research

between the EU and EU Third Countries—such as World Trade Organization (WTO) agreements—because of

- the **hazards** identified thanks to available scientific evidence;

- the reliable albeit incomplete—rather than uncertain—nature of available **scientific evidence**; and

- **uncertainty** with respect to the estimation of the risk owing to incomplete scientific knowledge.

Option 2 (to decree a moratorium), which some experts to the workshop advocated for cosmetics, seems feasible only if partial, for targeted engineered nanomaterials, because nanotechnologies have already entered the market and their ubiquitous and horizontal nature makes them difficult to control.

Option 3 (voluntary measures) has little appeal because voluntary measures generally prove ineffective in terms of fulfilling their objective, in economic jargon, "to internalize externalities" and, in plain language, to ensure that "polluters pay", and prove less efficient than alternatives in economic terms as indicated, in particular, by OECD studies.

Option 4 (a comprehensive, in-depth regulatory process specific to nanotechnologies) seems difficult because of the scope. Nanotechnologies will require establishing links between strikingly different pieces of legislation but they do not seem to justify developing an entirely new legislative framework specifically because existing legislative frameworks already address a number of issues and can be adapted if the need arises. In any event, a comprehensive, in-depth regulatory process specific to nanotechnologies would only make sense if countries agreed to negotiate at the international level, which presently appears improbable.

Option 5 (an incremental process) appears as the only realistic option. In particular, it would help:

- **avoid preventable hazards and risks** relating to nanotechnologies, taking practical steps to avoid potential hazards and risks when scientific evidence is not complete and still being assembled;

- **set up a framework** within which (a) stakeholders including scientists, industrialists, and citizens can participate in shaping the course of nanotechnologies and (b) nanotechnologies can develop safely;

- **monitor the development** of nanotechnologies by acquiring and generating the relevant data, keeping the possibility of further regulation in the future open and making sure that such regulation would rest on more complete data and a deeper scientific understanding.

1.1.3 Twelve recommendations from experts at the workshop

Expert recommendation 1: Developing a **nomenclature** for intermediate and finished engineered nanomaterials. Experts stated that this nomenclature must be an international

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programme, informing the public as to the adverse effects of a product or procedure, etc.). Under no circumstances may the measure be selected on the basis of an arbitrary decision." (Art. 8).

effort with the full support of the International Union of Pure and Applied Chemistry[10] and the American Chemical Society[11].

Expert recommendation 2: Assigning a universally recognized Chemical Abstract Service (**CAS**) Registry **number**[12] to engineering NPs. A consensus emerged among the scientists and engineers in the group. Indeed, the experts made the point that engineered NPs should receive a CAS number because engineering NPs amounts to creating a new chemical. The toxicological and ecotoxicological properties and potential risks of engineered NPs cannot be predicted or derived from the known properties of the bulk material. Therefore, since an engineered NP is like a new chemical and since a new chemical is assigned a unique CAS number, an engineered NP should be given a CAS number upon its creation. Attributing a new, unique CAS number to engineered NPs would require toxicology testing and provide information for the Material Safety Data Sheet (MSDS)[13] for NP as well as for NP risk assessment and risk management. Clearly, this proposal would have to be thought through. For instance, while it should be appropriate for free NPs, it may not be appropriate for fixed or embedded NPs. As with the nomenclature, this must be an international effort.

Expert recommendation 3: Advancing **science** by collecting **data** and performing their **analysis**. Pressing needs include

- acquiring **exposure data**—especially where there might already be relevant exposure levels, i.e., where nano-particles are produced;
- characterizing **dose-response**;
- performing a wide range of **toxicological and ecotoxicological studies** (especially studies examining the translocation to brain and placenta, investigating nuclear effects, scrutinizing interactions with basic mechanisms of cell and organ homeostasis, looking at kinetics and bioaccumulation, and studies focusing on immune response);
- studying in particular the **persistence** of free nano-particles in the environment, their ability to take on a **colloidal form** in suspension and to be **re-suspended**, and their **transport** characteristics;
- adapting existing available **methods to screen NPs** and developing new ones;
- etc.

An example will make this generic "advancing science by collecting data and analyzing it" recommendation concrete. The 0.1% weight per weight criterion classifies a material as a carcinogen when it contains more than 0.1% of a classified carcinogen. It is important to know if this criterion is still valid with NPs because, as previously mentioned, animal tests suggest that most durable NPs are positive carcinogens.

Expert recommendation 4: Developing measurement **instruments**.

Expert recommendation 5: Developing standardized **risk assessment methods**.

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[10] http://www.iupac.org/dhtml_home.html
[11] http://www.chemistry.org/
[12] http://www.cas.org/
[13] Cf., e.g., http://www.ilo.org/public/english/protection/safework/cis/products/safetytm/msds.htm

Expert recommendation 6: Promoting **good practices** with respect to risk assessment, human and environmental health and safety (e.g., wearing appropriate masks and clothing), and security to all stakeholders including researchers and industrialists and to all countries including intermediate/developing countries.

Expert recommendation 7: Creating **institutions** to monitor the development of nanotechnologies, to establish an internationally recognized nomenclature for engineered nanomaterials, to promote the establishment of laboratory and industrial production standards, and to evaluate the appropriateness of further, nano-specific regulation in the future. In this respect, the experts mentioned

- a French initiative concerning the appropriateness of a scientific, economic, and social observatory of nanotechnologies (Roure, 2004);

- a US proposal by the Centre for Biological and Environmental Nanotechnology at Rice University in Houston, Texas, USA, to create an independent International Nanotechnology Council.

Expert recommendation 8: Establishing a dialog with **the public** and with **industry** to ensure that both take part in decisional processes.

The **public dialog with European citizens and consumers** has to be a two-way process, not telling the public what to do or think. Scientists, industrialists, and public servants need to understand the concerns of the general public. Conversely, the public should learn about the risks and benefits of nanotechnologies and participate fully in shaping nanotechnologies. In this respect, the views offered by the experts are in agreement with the principles established in the "Food Law" regarding the "three interconnected components of risk analysis—risk assessment, risk management, and risk communication" (Figure 1).

The **dialog with concerned industries** should be strengthened. This dialog should, in particular, help understand better the contrasted perspectives industries differing in terms of size (SMEs vs. large corporations), in terms of sector (computing, medical, materials, catalysts, etc.), in terms of markets, in terms of R&D intensity, etc., might have on nanotechnologies. It should also allow other stakeholders to benefit from their experience. Finally, this dialog with concerned industries should lead to the exchange of scientific information including toxicological and ecotoxicological data that they acquired or generated internally.

Expert recommendation 9: Developing **guidelines** and **standards**. The experts recommended the establishment of guidelines for

- the risk assessment of intermediate and finished manufactured nanomaterials and products of nanotechnologies;

- the production and handling of intermediate and finished manufactured nanomaterials and products of nanotechnologies; and

- the commercialization of intermediate and finished manufactured nanomaterials and products of nanotechnologies.

The experts stressed the need to involve public and private laboratories in the standardization of intermediate and finished engineered nanomaterials. In this respect, they pointed out that the question of guidelines and standards had been raised by the German Society for Chemical

Engineering and Biotechnology (DECHEMA)[14] and would be on the agenda by the recently created European Centre for Standardization (CEN) working group on nanotechnology[15].

Expert recommendation 10: Revisiting existing **regulations** and, when appropriate, revising them to ensure that they take the specificities of nanotechnologies into account. Specifically, regulations should guarantee that manufacturers and importers of intermediate and finished engineered nanomaterials and nanoproducts register their product and document physical, chemical, toxicological, and ecotoxicological properties.

Expert recommendation 11: Maximizing the **containment** of free engineered nanoparticles until their possible hazards have been identified and addressed or until they have been rendered innocuous, e.g., by fixing the NPs in a matrix—in which case they cease to be *free* engineered nanoparticles.

Expert recommendation 12: Striving for the **elimination** whenever possible and otherwise the **minimization** of the production and unintentional release of nanosized particles

1.2. Options for future policies identified by the workshop secretariat

Options for future policies include

- **R&D:** Our present, incomplete state-of-knowledge demands more toxicological and ecotoxicological and the gathering of data on exposure. Consequently, the generation of new risk assessment data and the possible use and re-use of existing data (esp. on exposure, dose-response, and toxicology) should be stimulated.

- **International norms (including a nomenclature for nanoparticles), standards, guidelines, and recommendations:** International norms (including a nomenclature for nanoparticles), standards, guidelines, and recommendations would facilitate scientific exchanges, use of existing data, and intercomparisons of experimental results, strengthen consumer and environmental protection, and improve market transparency and facilitate trade. In addition, in view of the global nature of nanotechnologies, international norms (including a nomenclature for nanoparticles), standards, guidelines, and recommendations would ensure that any future human and environmental health and safety proposals comply with the international obligations of the European Union.[16]

- **International cooperation and initiatives:** International cooperation and initiatives aimed at pooling health related information and monitoring the development of nanotechnologies should be encouraged. Concerning this latter point, the Commission should foster the establishment of an **international observatory of nanotechnologies** to monitor the development of this new enabling technology, in particular by supporting international initiatives involving EU Member State and EU Third Countries.

- **Legislation:** Maximum use should be made of existing legislation. However, the particular nature and unique characteristics of nanotechnologies require the re-

[14] http://www.dechema.de/
[15] See http://www.cenorm.be/ for further information (CEN Resolution BT C005/2004)
[16] International standards, guidelines or recommendations are required by WTO under the agreement on Sanitary and Phytosanitary Measures (SPS) to justify national sanitary or phytosanitary measures that could set non-tariff barriers to trade (Article 3 "Harmonization", Paragraph 2). Similar requirements exist in the WTO agreement on Technical Barriers to Trade (TBT).

examination of existing legislation and, if needed, its revision. In particular, the visibility of nanotechnologies to the human and environmental health and safety regulatory "eye" should be guaranteed. A proactive approach should be taken. Advancing knowledge about science and society through national and Community R&D as well as international collaborations with EU Third Countries should play a key role in furthering action in this direction. Specifically, there is case for

- **reexamining and, if justified, lowering the current 1 ton per annum threshold** in existing national (cf., e.g., UK) and Community (cf., REACH) regulatory frameworks on the registration and documentation of manufactured and imported, intermediate and finished engineered nanomaterials and products of nanotechnologies—in particular engineered nanoparticles, engineered nanotubes, and engineered nanofibers—because the manufacturing and imports of given nanoproducts may represent a very low mass per annum and because, as a rule of thumb and in the absence of a coating that would make the surface inert, toxicity of nanoparticles tends to increase as size decreases;

- **examining thresholds and methods in risk assessment guidelines** such as the 0.1% weight per weight criterion classifying a material as a carcinogen when it contains more than 0.1% of a classified carcinogen;

- **making the legal characterization of nanotechnologies toxicologically and ecotoxicologically-relevant** by complementing characterizations in units of mass with other characteristics including numbers, surface area, size, chemical reactivity, and ability to disperse because, for engineered nanoproducts, surface and reactivity (and possibly other characteristics) matter more than mass, which constitutes the characterization standard generally used for bulk substances;

- **labeling products of nanotechnology and making them traceable** in the Single Market.

– **Risk assessment:** Assessment of risk to human health, the environment, consumers and workers should be integrated at all stages of the life cycle of the technology including conception, R&D, manufacturing, distribution, use, and disposal. Notably, disposal should not only be paid attention to at the macro, ecological level but also within the human body, as in the case of drug delivery devices.

– **Public understanding and shaping of nanotechnologies:** Among the various avenues to explore, the Commission should investigate how to open a dialog with EU consumers to promote informed judgment on nanotechnology based on impartial information and engage the public into participating in shaping nanotechnologies. This could include using known and tried techniques such as organizing public participation fora that simulate a microcosm of what one could expect in society as a whole. Such fora also provide an efficient means to communicate about risks.

– **Forthcoming international exchanges on nanotechnologies:** The Commission should ensure that forthcoming international exchanges on nanotechnologies take EU national and Community human and environmental health and safety policies into account and promote in-house risk assessment.

– **Privacy, security, and other aspects beyond nanoparticles:** The Commission should take a proactive stance on privacy, security, and other aspects beyond nanoparticles.

- **Good practices:** The Commission should promote good practices to all stakeholders including researchers and industrialists and to all nations including intermediate/developing countries, specifically with the definition of an international "code of good conduct", steering nanotechnologies towards a responsible development.

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2. General Statement on Nanotechnologies *by Joseph A. Put, Jürgen Altmann, Alexander Huw Arnall, Lütz Mädler, Françoise Roure, and Mark E. Welland*

1. "Nanotechnology" is in fact a wave of technologies that exploit specific properties that arise from structuring of matter at the nano length scale.

2. Nanotechnologies are enabling technologies e.g. for further development of information technology (miniaturization) and further development of biotechnology (genetics, genomics, proteomics, ...)

3. When addressing nanostructures, one has to distinguish between nanostructures fixed in matter and nanoparticles. Nanoparticles can be freely moving or bound in a matrix (Figure 1).

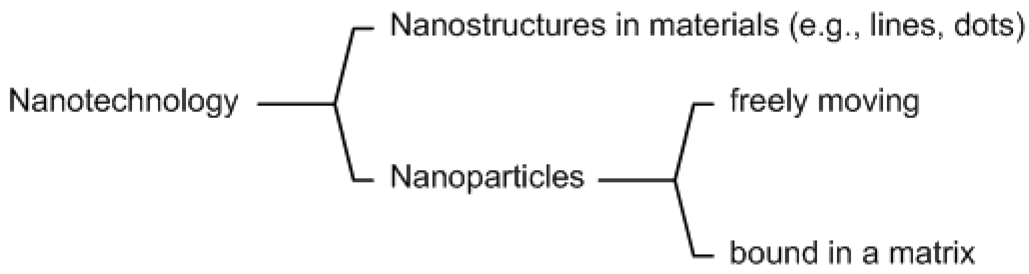

Figure 1: Distinctions to establish in the field of nanotechnology

Furthermore, nanostructures can be nanosized in just 1 dimension (surfaces) or in 2 dimensions (nanotubes) or in 3 dimensions (nanoparticles).

4. Biological nanostructures are abundant in nature. In this workshop we are only concerned with artificial nanostructures. With respect to risks, the focus is on freely moving nanoparticles (at least nanosized in 2 dimensions: tubes and particles).

5. One can further distinguish between 'engineered' nanoparticles, deliberately produced for certain applications, and 'unwanted, incidental, waste' nanoparticles.

   - Waste particles are unwanted side products of certain processes (e.g. combustion).
   - Engineered nanoparticles are especially created for certain functions.
   - In both cases more detailed studies are necessary to fully understand the risks.

6. Matter organized in nanosized structures can show properties that differ substantially from those of matter in bulk or organized in larger particles as well as from those of single molecules.

   These properties can be surface related (e.g., catalytic) or particle related (e.g., optical, magnetic, delivery, …). These nano-specific properties can be beneficial but they can create specific risks.

7. Whenever nanostructuring is present in a material, in view of the nanospecific properties, analysis has to be done:

   - o regarding mobility and ability to migrate into the environment of the nanostructures, and this during the whole life cycle
   - o regarding possible exposure of humans (at the workplace, using products, or in the environment)
   - o regarding the effect on humans and the environment

8. It will be necessary to establish standardized approaches to characterization and risk assessment of nanostructures.

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3. CONCEPT NOTE ON A HAZARD TRIGGER ALGORITHM AS A POTENTIAL PRIORITIZATION TOOL FOR USE BY REGULATORS *by C. Vyvyan Howard and Wim de Jong*

3.1. Preamble

The nanotechnology industry is faced with a considerable body of peer reviewed scientific literature, which indicates that particles of less than 100 nm tend to be highly mobile, both within the body and in the environment. There are also strong indications that, for insoluble particles, that decreasing particle size is associated with increasing toxicity. In the absence of scientific evidence to the contrary, precaution would suggest that an assumption of high mobility and toxicity should be the default.

Regulators are faced with a plethora of developments, a number of them already leading to the bulk manufacture of free nanoparticles. This activity is currently largely unregulated. Regulators need a tool whereby they can prioritise products into categories of urgency for attention. In view of the fact that exposure assessments are lacking, a full risk assessment is not feasible in most cases. However a ranking can be obtained by the use of a hazard trigger algorithm, such as that illustrated below. This will identify data gaps and guide the industry towards a systematic procedure for hazard characterisation of nanopowders and assist decision makers in prioritising their work.

It must be emphasised that this paper is a concept note. The algorithm described in the accompanying flow diagram is not a finalised methodology. Indeed it has been assembled after one brief meeting between a small number of interested experts and many of the trigger values provided are starting points for an academic discussion leading to a workable methodology. Many of the hazard triggers mentioned have no values attached. Each of these hazard triggers could have a sub algorithm associated with it, as a result of further discussions.

Additional considerations

Regarding the purpose of the flow chart, if it is applied as a preliminary hazard assessment by regulators, many of the hazard trigger values will be unknown. The priority ranking should therefore consider how to deal with unknown trigger values. A precautionary stance would be to assume that any unknown value is equivalent to a positive hazard trip, leading to a high priority categorisation. Subsequent provision of information to fill in data gaps can then lead to a lowering of the category. This will have the positive benefit of guiding the developer to conduct relevant hazard assessments.

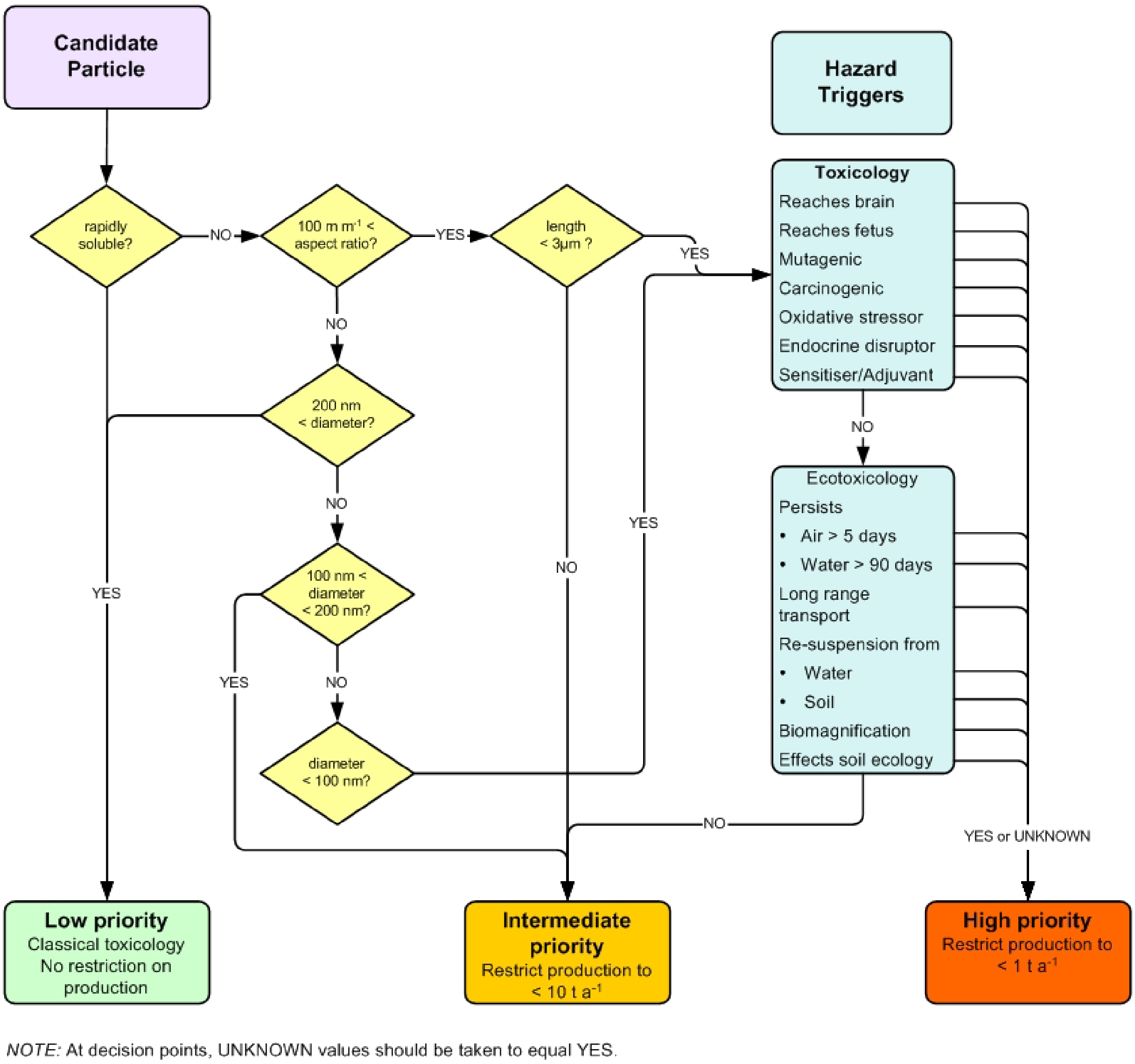
Notes on the hazard trigger flow diagram.

Aspect ratio: refers to the ratio of length to breadth of a particle. It is a way of classifying particles as fibrous.

The cut off of particle size at 200 nm is based upon the paper by Donalson et al (2000). *Phil. Trans. R. Soc. Lond. A* **358**:2741-2749.

The values of all the hazard triggers would have to be decided by an expert committee and would involve a review of the current literature and identification of data gaps. However, for many hazards including carcinogenicity, mutagenicity and reprotoxicity there are quantitative classification systems in place. These could be adapted for use in such a scheme as that proposed below.

When there are data gaps, the precautionary stance would be to assume that they are positive hazard trigger events until shown to the contrary.



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PART 2: DOCUMENTS PRODUCED AND CIRCULATED PRIOR TO 1 MARCH 2004

1. COLLECTION OF SHORT CONTRIBUTIONS BY THE INVITED EXPERTS

Security Problems from Nanotechnology

Jürgen Altmann

(16 February 2004, , corrected 18 April 2004, for EC SANCO Workshop “Mapping out Nano Risks” 1–2 March 2004)

With its prospects for fundamental changes in many areas, nanotechnology (NT) has a potential for great benefits and large risks. Many of these risks concern accidents and other unintended effects. By intention, NT could be abused to invade into privacy, damage property, injure or kill people, damage the environment. Actors could be criminals including terrorists, enterprises, government agencies, the armed forces. The military is special in that it by definition prepares destructive applications of new technology that civilian society will want to strictly prohibit. A different danger is a sliding change in what constitutes a human, brought about by advances in biotechnology including genetics and implants, brain research, artificial intelligence and robotics. Here, the military might proceed too fast, undermining a broad debate in civilian-society on what kinds of body manipulation or artificial/hybrid entities should be allowed.

Whereas in public funding of NT research and development (R&D) at large, the USA, Europe, Japan and the rest of the industrialised world are approximately on a par ($650-800 million each in 2003), in military NT R&D the USA leads by far: in the U.S. National NT Initiative (NNI) around one quarter goes to the Department of Defense – more than $ 200 million in 2003, probably far more than all other countries combined. National-security goals for nano, bio, info, cogno (NBIC) convergence include miniature sensors, high-speed processing, wide-bandwidth communication; uninhabited combat vehicles; improved virtual-reality training; enhancement of human performance and a brain-machine interface. Whereas for humans the latter is to be non-invasive for the time being, future visions include ‘artificial systems within the soldier’.

NT could be applied in all areas of the armed forces: smaller but faster electronics and computers, augmented by new levels of artificial intelligence, in small components as well as large battle-management and strategy-planning systems; networks of numerous cheap small sensors; lighter, stronger, more heat-resistant materials in engines and vehicles, conventional or new types of weapons; variable camouflage; battle suits that protect against bullets, chemical and biological agents, sense health and compress wounds; precision guidance even in small munitions; large and small autonomous robots with and without weapons function; small satellites for inspection or attack in outer space; body implants for sensing and manipulating biochemistry or for contacts to nerves, muscles and the brain; new chemical and biological warfare (CBW) agents for easier entry into the body, organs and cells that act selectively on certain gene or protein patterns; sensors for CBW agents and material for their neutralisation. Most of these could arrive in 10-20 years.

While some military uses could be beneficial and others will be too close to civilian developments, there are several that raise great concerns in terms of arms control and the law of warfare, military stability and non-proliferation, or the protection of humans, the environment and a democratic society. The following are the most dangerous:

- NT-enabled new **biological or chemical warfare agents** (selective, switch on/off, reliable inoculation): could undermine Biological Weapons Convention, Chemical Weapons Convention; use for criminal/terrorist attacks;

- **Autonomous fighting vehicles**: endanger international law of warfare if producing superfluous injury or unable to recognise non-combatants or combatants *hors de combat*, destabilise military situation;

- **Small satellites**: destabilisation in space with consequences on earth;

- Ubiquitous **sensor nets** and **micro-robot weapons**: destabilisation – attacker advantage, strong pressures for fast action; criminal attacks, in particular terrorism; invasion of privacy;

- **Implanted systems** and other body manipulation: military R&D and application could create facts before thorough societal debate.

In general, one has to fear arms races in many areas, even between partners, and proliferation of military systems, technologies, materials and knowledge to crisis regions as well as criminals.

To prevent the dangers from such military NT uses, general as well as specific preventive-arms-control measures are required, e.g. augmenting the Biological Weapons Convention (BWC) by a Verification Protocol, a general ban on space weapons, a prohibition on robotic weapons, a ban on small robots (with narrowly circumscribed exceptions for important civilian uses such as exploration of shattered buildings), a moratorium on non-medical body implants. These measures should be co-ordinated with regulation in the civilian sector. Verification could mostly rely on inspections of military installations and R&D laboratories, with intrusiveness at least as foreseen in the draft BWC Verification Protocol. For confidence building, national NT programmes should be transparent and co-operate with each other.

Molecular NT (characterised by autonomous production by universal molecular assemblers, self-replicating nano-robots, maybe also (super-)human artificial intelligence, improved humans without illnesses and ageing) would represent nightmares with respect to stability, arms races, threats to humans, the environment and society. Its feasibility is unclear. The most urgent task here is a reliable study of the practicability and potential time frames of introduction, then followed by detailed investigations about preventive limits on the national and international levels.

In the medium and long term, containing the risks of NT and NBIC on the international level will need legislation, investigation and criminal prosecution on a similar level as within societies. One can have doubts whether that will be possible in an international system in which the security of states is still seen as dependent on the threat of military force.

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Moving the nanoscience and technology (NST) debate forwards: Short-term impacts, long-term uncertainty and the social constitution

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(Excerpt from an article in *Technology in Society*, in press)

Nanoscience and technology (NST) are widely cited to be the defining technology for the 21st century. The most common definition regards NST as "the ability to do things – measure, see, predict and make – on the scale of atoms and molecules and exploit the novel properties found at that scale" (DTI, 2002). Traditionally, this scale is defined as being between 0.1 and 100 nanometres (nm), 1 nm being one-thousandth of a micron (micrometre), which is, in turn, one-thousandth of a millimetre (mm).

It is important to consider NST now because its emergence is anticipated to "affect almost every aspect of our lives" during the coming decades (DTI, 2002). This is because NST is said to be *disruptive*, *enabling* and *interdisciplinary*. *Disruptive* technologies are those that displace older technologies and enable radically new generations of existing products and processes to take over. As an *enabling* technology, NST, like electricity, the internal combustion engine, or the Internet (National Research Council, 1999), will have a broad and often unanticipated impact on society. Unlike these examples however, NST is considered harder to 'pin down' – it is a general capability that impacts on many scientific disciplines (Holister, 2002). This *interdisciplinary* feature of NST results in a driving force for innovation and discovery because it brings together scientists from traditionally separate academic groups.

Within recent years the debate surrounding NST has become increasingly public, involving civil society, non-governmental organisations and the media. Much of this interest stems from two competing long-term visions of a NST-enabled future. At one extreme, nano-optimists promise nothing less than complete control over the physical structure of matter – the same kind of control over the molecular and structural makeup of physical objects that a word processor provides over the form and content of text (Reynolds, 2002). For example, macrostructures will simply be grown from their smallest constituent components: an 'anything box' will take a molecular seed containing instructions for building a product and use tiny nano-bots or molecular machines to build it atom by atom (Miller, 2002). Inevitably, much excitement has followed these proclamations, largely because the associated possibilities seem virtually endless. Nano-optimists look forward to a society in which the costs of goods and services are massively reduced, computers operate at rates billions of times faster than today, and revolutions in medical technology have led to a virtual end to illness, aging and death, to name a few examples. In contrast, nano-pessimists see far more sinister implications. For some, NST will inevitably lead to severe exacerbation of present-day global inequalities and reinforcement of existing structures of societal control. Others foresee a world in which self-replicating 'nano-bots' have taken over the world; they consume its resources and render feebler carbon-based organisms such as our selves obsolete or even extinct. Both nano-optimism and nano-pessimism have received much popular attention and are consequently having considerable influence on present-day debate; present signs indicate that the public profiles of these opposing views are set to heighten within the coming years (Woods *et al*, 2003).

One consequence of these radical visions is that the NST industry has become plagued by both hype and cynicism. For example, many market analysts believe that it is too soon to produce reliable figures for the future NST global market share – it is simply too early to say where and when markets and applications will arrive (DTI, 2002). And yet at the same time nano-optimists have been charged with hyping figures to "reckless" and "impossibly high expectations for…economic benefits" (The Economist, 2002). Most strikingly, the Nanoscale Science, Engineering and Technology (NSET) subcommittee of the US National Science and Technology Council (NSTC) predicted in 2001 that the total market for nanotech products and services will reach US$1 trillion by 2015, although the evidence base for this figure is unclear. These sentiments are echoed by Roy (2002), a materials scientist, who describes the term 'nano' as a "halo regime" – a term that is sold to budget managers in order to increase funding. He concludes that "the [term] should be new, different, euphonious, and connected somehow, however tenuously, to science".

At present, there is a general understanding amongst industry that the level of hype surrounding NST has, to some extent, damaged investment potential. For example, Schultz (2002) advocates the need for nanotech supporters to dampen unquestioning enthusiasm for NST. This is because, without discussion of the potential pitfalls, future research could be subjected to such extreme pressure that funding is jeopardised and research progress is slowed, perhaps halted altogether in some cases.

Cynicism is also considered damaging to the arguments of nano-pessimists. For example, self-replication is probably the earliest-recognised and best-known potential danger of NST. This centres upon the idea that self-replicating nano-robots capable of functioning autonomously in the natural environment could quickly convert that natural environment (i.e. 'biomass') into replicas of themselves (i.e. 'nanomass') on a global basis. Such a scenario is usually referred to as the 'grey-goo' problem but is perhaps more properly termed 'global ecophagy' (Freitas, 2000). However, not only do such concerns deflect attention from short and medium-term issues that demand more immediate attention, but they are also easy to dismiss as "fanciful" (Adam, 2003). Consider this rebuttal to grey-goo by Freitas (2000):

"The replicators easiest to build will be inflexible machines, like automobiles or industrial robots…To build a runaway replicator that could operate in the wild would be like building a car that could go off-road and fuel itself from tree sap. With enough work, this should be possible, but it will hardly happen by accident. Without replication, accidents would be like those of industry today: locally harmful, but not catastrophic to the biosphere."

In fact NST is a complex and wide-ranging discipline, the future of which is characterised by uncertainty. There is a need, then, to move beyond current rhetoric:

instead of debating the speculative, long-term technical possibilities and ramifications of NST, it is necessary to broaden the discussion by focussing on present-day developments and asking "what are the real issues at stake here?" And "what do these imply for the long-term future of NST?" This means more than simply extrapolating current trends. Rather, the contemporary political and social processes surrounding the introduction of technologies must be taken as central to their development pathway. Only then can a serious discussion of the future costs and benefits of NST begin to emerge.

The "social constitution" of an emerging technology (Grove-White *et al*, 2000) is crucial. This social constitution is constructed from the answers to questions such as:

- Who is in control?
- Where can I get information that I trust?
- On what terms is the technology being introduced?
- What risks apply, with what certainty, and to whom?
- Where do the benefits fall?
- Do the risks and benefits fall to the same people? (E.g. mobile phones are popular while mobile phone masts are not)
- Who takes responsibility for resulting problems?

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A need for integrated testing of products in Nanotechnology

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Nanomedicine, develops devices and vehicles in micro- and nano-scale to be administered into the systemic circulation such as to carry drugs to specific sites for therapeutic purposes (Duncan, 2003). On the other hand, epidemiology and toxicology have shown that inhaled ultrafine particles are a risk factor to a variety of health outcomes in diseased subjects (Peters et al, 1997; Pope et al, 2002), as well as to cause lung cancer after inhalation in animal models (Borm et al, 2004). It is anticipated that before a wide introduction of Nanoparticles in society, and specifically in biomedical applications, the sustainability and side-effects should receive considerable attention (Colvin, 2003; Buxton et al, 2003). The paradox is that those considered to benefit mostly from new therapeutic approaches of Nanomedicine (Buxton et al, 2003) are also those that are risk when considering hazards of inhaled particles (Borm & Kreyling, 2004).

A large body of toxicological research is now directed to study the mechanisms how ultrafine particles can exert such acute and chronic effects associated with inhalation exposure, even though their chemical inventory is considered almost inert when used in a larger size range. Current theories about the mechanism of action include the (i) the reactivity of the nano-surface, (ii) the translocation of particles to systemic circulation, and (iii) the ability of ultrafine particles to cause a systemic response through pro-inflammatory mediators and acute-phase proteins (among systemic response autonomic deregulation, plaque destabilisation, and altered blood coagulation are being investigated as the major intermediates of nanoparticles when causing death in individuals with cardiovascular diseases).

Collaboration between experts in Nanotechnology on the one hand, and experts in toxicology and cell biology on the other hand is needed to map out potential "Nanorisks". It is anticipated that such a collaboration will (i) give insights in basic aspects of nanosurface chemistry and biological responses with major biological mechanisms involved in the organism's normal function (ii) develop and provide various tools and methods to test nanoparticle products (iii) thus deliver sustainable nanotechnology products in the future (iv) determine nanoparticle release and exposures during production and applications, and (v) thereby assess the risk associated with the use of new nanoparticle products in a policy-relevant way.

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<u>Engineered anomaterials and risks: One perspective</u>
Vicki L. Colvin

Control over matter at the nanometer scale provides a powerful tool for advancing industrial sectors ranging from electronics to pharmaceuticals. The sheer breadth of the term, 'nanotechnology', allows scientists of every discipline to envision the far-reaching impact of nanoscale science in their own fields. In the midst of this heady enthusiasm critics of nanotechnology have emerged. Their concerns about the environmental and health effects of engineered nanomaterials have generated questions about whether the pace of nanotechnology has outstripped our understanding of its risks.

This question must be considered within the context of the nanotechnology industry; until there are pressing applications entering the market nanotechnology's potential impact on the public will be minimal. Unfortunately, it is challenging to assess the status of nanomaterials in commerce. In the United States no manufacturing company has yet triggered the regulatory process for these systems which suggests their applications are not widespread. Still, some industries have for years used colloidal pigments and additives in products; while these may be nanostructured in some fashion, it is no clear whether they should be considered separately from the higher performance nanomaterials which drive current nanotechnology. What is known about these higher technology applications is that they are not yet commercialized. However, as the industry develops, nanotechnologists and regulators alike have a window of opportunity to evaluate the potential risks before products are produced. Such time will allow for an effective and measured policy response, and may encourage other emerging technology areas to consider risk assessment questions well before specific products are defined.

The relative youth of this industry is an important advantage right now, as the technical data does not provide a complete answer to the questions of nanomaterial risk. Currently, the toxicological studies of engineered nanomaterials can be counted on one hand, and more ambitious risk assessments are at least several years away. However, government funding in the area is steadily increasing, and some industries may begin supporting such research as well. If the technical community works together, in collaborative programs and with much critical discussion of the appropriate methods and strategies for this area, then when it is time to consider regulation, for example, policymakers won't have to act on the basis of only one or two studies of nanomaterial risks, but can count on a broader scientific consensus for guidance.

Because of the lack of specific data it is challenging to comment on engineered nanomaterial 'risk'; however, based on my experiences with these materials I approach them right now with a watchful confidence. One one hand, engineered nanomaterials are not 'new' substances. They are the products of chemical processes which now focus on control over nanoscale structures as opposed to molecules. The ruby red color of stained glass in Medieval churches comes from a nanoscale gold pigment, for example, and non-anthropogenic nanoparticles are widely found natural systems. These materials obey the same basic chemical laws as any other manmade substance, and will be amenable to conventional risk assessment and toxicological studies. In other words, they are not unfamiliar substances to chemists, toxicologists and environmental engineers.

My familiarity is tempered with the recognition that engineered nanomaterials do possess features distinctive from their bulk and molecular counterparts. It seems reasonable that the special chemical and physical properties of nanomaterials may also lead to unique biological properties. Academic research in this area is designed to test this hypothesis, and I am confident that over next few years a general understanding of these issues should develop. In the meantime, society should adopt a watchful confidence to permit research in the area to proceed unimpeded so that an accurate picture of risk can emerge when products are being considered for distribution.

As we begin to consider risks of nanotechnology, it is quite natural to draw analogies with other technologies, particularly biotechnology. The comparison is quite instructive, particularly because of the differences between these two areas. In biotechnology engineered genes are the enabling component for a specific product; genes can be named precisely, detected in small amounts, and manufactured without any need for large-scale infrastructure. Biotechnology products are thus easy to standardize, and the concrete assessments of the genetic 'fingerprints' of products enables intellectual property to be controlled and protected.

In contrast, nanotechnology is enabled by complex set of materials. Unlike the DNA in engineered genes, engineered nanomaterials encompass a broad range of material types, forms and shapes. These substances have no systematic nomenclature, and are typically challenging to manufacture with high quality. Often nanomaterial samples consist of a range of material sizes, and thus are more like a complex mixture than a pure substance. Most critically, both for regulatory issues as well as patent protection, nanomaterials are not easily detected or standardized with tabletop instruments. As the industry matures many of these features will necessarily be overcome; however, it is unlikely that nanotechnologies will ever be reduced to their nanomaterial 'fingerprint' in the way biotechnologies are.

While nanomaterial fingerprinting is not necessary for this industry to develop, the current approaches to nomenclature and standardization will severely hamper both risk assessment as well as communication efforts in this area. As it now stands, there is no agreed upon standard for nanomaterial quality or purity. It is not surprising that the recent toxicological studies of single-walled carbon nanotubes, for example, are difficult to interpret because of the varying and ill-defined composition of the samples. Additionally, we have no formal way of distinguishing among different nanomaterial classes in the technical community. With such imprecision in language, the carbon nanoparticles generated in the burning of diesel fuel are indistinguishable in the media from the engineered carbon nanostructures developed for nanotechnology. These housekeeping issues may not seem glamorous, but their completion is one of the most important needs in ensuring an accurate and effective management of the risks of engineered nanomaterials.

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Mapping Out Nano Risks. Some considerations on possible toxicity

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Meeting March 2004

Nanotechnology is an emerging science which has attracted much interest lately. This recent interest is not surprising as now we have not only the technology of producing particles at a nanoscale, but also the tools for identifying and studying these structures with powerful electronmicroscopes. Now we know that these particles exist, what follows is the question, whether they are harmful for man or not.

It is known that man has been exposed to ultrafine particles (nanoparticles) for some time due to the air pollution in the industrialized world. Also biological particles can exist with very small dimensions. Studies to particulate toxicity have so far been mainly limited to so called PM10 and/or PM2.5 particles, meaning airborne particles with a size below 10 micrometer or 2.5 micrometer, respectively. For the adverse effects found in inhalation toxicity studies with PM10 and PM2.5 some suggestions are made that the origin of the toxic effects might not be due to particles in the size range of PM10-PM2.5, but due to particles much smaller which are still part of the airborne fractions investigated. The toxicity might be due to particles at nanolevel with a size below 0.1 micrometer.

As we now have the technological means for producing materials/compounds at nanoscale, we also should consider how to address possible safety issues involved. For the moment it is still unclear whether there is a safety issue. The knowledge of toxic effects of nanoparticles is mainly coming from inhalation studies. In these studies also the air pollution itself (chemical composition) may be a (major?) contributor to the final effect detected.

However, there are some suggestions that nanoparticles may behave differently than larger particles of the same material. For ultrafine particles it was found that they have a different biological behaviour than the larger particles. Nanoparticles are much smaller than cells. How cells deal or whether they can deal with pure nanoparticle preparartions is not (yet) known. Especially the enormous increase in surface area obtained after micronizing the particles of a material might have a great impact. When we consider the migration of possible residues of toxic substances used during production, the increase in surface area would probably also result in an increase of migration/release of these residues form the particle. When such a product would be administered to man, this would result in a relative high exposure compared to a product with large particles, and thus a smaller overall surface area.

In view of the uncertainties with materials/compounds at nanolevel, research should be focused at identifying the risks involved with nanotechnology.

Some questions to be answered are:

Do pure homogeneous nanoparticle preparations have a different biological activity compared to larger particles of the same composition?

Is the biological behaviour (toxicity?) dependent on the size or size and chemical composition?

How do cells handle nanoparticles? Can cells degrade/metabolize nanoparticles?

How is the uptake and migration of nanoparticles in the body?

Is there accumulation at certain body sites?

What is the effect of chronic exposition to nanoparticles?

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Le problème théologico-scientifique et la responsabilité de la science[17]
Jean-Pierre Dupuy

1. La prétendue neutralité de la science

Tous ceux qui réfléchissent à la dimension politique des choix scientifiques se doivent d'avoir lu les deux conférences données par Max Weber en plein cœur de ce désastre que fut la première guerre mondiale et dans l'immédiat après-guerre et réunies en français sous le titre *Le savant et le politique*[18]. On retient en général de la première, *Wissenschaft als Beruf* – "Le métier et la vocation de savant" -, datée de 1917, le thème de la "neutralité axiologique": la science est "libre de valeurs" et, dans la "guerre des dieux" (c'est-à-dire la lutte inexpiable et éternelle qui oppose les différentes valeurs entre lesquelles nous sommes écartelés), la science n'a tout simplement rien à dire. La seconde conférence, donnée deux ans plus tard sous le titre *Politik als Beruf* – "Le métier et la vocation d'homme politique" -, est restée célèbre pour contraster l'éthique de la responsabilité, qui seule convient à ceux qui ont en charge le destin collectif, et l'éthique de conviction, qui n'a de pertinence qu'au plan personnel. Les rassemblant et les simplifiant outrageusement, on tire de ces deux conférences la leçon que la science est neutre et que c'est au politique de décider.

Si tant est que Weber ait jamais fait siennes les thèses simplistes qu'on lui prête, elles furent balayées par la même pensée allemande après la catastrophe encore plus cataclysmique que fut la seconde guerre mondiale. Il n'était plus possible de dédouaner la science de toute responsabilité et de toute neutralité par rapport au processus politique. La science décide bel et bien, mais comme peut le faire un mécanisme collectif et anonyme, un processus sans sujet, aveugle et irréfléchi – ce que Heidegger résuma dans l'aphorisme: "la science ne pense pas." Loin d'être neutre, la science porte un projet, elle est l'accomplissement de la métaphysique occidentale. Un autre aphorisme du même Heidegger est resté non moins célèbre: "La cybernétique est la métaphysique de l'âge atomique" - la cybernétique, cet ancêtre des sciences cognitives, en laquelle Heidegger voyait l'apothéose de la promesse cartésienne de rendre l'homme "comme maître et possesseur de la nature."

On n'est pas obligé de suivre Heidegger, et je ne le ferai pas. Mais il convient de noter que la pensée de Max Weber est plus complexe que ce qu'on en retient généralement, en particulier au sujet du rôle de la science dans le "désenchantement du monde". Weber écrit précisément ceci:

> Essayons d'abord de voir clairement ce que signifie en pratique cette rationalisation intellectualiste que nous devons à la science et à la technique scientifique. Signifierait-elle par hasard que tous ceux qui sont assis dans cette salle possèdent sur leurs conditions de vie une connaissance supérieure à celle qu'un Indien ou un Hottentot peut avoir des siennes ? Cela est peu probable. Celui d'entre nous qui prend le tramway n'a aucune notion du mécanisme qui

[17] D'après la conférence donnée en ouverture des Premières Rencontres "Science et Décideurs", intitulées *Prévenir et gérer les risques*, sous l'égide du Ministère de la recherche et des nouvelles technologies, au Futuroscope, à Poitiers, le 28 novembre 2003.

[18] Librairie Plon, 1959. Rééd. en 10/18.

> permet à la voiture de se mettre en marche - à moins d'être un physicien de métier. Nous n'avons d'ailleurs pas besoin de le savoir. Il nous suffit de pouvoir « compter » sur le tramway et d'orienter en conséquence notre comportement; mais nous ne savons pas comment on construit une telle machine en état de rouler. […] L'intellectualisation et la rationalisation croissantes ne signifient donc nullement une connaissance générale croissante des conditions dans lesquelles nous vivons. Elles signifient bien plutôt que nous savons *ou que nous croyons qu'à chaque instant nous pourrions, pourvu seulement que nous le voulions, nous prouver qu'il n'existe en principe aucune puissance mystérieuse et imprévisible qui interfère dans le cours de la vie*; bref que nous pouvons maîtriser toute chose par la prévision. Mais cela revient à désenchanter le monde. Il ne s'agit plus pour nous, comme pour le sauvage qui croit à l'existence de ces puissances, de faire appel à des moyens magiques en vue de maîtriser les esprits ou de les implorer mais de recourir à la technique et à la prévision. Telle est la signification essentielle de l'intellectualisation[19].

Le désenchantement ne correspond donc pas forcément à un savoir et à une maîtrise, et pour la très grande masse des citoyens des sociétés dominées par la science et la technique, il n'y a de fait ni savoir ni maîtrise[20]. Il relève, paradoxalement, de la croyance et de l'acte de foi!

Je me propose de réfuter la thèse que la science et la technique ne seraient qu'"un moyen inerte au service d'une volonté qui serait politique.[21]" Cette question est indissociable de ce que j'appelle le problème théologico-scientifico-politique. Le problème théologico-politique, ainsi nommé par Spinoza, est celui de savoir si les hommes peuvent vivre ensemble et résoudre leurs problèmes en toute *autonomie*, c'est-à-dire en dehors de toute transcendance, religieuse ou autre. Telle est la question directrice de la philosophie politique moderne. On pourrait plaider que celle-ci n'a jamais vraiment réussi à y répondre positivement. La question que je voudrais poser est celle de la possibilité d'une science qui serait elle-même pure immanence. Mais aussi la question de savoir si la science peut et doit viser à n'être que pure opérationnalité, ayant renoncé une fois pour toutes à la tâche, qu'elle laisse à la philosophie, de donner sens au monde.

2. Le problème théologico-scientifico-politique

Je rencontre sur mon chemin de pensée le dernier livre de Dominique Lecourt, *Humain, posthumain*[22], enquête passionnante qui pose des questions très semblables à celles que je pose ici, mais y répond très différemment. Lecourt met en scène l'affrontement entre deux variantes de théologie scientifique: le catastrophisme et le

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19 *Le savant et le politique*, op. cit., p. 69-70. Je souligne.

20 Faut-il parler de révélation? Une enquête commandée en novembre 2003 par la National Science Foundation conclut qu'une bonne moitié des Américains adultes ne sait pas le temps qu'il faut à la Terre pour faire le tour du Soleil ou ne comprend pas la question, et que la plupart d'entre eux croient aux miracles et aux fantômes tout en déclarant faire confiance à l'astrologie.

21 Christian Godin, *La fin de l'humanité*, Champ Vallon, 2003, p. 54.

22 P.U.F., 2003.

techno-prophétisme glorieux. Il montre la solidarité qui unit ces deux courants opposés mais issus l'un et l'autre d'une même source religieuse, laquelle assigne au projet technologique une mission salvatrice et millénariste. Il se donne pour tâche philosophique de "repenser la technologie *comme telle*, abstraction faite de ce qui fut le motif théologique initial de son développement, qui reste, aux yeux de certains, son ultime justification et, au contraire, pour d'autres, le chef principal de sa condamnation.[23]" Repenser la technologie et la science "comme telles", c'est-à-dire en termes purement positivistes ou scientistes, dégagés de toute métaphysique et de toute idéologie, voilà précisément ce que je prétends être tout à la fois impossible et vain, dans la situation qui est présentement la nôtre.

J'ai omis de préciser que Dominique Lecourt me range parmi les champions du premier camp, celui des "bio-catastrophistes", sans doute au seul vu du titre d'un de mes récents ouvrages[24]. Privilège douteux, à lire ce que Lecourt reproche au camp catastrophiste: ce dernier hait la science, il dresse l'opinion publique contre les savants et décourage les jeunes d'embrasser une carrière scientifique, il est technophobe, irrationaliste, et il n'hésite pas, dans les cas extrêmes, à recourir au terrorisme et aux assassinats ciblés pour aboutir à ses fins[25]. Lecourt note cependant en passant qu'on trouve dans ce camp "des individualités prestigieuses" et, parmi elles, nombre de scientifiques, "des autorités spirituelles vénérables" et des responsables politiques[26]. Mais il ne lui vient aucunement à l'esprit que si tant de scientifiques éminents poussent, depuis Hiroshima, des cris d'alarme, c'est qu'ils le font à bon escient. Il ne peut envisager que l'on puisse à la fois, comme moi, placer l'amour de la science et le désir de connaître au sommet des valeurs qui fondent l'humanité, se passionner pour la technique, pratiquer et enseigner la première avec ferveur et s'efforcer de penser la seconde avec les pleines ressources de la raison, tout en affirmant qu'elles constituent aujourd'hui, l'une et l'autre, conjointement, l'une des principales menaces qui pèsent sur l'avenir de l'humanité. L'épicurisme revendiqué par Dominique Lecourt, qui le conduit à vouloir *dégriser* le discours sur la science et la technique, le rend aveugle, selon moi, au tragique de notre condition et à la gravité de notre situation.

L'une des dernières mises en garde nous vient de Grande-Bretagne. L'auteur est au-dessus de tout soupçon d'irrationalisme ou d'anti-science ou de technophobie. Il s'agit de l'astronome royal Sir Martin Rees qui occupe la chaire d'Isaac Newton à Cambridge. Il vient de publier un livre au titre et au sous-titre éloquents: *Our Final Hour. A Scientist's Warning: How Terror, Error, and Environmental Disaster Threaten Humankind's Future in this Century – on Earth and Beyond*[27]. ["Notre dernière heure. L'avertissement d'un scientifique: comment la terreur, l'erreur et la

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[23] Ibid., p. 14.

[24] *Pour un catastrophisme éclairé*, Seuil, 2002.

[25] Dominique Lecourt consacre une annexe entière de son livre à analyser le cas du mathématicien américain Theodore Kaczynski, devenu "*Unabomber*", ce terroriste qui sema la mort dans le milieu des scientifiques et des informaticiens pendant de nombreuses années, avant de se faire prendre par le F.B.I. en 1996.

[26] *Humain, posthumain*, op. cit., p. 2.

[27] Basic Books, New York, 2003.

catastrophe écologique menacent l'avenir de l'humanité dans ce siècle – sur la terre et au-delà".]

En conclusion de son livre, Sir Martin donne à l'humanité une chance sur deux de survivre au vingt-et-unième siècle. Je ne vais pas ici entrer dans le détail de ce qui ainsi, selon lui, nous menace à ce point. Qu'il s'agisse des comportements prédateurs de l'humanité détruisant la biodiversité et les équilibres climatiques de la planète; de la prolifération du nucléaire, des avancées du génie génétique et bientôt des nanotechnologies; du risque que ces produits de l'ingéniosité de l'homme échappent à son contrôle, soit par erreur, soit par terreur – il existe sur tous ces dangers une littérature immense et un savoir très précis. Contrairement à ce que pensent les promoteurs du principe de précaution, ce n'est pas l'incertitude scientifique qui est la cause de notre inaction. Nous savons, mais nous n'arrivons pas à croire ce que nous savons.

Sir Martin n'est certes pas isolé dans son avertissement. Les signes s'accumulent, et tant chez les scientifiques que chez les hommes politiques, la prise de conscience progresse. Je pense à la mise en garde, très remarquée et discutée, de l'un des informaticiens américains les plus brillants, Bill Joy, l'inventeur du programme Java (le langage d'Internet) parue dans la revue très "branchée", *Wired*, sous le titre éloquent: "Why the future doesn't need us" ["Pourquoi l'avenir n'a pas besoin de nous"] (avril 2000). Le sous-titre précise: "Our most powerful 21st-century technologies – robotics, genetic engineering, and nanotech – are threatening to make humans an endangered species." ["Les technologies les plus puissantes du XXIème siècle – la robotique, le génie génétique et les nanotechnologies – menacent de faire de l'humanité une espèce en voie de disparition."] Le Président du CNRS français, Gérard Mégie, spécialiste incontesté de la physico-chimie de la haute atmosphère, à qui nous devons de connaître la responsabilité des aérosols et autres produits chlorés dans le trou que nous avons ouvert dans la couche d'ozone stratosphérique, affirmait récemment que si nous ne changeons pas drastiquement nos modes de vie, nous courons à la catastrophe. Les scientifiques du mouvement Pugwash et ceux qui se réunissent autour du *Bulletin of Atomic Scientists* ont mis au point en 1947 une horloge du Jugement dernier qui depuis lors indique à tout instant le temps qui nous sépare de celui-ci, fixé à minuit. Nous sommes aujourd'hui à quelques minutes seulement des douze heures fatales, aussi près qu'à quelques moments clés de la guerre froide, comme lors de la crise de Cuba.

Citerai-je enfin le Président de la République? Les fortes paroles qu'il prononça au sommet de Johannesbourg, l'été 2002, résonnent encore dans toutes les oreilles: "La maison Terre brûle, mais nous regardons ailleurs." Prenant l'initiative d'une réforme de la Constitution qui inscrirait dans son préambule une référence au "principe de précaution", il a reconnu, dans divers discours, que notre première "responsabilité envers les générations futures" est de leur éviter "des risques écologiques majeurs", donc de "mettre fin à la dégradation générale qui est en train de s'opérer sous nos yeux", et pour atteindre ce but, d'inventer "une nouvelle relation entre l'homme et la nature", ce qui implique de changer radicalement nos modes de production et de consommation.

On me dira que ce qui est en cause ici, ce n'est pas la science et la technologie *en tant que telles*, mais ce que la société fait de ce que la science et la technique lui apportent. Certes, mais je l'affirme de nouveau avec force, la science et la technique ne peuvent se défausser sur la société de leur responsabilité dans ce que la société fait d'elles. Elles font partie intégrante d'une civilisation globale et c'est cette civilisation qui est aujourd'hui en crise. Crise d'une humanité qui est en train de naître à elle-même au moment même où elle comprend que sa survie est en jeu. Le mode de développement scientifique, technique, économique et politique du monde moderne souffre d'une contradiction rédhibitoire. Il se veut, il se pense comme universel, il ne conçoit même pas qu'il pourrait ne pas l'être. L'histoire de l'humanité, va-t-il même jusqu'à croire dans ses délires les plus autistiques, ne pouvait pas ne pas mener jusqu'à lui. Il constitue la fin de l'histoire, une fin qui rachète en quelque sorte tous les tâtonnements qui l'ont péniblement précédée et par là même leur donne sens. Et pourtant il sait désormais que son universalisation, tant dans l'espace (égalité entre les peuples) que dans le temps (durabilité ou "soutenabilité" du développement), se heurte à des obstacles internes et externes inévitables, ne serait-ce que parce que l'atmosphère de notre globe ne le supporterait pas. Dès lors, il faut que la modernité choisisse ce qui lui est le plus essentiel: son exigence éthique d'égalité, qui débouche sur des principes d'universalisation, ou bien le mode de développement qu'elle s'est donné. Ou bien le monde actuellement développé s'isole, ce qui voudra dire de plus en plus qu'il se protège par des boucliers de toutes sortes contre des agressions que le ressentiment des laissés pour compte concevra chaque fois plus cruelles et plus abominables; ou bien s'invente un autre mode de rapport au monde, à la nature, aux choses et aux êtres, qui aura la propriété de pouvoir être universalisé à l'échelle de l'humanité. La science et la technique devront jouer un rôle essentiel dans cette métamorphose qui reste complètement à concevoir.

3. Pourquoi nous avons besoin de l'avenir

Non, l'époque n'est pas aux pensées aimables et dégrisées, n'en déplaise à Dominique Lecourt. Je voudrais le montrer d'abord sur la question de la responsabilité, en mettant en question l'idée, trop facilement reçue, et qui est devenue un cliché, que c'est devant les générations futures que nous avons à répondre de nos actes.

Le recours au langage des droits, des devoirs et de la responsabilité pour traiter de "notre solidarité avec les générations futures" soulève des problèmes conceptuels considérables, que la philosophie occidentale s'est révélée pour l'essentiel incapable d'éclairer. En témoignent éloquemment les embarras du philosophe américain John Rawls, dont la somme, *Théorie de la justice*[28], se présente comme la synthèse - dépassement de toute la philosophie morale et politique moderne. Ayant fondé et établi rigoureusement les principes de justice qui doivent gérer les institutions de base d'une société démocratique, Rawls est obligé de conclure que ces principes ne s'appliquent pas à la justice entre les générations. A cette question, il n'offre qu'une réponse floue et non fondée. La source de la difficulté est l'irréversibilité du temps. Une théorie de la justice qui repose sur le contrat incarne l'idéal de réciprocité. Mais il ne peut y avoir de réciprocité entre générations différentes. La plus tardive reçoit quelque chose de la précédente, mais elle ne peut rien lui donner en retour. Il y a plus grave. Dans la perspective d'un temps linéaire qui est celle de l'Occident, la perspective du progrès héritée des Lumières, il était présupposé que les générations futures seraient plus heureuses et plus sages que les générations antérieures. Or la théorie de la justice incarne l'intuition morale fondamentale qui nous amène à donner

[28] Seuil, 1987 (origin. 1971).

la priorité aux plus faibles. L'aporie est alors en place: entre les générations, ce sont les premières qui sont moins bien loties et pourtant ce sont les seules qui peuvent donner aux autres![29] Kant, qui raisonnait dans ce cadre, trouvait inconcevable ("*rätselhaft*") que la marche de l'humanité pût ressembler à la construction d'une demeure que seule la dernière génération aurait le loisir d'habiter. Et cependant, il ne crut pas pouvoir écarter ce qui se présente en effet comme une ruse de la nature ou de l'histoire accomplissant en quelque sorte le chef d'œuvre de la rationalité instrumentale: les générations antérieures se sacrifient pour les générations terminales[30].

Notre situation est aujourd'hui très différente, puisque notre problème majeur est d'éviter la catastrophe suprême. Est-ce à dire qu'il nous faut substituer à la pensée du progrès une pensée de la régression et du déclin? C'est ici qu'une démarche complexe est requise. Progrès ou déclin?, ce débat n'a pas le moindre intérêt. On peut dire les choses les plus opposées au sujet de l'époque que nous vivons, et elles sont également vraies. C'est la plus exaltante et c'est la plus effrayante. Il nous faut penser à la fois l'éventualité de la catastrophe et la responsabilité peut-être cosmique qui échoit à l'humanité pour l'éviter. A la table du contrat social selon Rawls, toutes les générations sont égales. Il n'y a aucune génération dont les revendications aient plus de poids que celles des autres. Eh bien non, les générations ne sont pas égales du point de vue moral. La nôtre et celles qui suivront ont un statut moral (*a moral standing*, comme dirait l'anglais) considérablement plus élevé que les générations anciennes, dont on peut dire aujourd'hui, par contraste avec nous, qu'elles ne savaient pas ce qu'elles faisaient. Nous vivons à présent l'émergence de l'humanité comme quasi-sujet; la compréhension inchoative de son destin possible: l'autodestruction; la naissance d'une exigence absolue: éviter cette autodestruction.

Non, notre responsabilité ne s'adresse pas aux "générations futures", ces êtres anonymes et à l'existence purement virtuelle, au bien-être desquels on ne nous fera jamais croire que nous avons une quelconque raison de nous intéresser. Penser notre responsabilité comme exigence d'assurer la justice distributive entre générations mène à une impasse philosophique. A ce propos, une anecdote circule dans le milieu des astrophysiciens. A la suite d'une conférence donnée par l'un d'entre eux, quelqu'un dans la salle pose la question: "Combien de temps avez vous dit qu'il va se passer avant que le soleil vaporise tout ce qui se trouve sur la terre?". Entendant de nouveau la réponse: "six milliards d'années", le questionneur pousse un soupir de soulagement: "Ah bon, Dieu merci! J'avais compris six millions.[31]"

C'est par rapport au destin de l'humanité que nous avons des comptes à rendre, donc par rapport a nous-mêmes, ici et maintenant. Au chant X de *l'Enfer*, le poète écrit: "Tu comprends ainsi que notre connaissance sera toute morte à partir de l'instant où sera fermée la porte du futur." Si nous devions être la cause de ce que la porte de l'avenir se referme, c'est le sens même de toute l'aventure humaine qui serait à jamais, et

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29 *Théorie de la justice*, section 44, "Le problème de la justice entre les générations".

30 *Idée d'une histoire universelle au point de vue cosmopolitique*.

31 Anecdote rapportée par Martin Rees, *Our final hour*, op. cit., p. 182. La plaisanterie marche mieux en anglais, jouant sur l'allitération *billion/million*.

rétrospectivement, détruit. Je crains qu'une philosophie du bonheur ou du plaisir ne soit ici tout simplement pas à la hauteur de l'enjeu.

Pouvons-nous trouver des ressources conceptuelles hors de la tradition occidentale? C'est la sagesse amérindienne qui nous a légué la très belle maxime: "La Terre nous est prêtée par nos enfants". Certes, elle se réfère à une conception du temps cyclique, qui n'est plus la nôtre. Je pense, cependant, qu'elle prend encore plus de force dans la temporalité linéaire, au prix d'un travail de re-conceptualisation qu'il s'agit d'accomplir. Nos "enfants" – comprendre les enfants de nos enfants, à l'infini – n'ont d'existence ni physique ni juridique, et cependant, la maxime nous enjoint de penser, au prix d'une inversion temporelle, que ce sont eux qui nous apportent "la Terre", ce à quoi nous tenons. Nous ne sommes pas les "propriétaires de la nature", nous en avons l'usufruit. De qui l'avons-nous reçu? De l'avenir! Que l'on réponde: "mais il n'a pas de réalité!", et l'on ne fera que pointer la pierre d'achoppement de toute philosophie de la catastrophe future: nous n'arrivons pas à donner un poids de réalité suffisant à l'avenir.

Or la maxime ne se limite pas à inverser le temps: elle le met en boucle. Nos enfants, ce sont en effet nous qui les faisons, biologiquement et surtout moralement. La maxime nous invite donc à nous projeter dans l'avenir et à voir notre présent avec l'exigence d'un regard que nous aurons nous-mêmes engendré. C'est par ce dédoublement, qui a la forme de la conscience, que nous pouvons peut-être établir la réciprocité entre le présent et l'avenir. Il se peut que l'avenir n'ait pas besoin de nous, mais nous, nous avons besoin de l'avenir, car c'est lui qui donne sens à tout ce que nous faisons.

4. Quand les technologies convergeront

La question essentielle est la suivante : comment expliquer que la science soit devenue une activité si « risquée » que, selon certains scientifiques de premier plan, elle constitue aujourd'hui la principale menace à la survie de l'humanité. Certains philosophes répondent à cette question en disant que le rêve de Descartes – "se rendre maître et possesseur de la nature" – a mal tourné. Il serait urgent d'en revenir à la "maîtrise de la maîtrise". Ils n'ont rien compris. Ils ne voient pas que la technologie qui se profile à l'horizon, par "convergence" de toutes les disciplines, vise précisément à la non-maîtrise. L'ingénieur de demain ne sera pas un apprenti sorcier par négligence ou incompétence, *mais par finalité*. Il se "donnera" des structures ou organisations complexes et il se posera la question de savoir ce dont elles sont capables, en explorant le paysage de leurs propriétés fonctionnelles – démarche "ascendante", *bottom-up* comme on dit en anglais. Il sera au moins autant un explorateur et un expérimentateur qu'un réalisateur. Ses succès se mesureront plus à l'aune de créations *qui le surprendront lui-même* que par la conformité de ses réalisations à des cahiers des charges préétablis. Des disciplines comme la vie artificielle, les algorithmes génétiques, la robotique, l'intelligence artificielle distribuée répondent déjà à ce schéma. Ce qui va cependant porter cette visée de non-maîtrise à son accomplissement est le programme nanotechnologique, ce projet démiurgique fait de toutes les techniques de manipulation de la matière, atome par atome, pour la mettre en principe au service de l'humanité. Comme, par ailleurs, le savant sera de plus en plus celui qui, non pas découvre un réel indépendant de l'esprit, mais explore les propriétés de ses inventions (disons le spécialiste d'intelligence artificielle plutôt que le neurophysiologiste), les rôles de l'ingénieur et du savant tendront à se confondre. La nature elle-même deviendra ce que l'homme en a fait, en y déclenchant des processus dont il n'a pas la maîtrise, à dessein.

Un regroupement de centres de recherches européens en nanotechnologies s'est donné pour nom *NanoToLife* – abréviation de "Bringing Nanotechnology to Life". L'ambivalence de l'expression est un chef d'œuvre de ce double langage que les scientifiques pratiquent de plus en plus. Elle peut signifier, dans une attitude de retrait modeste, "Faire venir les nanotechnologies à l'existence", ou bien encore "Rapprocher les nanotechnologies des sciences de la vie". Mais on ne peut pas ne pas y entendre le projet démiurgique de fabriquer de la vie au moyen de la technique. Et celui qui veut fabriquer - en fait, *créer* – de la vie ne peut pas ne pas ambitionner de reproduire sa capacité essentielle, qui est de créer à son tour du radicalement nouveau.

J'emprunte l'expression "technologies convergentes" au document officiel américain qui a lancé en juin 2002 un vaste programme interdisciplinaire, richement doté en fonds fédéraux, dénommé "Converging Technologies", mais plus connu sous l'acronyme NBIC: la convergence dont il s'agit est en effet celle des Nanotechnologies, des Biotechnologies, des technologies de l'Information et des sciences Cognitives.[32]. Je mène depuis deux ans déjà une mission[33] dont l'objectif est d'anticiper les implications économiques, sociales, politiques, militaires, culturelles, éthiques et métaphysiques du développement prévisible des NBIC et de leur convergence. C'est à leur propos que je voudrais porter maintenant ma réflexion sur la problématique des risques.

Je défends une thèse qui peut se dire simplement: l'évaluation normative des technologies convergentes doit donner sa juste place à la question des "risques", cela va de soi, mais ni plus ni moins. Or, dans la confusion actuelle qui tient lieu de débat, les "risques" occupent toute la place. La seule façon de sortir de l'ornière est de se libérer de ce carcan mental et cela à deux niveaux: il faut comprendre que 1) les risques ne sont qu'un type d'effets parmi beaucoup d'autres, et certainement ni les plus importants ni les plus intéressants; 2) le calcul des risques, qui est la seule méthode d'évaluation envisagée[34], est complètement inadapté à l'appréhension normative de la plupart des effets.

J'ai proposé une typologie des effets à attendre du développement des NBIC, qui met en évidence que ces effets ne sont pour la plupart pas réductibles à des risques. La notion de risque porte déjà en elle l'économisme normatif dont je demande (point 2) qu'on se déprenne. Le risque fait intervenir trois éléments: a) une éventualité de dommage, affectée normativement d'un signe moins; b) un degré de vraisemblance assigné en principe à l'occurrence de ce dommage; c) une population d'individus touchés potentiellement par le dommage et dont les "utilités" (ou "satisfactions", ou "ophélimités" etc.) servent d'étalon pour l'appréciation du dommage. Le débat sur la

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32 Le rapport est accessible sur la Toile à http://www.wtec.org/ConvergingTechnologies/

33 Sous l'égide du Conseil Général des Mines, ainsi que dans le cadre d'un groupe d'experts "de haut niveau" chargé par la Commission de Bruxelles de préparer une réponse européenne à l'initiative américaine "Converging Technologies".

34 Sous divers avatars – calcul économique, démarche coûts-avantages, etc. – dont le dernier en date est le "principe de précaution".

"précaution" a introduit une distinction d'ordre *épistémique*, à savoir le type de connaissance que les acteurs ont ou n'ont pas du degré de vraisemblance de l'occurrence du dommage, par exemple sous la forme de probabilités objectives. Ce débat aura surtout brouillé les pistes et masqué l'essentiel. L'essentiel, c'est l'urgence de remettre en cause le monopole que la notion de risque et le calcul économique des risques exercent conjointement sur les esprits.

On vérifiera sans peine que les effets que je vais typer ne sont pas des risques, en ce qu'ils ne satisfont aucune des trois conditions que je viens de rappeler. Lorsque la National Science Foundation dit des NBIC qu'elles vont "entraîner un changement de civilisation", bien malin serait celui qui s'aventurerait à mettre un signe, plus ou moins, devant cette éventualité, qui se prononcerait sur son degré de vraisemblance ou qui en évaluerait les conséquences en additionnant les différentiels d'"utilités" sur toute la population. Lorsqu'on refuse leur méthode, les économistes vous renvoient dans l'enfer obscurantiste de l'écologie dite "profonde". Cependant, on peut accepter, au rebours d'un certain fondamentalisme écologique, l'*anthropocentrisme* – "L'homme est la mesure de toutes choses" -, sans tomber pour autant dans les naïvetés de l'*individualisme* méthodologique propre au calcul économique des risques: entre les deux positions il y a un vaste espace où une démarche normative exigeante et originale devrait trouver sa place.

5. Dépasser la problématique des risques

Je ne parlerai ici que de méthode et je n'ai nullement l'ambition de traiter au fond de la question des effets des NBIC. Il y faudrait un ouvrage. Les quelques éléments de substance que j'avancerai ne sont là que pour illustrer les arguments et donner chair à la méthode.

Outre les risques au sens strict, sur lesquels je ne reviens pas ici, on peut distinguer:

Les effets sur le rapport à la nature (effets ontologiques)

Le débat actuel sur la transformation du rapport à la nature provoquée par les techniques nouvelles se présente ainsi. D'un côté, l'écologie profonde qui fait de la nature un modèle immuable d'équilibre et d'harmonie, et de l'homme un prédateur irresponsable et dangereux; de l'autre, le projet humaniste moderne d'arracher l'homme à la nature et de le rendre maître et possesseur du monde et de lui-même. Dans un cas la "transgression" est vilipendée, dans l'autre elle est revendiquée. Entre les deux, peut-être, une série de positions intermédiaires: les scientifiques sur la défensive soulignent que l'homme fait partie de la nature, que ses interventions sont donc par essence naturelles et que les techniques actuelles ne font qu'accélérer des processus qui ont toujours eu lieu; une position raisonnable ne consisterait-elle pas à limiter l'action de l'homme sur la nature à des interventions qui ne mettent pas en péril son bien-être ou sa survie?

Je crains que le débat ainsi engagé ne passe à côté de l'essentiel. En arrière-fond de tout "paradigme" scientifique et technique, il y a ce que Karl Popper appelait un "programme métaphysique de recherches" – ensemble non "testable" de propositions que l'on tient pour vraies sans chercher à les remettre en cause, cadre théorique qui limite le type de questions que l'on pose mais aussi qui en donne l'inspiration première. Le programme métaphysique de recherches des NBIC tient dans les deux mots d'ordre suivants: a) Il faut viser à naturaliser l'esprit pour qu'il retrouve sa place au sein de la nature qui l'a engendré; b) Cette naturalisation de l'esprit passe par une mécanisation et une artificialisation, tant de la nature que de l'esprit[35]. Par rapport au débat en cours, le paradoxe est considérable et fait penser au tour du célèbre clown Grock qui, avant de se mettre à jouer -magnifiquement - les variations Goldberg, trouvait la juste distance entre le tabouret et son Steinway ... en déplaçant péniblement ce dernier. Si les NBIC, ce chef d'œuvre de l'esprit humain, font mine de s'inscrire dans la continuité de la nature et de la vie pour en fait prendre leur relais, ce n'est que parce qu'elles ont auparavant complètement redéfinies ces dernières à leur image. Voici comment l'un de leurs promoteurs réécrit en termes purement technologiques l'évolution qui a conduit de l'origine de la vie à la complexité présente de la biosphère: "[Au départ], des algorithmes génétiques en nombre astronomique se déplaçaient en titubant à la surface de la terre et dans les profondeurs sous-marines […] Finalement, l'écologie tout entière du monde vivant sur la planète a accumulé, et représente aujourd'hui, sous forme comprimée et schématique, une quantité colossale d'information. [36]."

Une fois admise une telle vision du monde, il n'y a qu'un pas pour en arriver à former le projet de se rendre maître de ces machines informationnelles ou algorithmiques, d'abord en les simulant et en les reproduisant (naissance de l'intelligence, puis de la vie artificielles), ensuite en intervenant sur elles à la manière de l'ingénieur (biotechnologies, technologies cognitives, etc.). Le problème n'est plus de savoir jusqu'à quel point on peut ou on doit "transgresser" la nature. Le problème, c'est que la notion même de transgression est sur le point de perdre tout son sens. L'homme ne rencontrera jamais plus qu'un monde à l'image de ses propres créations artificielles.

Les effets sur le rapport à la connaissance (effets épistémiques)

A l'aube des temps modernes, Jean-Baptiste Vico formula dans les termes célèbres le postulat de la « nouvelle science » (1725): "*Verum et factum convertuntur"* (Ce qui est vrai et ce que l'on fait sont convertibles). Nous ne pouvons connaître rationnellement que ce dont nous sommes la cause, que ce que nous avons fabriqué. A l'origine, le principe du *verum factum* s'entendit sur le mode du manque : nous ne pourrons jamais connaître la nature comme Dieu, car celui-ci l'a créée et nous ne pouvons que l'observer. Bientôt cependant, le principe acquit une valeur positive, plus en conformité avec l'affirmation croissante du subjectivisme moderne. Ce que l'homme fait, il peut le connaître rationnellement, de façon démonstrative et déductive, malgré la finitude de son entendement. Par ordre décroissant de perfection de la connaissance, les mathématiques, selon ce critère, étaient classées en premier, suivies cependant non par les sciences de la nature, mais par les sciences morales et politiques. « L'Histoire [était] la seule et unique sphère où l'homme pourrait obtenir la connaissance certaine puisqu'il n'y aurait affaire qu'aux produits de l'activité humaine"[37]. Cependant , la science de la nature elle-même devait être dès les

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[35] Cf. Jean-Pierre Dupuy, *The Mechanization of the Mind*, Princeton University Press, 2000; et "L'Esprit mécanisé par lui-même", *Le Débat*, 1er trimestre 2000.

[36] Damien Broderick, *The Spike. How our lives are being transformed by rapidly advancing technologies*, New York, Forge, 2001.

[37] Hannah Arendt, *Condition de l'homme moderne* , Calmann-Lévy, 1961, p. 336.

commencements orientée par la conviction qu'on ne peut connaître qu'en faisant, ou plutôt qu'en re-faisant. "Dès le début (...) le savant aborda la nature du point de vue de Celui qui l'a créée"[38]. L'insistance sur le comment des processus plutôt que sur l'être des choses s'explique ainsi, mais aussi et surtout le rôle considérable dévolu à l'expérimentation et à la modélisation par la science. "Pour utiliser l'expérimentation afin de connaître, il fallait déjà être convaincu que l'on ne peut connaître que ce que l'on a fait, car cette conviction signifiait que l'on peut s'informer des choses que l'homme n'a point faites en se représentant et en imitant les processus qui les ont amenées à l'existence"[39].

Avec les NBIC, cependant, le *verum factum* devrait trouver son aboutissement ultime. Ce n'est plus seulement en faisant des expériences sur elle, ce n'est plus seulement en la modélisant, que les hommes désormais connaîtront la nature. C'est en la re-faisant. Mais, du coup, ce n'est plus la nature qu'ils connaîtront, mais ce qu'ils auront fait. Ou plutôt, c'est l'idée même de nature, donc de donné extérieur à soi, qui apparaîtra comme dépassée. La distinction même entre connaître et faire perdra, avec les NBIC, tout son sens, de même que celle qui sépare encore aujourd'hui le savant de l'ingénieur[40].

Les effets sur la possibilité même de l'éthique (effets éthiques)

En traitant la nature comme un artefact, l'homme se donne le pouvoir d'agir sur la nature à un degré qu'aucune technoscience jusqu'ici n'a jamais rêvé d'atteindre. Cette nature artificielle, l'homme peut espérer non seulement la manipuler à volonté, mais même la fabriquer selon ses désirs et ses fins. Les nanotechnologies ouvrent un continent immense que l'homme va devoir normer s'il veut leur donner sens et finalité. Il faudra alors que le sujet humain recoure à un surcroît de volonté et de conscience pour déterminer, non pas ce qu'il peut faire, mais bien ce qu'il *doit* faire. Il y faudra toute une éthique, infiniment plus exigeante que celle qui, aujourd'hui, se met lentement en place pour contenir le rythme et les dérives des biotechnologies. Qui dit "éthique", "conscience", "volonté" dit le triomphe du sujet. Mais que signifie ce triomphe dans une conception du monde qui traite la nature, y compris l'homme, comme une machine computationnelle ? Cet homme qui s'est ainsi fait machine, au nom de quoi ou de qui va-t-il exercer son immense pouvoir sur la nature et sur lui-même? Au nom du mécanisme aveugle auquel il s'identifie? Au nom d'un sens dont il prétend qu'il n'est qu'apparence ou phénomène? Sa volonté et ses choix ne peuvent qu'être suspendus dans le vide. L'élargissement sans limites du champ de l'éthique se traduit par la négation de l'éthique, de la même manière que la connaissance d'une nature devenue tout entière l'objet du faire humain se traduit par la négation, et de la nature, et de la connaissance.

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38 Ibid. p. 333.

39 Ibid., p. 332. Cf. aussi *The Mechanization of the Mind*, op. cit., chapitre premier.

40 On voit déjà aujourd'hui avec les seules biotechnologies que la distinction entre découverte et invention, sur laquelle repose le droit des brevets, est de plus en plus délicate à tracer, ainsi que l'attestent les débats sur la brevetabilité du vivant.

Les effets sur les catégories (effets métaphysiques)

Avec le biophysicien et philosophe Henri Atlan, on peut tout à la fois considérer que les métaphores mécanistes et informationnelles sur lesquelles se sont bâties tant les sciences cognitives que la biologie moléculaire sont scientifiquement et philosophiquement fausses et concéder qu'elles nous donnent une puissance d'agir et une maîtrise radicalement inédites sur le donné naturel et vivant[41]. Si tel est le cas, les succès mêmes que remporteront ces nouvelles technologies rendront les représentations mécanistes et informationnelles de la nature et de la vie incontestables et nul ne pourra plus voir qu'elles sont illusoires. Il n'est pas exagéré de parler d'effets métaphysiques.

L'effet le plus troublant est sans conteste le brouillage des distinctions catégorielles au moyen desquelles l'humanité, depuis qu'elle existe, s'est toujours repérée dans le monde. Le naturel non vivant, le vivant et l'artefact sont en bonne voie de fusionner.

6. *The Matrix* , la science et les transhumanistes

Peu de Français ont entendu parler de M. William Sims Bainbridge. Ce citoyen américain est pourtant un personnage fascinant et quelque peu inquiétant. En lisant son curriculum vitæ[42], on ne découvre pas d'emblée qu'il est membre actif d'un mouvement international qui se nomme "transhumanisme"[43]. Les transhumanistes se donnent pour tâche d'accélérer grâce aux technologies convergentes le passage à l'étape prochaine de l'évolution biologique. Les biotechnologies prennent les produits de l'évolution biologique pour donnés et se contentent de les utiliser ou de les reproduire pour les mettre au service des fins humaines. Le projet "convergent" nanobiotechnologique est beaucoup plus radical. Il part du constat que l'évolution est un piètre ingénieur, qui a fait son travail de conception plus ou moins au hasard, se reposant sur ce qui marchait à peu près pour échafauder de nouvelles constructions plus ou moins branlantes – bref, en bricolant. L'esprit humain, relayé par les technologies de l'information et de la computation qui le dépasseront bientôt en capacités d'intelligence et d'imagination, fera beaucoup mieux, et arrivera à se transcender lui-même. Dans une communication de juillet 2003 à la World Transhumanist Association, M. Bainbridge dessinait ce que pourrait être la *transition* – d'où le terme "transhumanist", qui signifie humain en transition – à une étape post-humaine de l'évolution, où les machines auront remplacé les hommes, et les obstacles qui se dresseraient sur le chemin. La cyber-post-humanité qui se prépare pourra accéder à l'immortalité lorsqu'on saura transférer le contenu informationnel du cerveau, "donc" l'esprit et la personnalité de chacun, dans des mémoires d'ordinateur. On peut donc s'attendre, conjecturait Bainbridge, que les religions établies, qui bâtissent leur fonds de commerce sur la peur de la mort, ne laisseront pas la *transhumance* se dérouler sans encombre, pas plus d'ailleurs que les institutions de

41 Voir Henri Atlan, *La fin du "tout génétique"?*, Paris, INRA Éditions, 1999.

42 http://mysite.verizon.net/william.bainbridge/misc/wsbvita.htm

43 La revue principale de la World Transhumanist Association, après s'être appelée *Journal of Transhumanism*, a récemment pris le nom sans doute jugé plus anodin de *Journal of Evolution and Technology*. M. Bainbridge est l'un des rédacteurs en chef adjoints de la revue. Voir http://www.jetpress.org/Editorial%20Board.html

base de la société, y compris l'establishment scientifico-technologique, foncièrement conservatrices, voire réactionnaires. En conclusion de son propos, William Bainbridge appelait les "progressistes" de tous les pays à se constituer en sociétés secrètes et, si nécessaire, à entrer en résistance et en rébellion contre un ordre social mortifère[44].

Après Jürgen Habermas et Bruno Latour, Dominique Lecourt fait un sort à ces champions de la post-humanité – d'où le titre de son livre – et, comme ses prédécesseurs, il ne se prive pas de les tourner en dérision. Il ne conviendrait pas de prendre ces techno-prophètes au sérieux, même si leur prédication appelle en retour le catastrophisme des technophobes. Lecourt leur reconnaît cependant une filiation: ils descendent tout droit de la théologie chrétienne qui voyait dans la technique un instrument de rédemption et de salut.

Je crois que c'est là une erreur sérieuse d'analyse et d'appréciation, et ce pour trois raisons fondamentales.

Pour éclairer la première de ces raisons, je dois révéler qui est M. Bainbridge dans le civil, pour ainsi dire. William Bainbridge est un haut fonctionnaire de la National Science Foundation et c'est lui qui est responsable, en collaboration avec Mihail Roco, de l'initiative américaine NBIC, laquelle va faire pleuvoir quelque 850 millions de dollars d'argent fédéral par an sur les chercheurs du domaine. M. Bainbridge n'est pas lui-même un scientifique "dur": c'est un sociologue spécialisé dans l'étude des sectes religieuses. Il est donc bien placé pour évaluer le type de résistance que l'esprit religieux opposera à la progression des recherches.

Nos sociologues et philosophes n'ont donc pas vu que ceux qu'ils prennent pour des illuminés occupent d'éminentes positions de pouvoir[45].

La seconde raison qui m'amène à ne pas accepter l'analyse de Dominique Lecourt découle immédiatement de ce que je viens d'expliquer. Il est pour le moins singulier de voir dans le transhumanisme une rémanence religieuse alors même que le religieux est son ennemi déclaré. Et si l'organisation et le discours des transhumanistes font irrésistiblement penser à ceux d'une secte, le paradoxe n'est qu'apparent: c'est le même paradoxe que celui qui, dans notre pays, transforme certains champions de la laïcité en gardiens d'une religion républicaine. L'être suprême, pour les transhumanistes, c'est

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[44] Pour qu'on n'imagine pas que j'invente ces choses, je renvoie à la communication de M. Bainbridge, que l'on trouve sur la Toile – signe que les Transhumanistes ne se cachent pas – à http://www.transhumanism.com/articles_more.php?id=P697_0_4_0_C

[45] La mission que j'accomplis sur les NBIC a pris, à ma grande surprise, partiellement l'allure d'une enquête policière. Qu'on en juge. L'organisme de recherche du Pentagone, la DARPA, laquelle est sans conteste l'une des boîtes à idées les plus inventives du monde – nous lui devons entre autres l'Internet – a imaginé l'été 2003 d'organiser un marché spéculatif où s'échangeraient des paris – en termes techniques, des "*futures*" -, portant sur des événements du type instabilité politique, attentat terroriste, crise internationale majeure, voire assassinat de tel leader du Proche Orient. Le projet a fait grand bruit et a été rapidement abandonné tant les réactions outragées ont été violentes, mais son soubassement conceptuel, à savoir la capacité des marchés à anticiper les crises, a été vigoureusement défendu par des économistes de premier plan. Quand j'ai découvert que le concepteur du projet, l'économiste Robin Hanson, est, aux côtés de William Bainbridge, rédacteur en chef adjoint de la revue de la World Transhumanist Association, je n'ai pu, je l'avoue, m'empêcher de frissonner. Après la NSF et le Pentagone, je redoute de découvrir que d'autres institutions majeures sont infiltrées par le transhumanisme.

l'homme. Le créateur capable de créer une créature à son image, de la doter d'autonomie et d'accepter de se laisser déposséder par elle, c'est l'homme, et non la divinité. Si Dieu est mort, avertissait Dostoïevski, alors les hommes seront des dieux les uns pour les autres. Je ne sache pas que la théologie, qu'elle soit juive ou chrétienne, ait quoi que ce soit à voir avec la déification de l'homme. C'est même pour elle la faute suprême, qui a nom: idolâtrie. Le transhumanisme est typiquement l'idéologie d'un monde sans Dieu.

La troisième raison est la plus importante. L'idéologie transhumaniste est en parfaite contradiction avec la métaphysique qui sous-tend le programme NBIC. La métaphysique est celle des sciences cognitives: il s'agit d'un monisme matérialiste non réductionniste: l'esprit et la matière ne font qu'un, l'un et l'autre relevant de l'algorithmique. Le caractère non réductionniste de ce monisme se voit à l'importance accordée au thème de la complexité par les nanosciences et à la démarche ascendante (*bottom-up*) par les nanotechnologies. L'idéologie, elle, est sans le moindre complexe dualiste: les esprits s'y détachent de leur support matériel contingent plus facilement que la peau d'une orange que l'on pèle. Ils vagabondent du "*wetware*" (le système neuronal) au "*hardware*" (le disque dur des ordinateurs futurs) sans la moindre difficulté. Il suffit de voir ce que la culture populaire américaine fait de cette idéologie dans des films comme *The Matrix*! Noyer ensemble l'idéologie et la métaphysique dans la mer opaque du religieux ou du théologique, c'est s'interdire de voir qu'ici elles s'opposent, et de réfléchir aux raisons de cette opposition.

Je voudrais résumer mon propos en considérant les cinq propositions suivantes et en méditant sur leur différence de statut.

[1] $ih\,\mathbf{d}u/\mathbf{d}t \;=\; -h^2/2m\,\Delta u + \mathbf{V}u$ [Equation de Schrödinger]

Cette première proposition, que le lecteur non physicien ne se reprochera pas de ne pas comprendre, représente l'un des plus grands chefs d'œuvre de l'esprit scientifique, et de l'esprit humain tout court. Je lui laisse à dessein son apparence ésotérique de chaîne de symboles non interprétés, car il s'agit de marquer qu'il s'agit d'une pure syntaxe, où des opérateurs agissent de façon réglée et aveugle sur des signes algébriques.

[2] "It from Bit" [John Archibald Wheeler]

Cette deuxième proposition exprime de façon très concise l'une des interprétations possibles de la mécanique quantique: l'information ["Bit"] précède et engendre l'existence [Le "It", c'est-à-dire l'étant]; ou encore: la théorie quantique, et au-delà toute la physique, est déductible de la théorie de l'information.

[3] On peut décomposer 15 en facteurs premiers [15 = 3 fois 5] en recourant à la computation quantique [MIT, 2002]

Cette troisième proposition décrit une réalisation technique prodigieuse qui annonce une révolution dans les technologies de l'information dont les conséquences seront phénoménales. Dans le monde quantique, l'information n'est plus liée à un choix binaire "0 *ou* 1", mais elle s'incarne dans la superposition des deux états: c'est "0 *et* 1", tout à la fois. La computation quantique va multiplier les performances de l'informatique par des facteurs supérieurs au million.

Il existe bien d'autres interprétations possibles de la mécanique quantique que celle qu'exprime la deuxième proposition, qui suscite la controverse. Ce qui n'empêche pas les scientifiques de s'accorder sur la première ni la troisième d'être un fait, une prouesse technologique majeure.

Ces trois premières propositions, considérées ensemble, illustrent l'une des dimensions de l'irréflexion constitutive de la science. La science n'est, à tout stade de son développement, consensuelle que pour autant qu'elle se limite à n'être qu'une syntaxe, délestée de tout appareil interprétatif, mais cette syntaxe est tout ce dont elle a besoin pour avoir un pouvoir opératoire souvent considérable sur le monde. La science nous permet donc d'agir sur le réel au moyen de la technique sans savoir vraiment ce que nous faisons.

Soit maintenant les deux dernières propositions:

[4] La conscience est de l'ordre de la computation quantique [Center for Consciousness Studies, The University of Arizona at Tucson]

[5] Nous devons accélérer le passage, grâce à la science et à la technique, au stade prochain de l'évolution biologique, et fabriquer les machines conscientes qui nous remplaceront [Transhumanisme]

La quatrième proposition est un constituant possible du "programme métaphysique de recherches" des NBIC. C'est grâce à la croyance en de telles propositions que des recherches sont engagées dans des directions radicalement neuves, menant, dans le meilleur des cas, à des découvertes, à des réalisations et à des interprétations telles que celles qu'expriment les trois premières propositions.

La cinquième proposition relève de l'idéologie. Il convient de nettement marquer sa différence d'avec la quatrième. Bien que "non scientifiques" au sens de Popper, des propositions telles que cette dernière sont indispensables à la science. Elles lui donnent son *impetus*, sa raison d'être et surtout son sens. Les propositions idéologiques poussent sur l'humus scientifique comme des parasites: elles ne peuvent se passer de la science, mais la science pourrait en principe fort bien se passer d'elles. L'une des questions qui se posent est dans quelle mesure, cependant, ce parasitage ne joue pas un rôle, peut-être très important, dans la marche de l'institution scientifique. Auquel cas l'on aurait là une deuxième dimension de l'irréflexion scientifique: la science tributaire de l'idéologie.

L'exemple des NBIC, je l'ai dit, illustre on ne peut plus clairement la différence de contenu entre métaphysique et idéologie. Si l'idéologie influe sur la science, ce n'est donc pas dans le monde des idées que le lien causal s'établit, c'est en passant par des connexions sociales et institutionnelles.

Non, vraiment, je ne vois aucune contradiction à avouer mon amour pour la science, à dire mon admiration devant les prouesses techniques, à exprimer le besoin que j'éprouve, en tant que philosophe, de m'abreuver aux idées de la science, tout en affirmant que la science, de par son irréflexion foncière, est plus que jamais susceptible d'engendrer des processus aveugles qui peuvent nous mener au désastre.

7. La responsabilité de la science

Les promoteurs des nanosciences et des nanotechnologies sont nombreux, puissants et influents: les scientifiques et les ingénieurs enthousiasmés par la perspective de percées fabuleuses; les industriels attirés par l'espoir de marchés gigantesques; les gouvernements des nations et des régions du globe terrorisés à l'idée de perdre une course industrielle, économique et militaire très rapide où vont se jouer les emplois, la croissance, mais aussi les capacités de défense de demain[46]; et, enfin, les représentants de ce vaste sujet collectif et anonyme qu'est la fuite en avant technologique où la technique apparaît seule capable de contenir les effets indésirables et non voulus de la technique.

On ne s'étonne donc pas que soient vantés partout en termes hyperboliques les bienfaits pour l'humanité de la révolution scientifique et technique en cours. Le rapport américain de la National Science Foundation sur les technologies convergentes, dont le titre complet est "Converging Technologies *for Improving Human Performances*", bat sans doute tous les records. Il ne promet pas moins à terme que l'unification des sciences et des techniques, le bien-être matériel et spirituel universel, la paix mondiale, l'interaction pacifique et mutuellement avantageuse entre les humains et les machines intelligentes, la disparition complète des obstacles à la communication généralisée, en particulier ceux qui résultent de la diversité des langues, l'accès à des sources d'énergie inépuisables, la fin des soucis liés à la dégradation de l'environnement. Le rapport va jusqu'à conjecturer que "l'humanité pourrait bien devenir comme un 'cerveau' unique, [dont les éléments seraient] distribués et interconnectés par des liens nouveaux parcourant la société." Prudent, William Sims Bainbridge, qui en est l'un des deux signataires, ne se hasarde pas à y rendre public le programme des transhumanistes.

Quelques chercheurs de base sont assez lucides pour comprendre ceci. A trop vanter les conséquences positives "fabuleuses" de la révolution en cours, on s'expose à ce que des critiques non moins hypertrophiées s'efforcent de la tuer dans l'œuf. Si l'on prend au sérieux le programme nanotechnologique maximaliste, alors on ne peut pas ne pas s'effrayer des risques inouïs qui en résulteraient[47]. Le succès du dernier roman de Michael Crichton, *Prey*[48], a rendu célèbre dans toute l'Amérique le risque de *gray goo*, dit encore d'écophagie globale: le risque d'une autoréplication sauvage de nanomachines à la suite d'un accident de programmation. Tout ou partie de la biosphère serait alors détruite par épuisement du carbone nécessaire à l'autoreproduction des nano-engins en question. Ce risque ne peut vraiment effrayer que celui qui croit à la possibilité de telles machines. Il suffit de nier cette possibilité pour écarter le pseudo risque d'un haussement d'épaules.

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[46] Des aspects militaires je ne dis rien ici – la confidentialité du sujet est maximale – sinon ceci: la concurrence que se livrent sur les NBIC à coup de milliards de dollars l'Amérique, le bloc asiatique (Chine, Taïwan, Japon) et l'Europe – laquelle a pris du retard -, est déjà pour une bonne part une course aux armements.

[47] Voir le rapport du groupe ETC - qui fit naguère plier Monsanto sur les OGM -, *The BigDown*, accessible sur la Toile à <http://www.etcgroup.org/documents/TheBigDown.pdf>. ETC a déposé un projet de moratoire sur les nanotechnologies à la conférence de Johannesbourg, qui n'a évidemment pas été retenu.

[48] HarperCollins, 2002.

La communauté scientifique se retrouve prisonnière du double langage qu'elle a souvent pratiqué dans le passé. Lorsqu'il s'agit de vendre son produit, les perspectives les plus grandioses sont agitées à la barbe des décideurs. Lorsque les critiques, alertés par tant de bruit, soulèvent la question des risques, on se rétracte: la science que nous faisons est modeste. Le génome contient l'essence de l'être vivant mais l'ADN n'est qu'une molécule comme une autre – et elle n'est même pas vivante! Grâce aux OGM, on va résoudre une fois pour toutes le problème de la faim dans le monde, mais l'homme a pratiqué le génie génétique depuis le Néolithique. Les nanobiotechnologies permettront de guérir le cancer et le Sida, mais c'est simplement la science qui continue son bonhomme de chemin. Par cette pratique du double langage, la science ne se montre pas à la hauteur de sa responsabilité.

Le lobby nanotechnologique a actuellement peur. Il a peur que son opération de relations publiques aboutisse à un ratage encore plus lamentable que celui qu'a connu le génie génétique. Avec la conférence d'Asilomar en 1975, les choses avaient pourtant bien commencé pour la communauté scientifique, du moins le croyait-elle. Elle avait réussi à se donner le monopole de la régulation du domaine. Trente ans plus tard, le désastre est accompli. La moindre réalisation biotechnologique fait figure de monstruosité aux yeux du grand public. Conscients du danger, les nanotechnologues cherchent une issue du côté de la "communication": calmer le jeu, rassurer, assurer l'"acceptabilité". Ce vocabulaire de la pub a quelque chose d'indécent dans la bouche des scientifiques.

Que faire? Il serait naïf de croire que l'on pourrait envisager un moratoire des recherches, ou même, à court terme, un encadrement législatif ou réglementaire, lequel, en tout état de cause, ne pourrait être que mondial. Les forces et les dynamiques à l'œuvre n'en feraient qu'une bouchée. Le mieux que l'on puisse espérer est d'accompagner, à la même vitesse que leur développement et, si possible, en l'anticipant, la marche en avant des nanotechnologies, par des études d'impact et un suivi permanent, non moins interdisciplinaires que les nanosciences elles-mêmes. Une sorte de mise en réflexivité en temps réel du changement scientifique et technique serait une première dans l'histoire de l'humanité. Elle est sans doute rendue inévitable par l'accélération des phénomènes.

La science, en tout cas, ne peut plus échapper à sa responsabilité. Cela ne veut évidemment pas dire qu'il faut lui donner le monopole du pouvoir de décision. Aucun scientifique ne le souhaite. Cela veut dire qu'il faut obliger la science à sortir de son splendide isolement par rapport aux affaires de la Cité. La responsabilité de décider ne peut se concevoir que partagée. Or c'est de cela que les scientifiques, tels qu'ils sont formés et tels qu'ils s'organisent à présent, ne veulent absolument pas. Ils préfèrent de beaucoup s'abriter derrière le mythe de la neutralité de la science. Qu'on les laisse accroître les connaissances en paix et que la société, sur cette base, décide de là où elle veut aller. Si tant est que ce discours ait jamais eu une quelconque pertinence, il est aujourd'hui irrecevable.

Les conditions de possibilité d'un partage et d'une articulation des responsabilités entre la science et la société ne sont aujourd'hui nulle part réunies. L'une de ces conditions, la principale peut-être, exige de l'un et l'autre partenaire une révolution mentale. Ils doivent ensemble viser, selon la belle expression du physicien Jean-Marc Lévy-Leblond, à mettre la science en culture. *Connaître* la science, c'est tout autre chose que s'informer à son sujet. La débilité des programmes scientifiques mis en place par les médias à l'adresse du grand public résulte, soit dit en passant, de la confusion entre information et culture scientifiques. C'est évidemment la manière dont on enseigne la science dans l'enseignement secondaire mais aussi supérieur qui est complètement à revoir. Introduire dans le cursus l'histoire et la philosophie des sciences est une nécessité[49], mais qui est loin d'être suffisante: la réflexion sur la science doit faire partie intégrante de l'apprentissage de la science. De ce point de vue, hélas, la plupart des scientifiques ne sont pas plus cultivés que l'homme de la rue. La raison en est la spécialisation du métier de scientifique. Dès le début du vingtième siècle, Max Weber, pour en revenir à lui, l'avait parfaitement senti. Dans sa conférence de 1917, *Wissenschaft als Beruf*, il prononçait ces terribles paroles:

> De nos jours, et au regard de l'organisation [*Betrieb*] scientifique, [la] vocation [scientifique] est d'abord déterminée par le fait que la science est parvenue à un stade de spécialisation qu'elle ne connaissait pas autrefois et dans lequel elle se maintiendra à jamais, pour autant que nous puissions en juger. L'affaire ne tient pas tellement aux conditions extérieures du travail scientifique qu'aux dispositions intérieures du savant lui-même: car jamais plus un individu ne pourra acquérir la certitude d'accomplir quelque chose de vraiment parfait dans le domaine de la science sans une spécialisation rigoureuse. [...] De nos jours l'œuvre vraiment définitive et importante est toujours une œuvre de spécialiste. Par conséquent, tout être qui est incapable de se mettre pour ainsi dire des œillères [...] ferait mieux tout bonnement de s'abstenir du travail scientifique. Jamais il ne ressentira en lui-même ce que l'on peut appeler l'"expérience" vécue de la science[50].

En dépit de leur brio, il faut souhaiter que les analyses de Max Weber soient, là comme ailleurs, démenties par l'avenir. Des savants avec des œillères, c'est précisément ce que nos sociétés ne peuvent plus se permettre de former, d'entretenir et de protéger. Il y va de notre survie. Nous avons besoin de scientifiques "réflexifs": moins naïfs par rapport à la gangue idéologique dans laquelle se trouvent souvent pris leurs programmes de recherche; mais aussi plus conscients que leur science repose irréductiblement sur une série de décisions métaphysiques. Quant à Dieu, qu'ils se passent de cette hypothèse si tel est leur bon plaisir.

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[49] Le rapport Lecourt sur l'enseignement de la philosophie des sciences aura été une œuvre de salut pubic. Voir http://www.ac-toulouse.fr/philosophie/ensei/rapportlecourt.htm

[50] *Le savant et le politique*, op. cit., p. 62-63.

Complexity and Uncertainty
A Prudential Approach To Nanotechnology[1]

Jean-Pierre Dupuy[2]

March 2004

1. Summary

We have become capable of tampering with, and triggering off, *complex* phenomena. As a consequence we have to confront a new kind of *uncertainty*. The "Precautionary Principle" is of little help in that task. *Anticipating the consequences* of our technological choices is at the same time more important and more difficult than ever. What is desperately required is a novel *science of the future*.

2. Table of Contents

1. The debate about molecular manufacturing

Eric Drexler, the inventor of the notion of nanotechnology, and Christine Peterson, the President of the Foresight Institute, are notoriously keen to make the distinction between "near-term nanotechnology" and "advanced nanotechnology". The former refers to any technology smaller than microtechnology, e.g. nanoparticles; the latter to " complete control of the physical structure of matter, all the way down to the atomic level.[3]" It is of course advanced nanotechnology, also known as molecular

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[1] A paper prepared for the March 1-2, 2004 meeting of the Directorate-General for Health and Consumer Protection of the European Commission, "Mapping Out Nano Risks".

[2] Ecole Polytechnique, Paris, and Stanford University. Email: jpdupuy stanford.edu.

[3] Christine Peterson, a testimony given before the U.S. House of Representatives Committee on Science, April 9, 2003.

manufacturing, that will have major societal impact and possibly entail major risks, provided that ... it will see the light of day.

As is well known, controversy is still raging about the physical, technical, industrial, economical feasibility of molecular manufacturing. As Peterson puts it, "Until this issue has been put to rest, neither a funded molecular manufacturing R&D project nor effective study of societal implications can be carried out. [...] We urgently need a basic feasibility review in which molecular manufacturing's proponents and critics can present their technical cases to a group of unbiased physicists for analysis[4]."

In July 2003, the UK Economic and Social Research Council published a report entitled "The Social and Economic Challenges of Nanotechnology". It pointed to the current debate "about whether the radical view of nanotechnology, leading to molecular manufacturing, is feasible or practical, whether by the route sketched out by Drexler or some other means. Those who consider this radical view of nanotechnology to be feasible are divided as to whether it will lead to a positive or negative outcome for society. This debate takes for granted that nanotechnology will have a revolutionary effect on society, and the contrasting visions are correspondingly utopian or dystopian."

On 18 November 2003, the US Senate passed the 21st Century Nanotechnology Research and Development Act, "to authorize appropriations for nanoscience, nanoengineering and nanotechnology research, and for other purposes". It called for a one-time study on the responsible development of nanotechnology "including, but not limited to, *self-replicating nanoscale machines or devices; the release of such machines in natural environments*; encryption; the development of defensive technologies; the use of nanotechnology in the enhancement of human intelligence; and the use of nanotechnology in developing AI.[5]" Many have interpreted this as an opportunity and a challenge to those who support Drexler's vision of molecular manufacturing to make their case, or even as an endorsement of the feasibility of that program. In contrast, the studies performed by the UK's Royal Society/Royal Academy of Engineering are still wondering what nanotechnology is all about, without the least mention of molecular manufacturing.

Richard Smalley, the Nobel laureate in chemistry who was one of the discoverers of the fullerene (C 60), has been challenging Eric Drexler on the possibility of molecular manufacturing. Recently the former accused the latter of scaring children with stories of self-replicating nanobots going haywire, and the latter replied by saying, "U.S. progress in molecular manufacturing has been impeded by the dangerous illusion that it is infeasible. [...]Building with atomic precision will dramatically extend the range of potential products and decrease environmental impact as well. The resulting

4 Ibid.

5 My emphasis.

abilities will be so powerful that, in a competitive world, failure to develop molecular manufacturing would be equivalent to unilateral disarmament.[6]"

The debate between the two men has also been quite technical, and it is all about the limitations of chemistry. Smalley asserts that atoms cannot simply be pushed together to make them react as desired, in the manner fancied by Drexler, but that their chemical environment must be controlled in great detail, through a many-dimensional hyperspace, and that this cannot be achieved with simple robotics. Drexler rejoins that such components of cells as enzymes or ribosomes are able to do precise and reliable chemistry. Smalley agrees but adds that this can occur only under water. Drexler replies that his proposal does assert that chemistry in dry surfaces and a vacuum ("machine-phase chemistry") can be quite flexible and efficient, since holding a molecule in one place can have a strong catalytic effect. Drexler ends his statements by calling for further research, beginning with an independent scientific review of molecular manufacturing concepts.

An advocate of Drexler's program recently wrote:

> *Failure to anticipate the development of molecular manufacturing could have serious consequences.* Simple physics theories, conservatively applied, predict that the technology will be dangerously powerful. A working molecular nanotechnology will likely require the design and enforcement of policies to control the use of compact advanced manufacturing systems and their products. But panicked last-minute policy will be bad policy—simultaneously oppressive and ineffective. The military implications are even more perilous. Molecular manufacturing systems are expected to be able to produce weapons as powerful as nuclear bombs, but much more selective, easier to manufacture, and easier to use. If a powerful nation suddenly realizes that molecular manufacturing is possible, and discovers that rival nations are already making material progress, they may react violently, or may enter into an arms race that will probably be unstable and thus may result in war with weapons of unprecedented power.
>
> On the positive side, molecular manufacturing may be able to mitigate many of the world's humanitarian and environmental crises. Advancing its development by even a year or two could alleviate untold suffering, raising standards of living worldwide while sharply reducing our environmental footprint. However, rapid and effective humanitarian use may also depend on sound policy developed well in advance[7].

My opinion on this is the following. The Smalley – Drexler debate is a red herring, and we should refrain from taking a position about it, even if we had the scientific and technological expertise to do so. There is no doubt that molecular manufacturing is feasible once we regard molecular biology itself as a form of it. *The issue is not one of essence but of point of view*. As soon as we construe the cell as natural machinery, the

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6 "Nanotechnology. Drexler and Smalley make the case for and against 'molecular assemblers'", *Chemical & Engineering News*, December 1, 2003.
See http://pubs.acs.org/cen/coverstory/8148/8148counterpoint.html

7 Chris Phoenix, "Of Chemistry, Nanobots, and Policy", Center for Responsible Nanotechnology, December 2003. http://crnano.org/Debate.htm.

possibility of tampering with it becomes a forgone conclusion. If the feasibility of molecular self-assembly is beyond question, it is because we have developed a view of nature and the living system that is akin to our own artifacts.

2. Complexity and Self-organization

It is often asserted that the starting point of nanotechnology was the classic talk given by Feynman in 1959[8], in which he said: "The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom. [...] It would be, in principle, possible (I think) for a physicist to synthesize any chemical substance that the chemist writes down. Give the orders and the physicist synthesizes it. How? Put the atoms down where the chemist says, and so you make the substance." Today's champions of nanotech add: "We need to apply at the molecular scale the concept that has demonstrated its effectiveness at the macroscopic scale: making parts go where we want by *putting* them where we want![9]"

I tend to disagree. If such were the essence of (advanced) nanotechnology, the worries that it raises would rest on sheer ignorance. As *Nature* science writer Philip Ball puts it in his excellent essay, "2003: nanotechnology in the firing line"[10]:

> In March [2003], the Royal Institution (RI) in London hosted a day-long seminar on nanotech called "Atom by atom", which I personally found useful for hearing a broad cross-section of opinions on what has become known as *nanoethics*. [...] First, the worry was raised that what is qualitatively new about nanotech is that it allows, for the first time, the manipulation of matter at the atomic scale. This may be a common view, and it must force us to ask: how can it be that we live in a society where it is not generally appreciated that this is what chemistry has done in a rational and informed way for the past two centuries and more? How have we let that happen? It is becoming increasingly clear that the debate about the ultimate scope and possibilities of nanotech revolve around questions of basic chemistry [...]. The knowledge vacuum in which much public debate of nanotech is taking place exists because we have little public understanding of chemistry: what it is, what it does, and what it can do.

Writing about nanoethics, Ball goes on to say:

> Questions about safety, equity, military involvement and openness are ones that pertain to many other areas of science and technology. It would be a grave and possibly dangerous distortion if nanotechnology were to come to be seen as a discipline that raises unprecedented ethical and moral issues. In this respect, I think it genuinely does differ from some aspects of biotechnological research, which broach entirely new moral questions. Yet it is perhaps the first major field of science, applied science or technology - call it what you will - to have emerged in a social climate that is sensitized in advance to the need for ethical debate in emerging technologies.

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8 "There's Plenty of Room At the Bottom".

9 See http://www.zyvex.com/nano/.

10 Nanotechweb.org, 23 December 2003. http://www.nanotechweb.org/articles/society/2/12/1/1

> [...]Yet the pragmatic truth is that if nanotechnology does not acknowledge some kind of ethical dimension, it will be forced upon it in any case. Those working in the field know that nanotech is not really a discipline at all, that it has no coherent aims and is not the sole concern of any one industrial sector. But even funding agencies speak of it as though this were not so. To the public mind, organizations such as the US National Nanotechnology Initiative surely suggest by their very existence that nanotech has some unity, and it is therefore quite proper that people will want to be reassured that its ethical aspects are being considered.

Here I cannot follow Philip Ball. I believe him to be wrong on two major accounts. I believe there is indeed some kind of unity behind the nanotech enterprise and even behind the NBIC convergence; but that this unity lies at the level of the metaphysical research program that underpins such convergence. I also believe that the ethical issues raised by it are to a large extent novel and that they find their source in the very *ideas* that govern the field.

In order to substantiate those two claims, I submit that the origin of the new field is to be sought in another classic conference, the one John von Neumann gave at Caltech in 1948 on complexity and self-reproducing automata.

Turing's and Church's theses were very influential at the time, and they had been supplemented by cyberneticians Warren McCulloch and Walter Pitts' major finding on the properties of neural networks. Cybernetics' Credo was then: every behavior that is unambiguously describable in a finite number of words is computable by a network of formal neurons---a remarkable statement, as John von Neumann recognized. However, he put forward the following objection: is it reasonable to assume as a practical matter that our most complex behaviors are describable in their totality, without ambiguity, using a finite number of words? In specific cases it is always possible: our capacity, for example, to recognize the same triangular form in two empirical triangles displaying differences in line, size, and position can be so described. But would this be possible if it were a matter of globally characterizing our capacity for establishing "visual analogies"? In that case, von Neumann conjectured, *it may be that the simplest way to describe a behavior is to describe the structure that generates it.* It is meaningless, under these circumstances, to "discover" that such a behavior can be embodied in a neural network since it is not possible to define the behavior other than by describing the network itself.

Von Neumann thus posed the question of complexity, foreseeing that it would become the great question for science in the future. Complexity implied for him in this case the futility of the constructive approach of McCulloch and Pitts, which reduced a function to a structure---leaving unanswered the question of what a complex structure is capable[11].

[11] Here as elsewhere, the irony of intellectual history is great. Marvin Minsky, who wrote his doctoral thesis under von Neumann, regarded his teacher's attack on McCulloch's approach as an aberration, an admission of weakness, a lack of faith in what he himself, John von Neumann, had managed to accomplish. Now, as is well known, Eric Drexler wrote his dissertation on nanotech under Minsky's supervision!

It was of course in the course of his work on automata theory that von Neumann was to refine this notion of complexity. Assuming a magnitude of a thermodynamical type, he conjectured that below a certain threshold it would be degenerative, meaning that the degree of organization could only decrease, but that above this threshold an increase in complexity became possible. Now this threshold of complexity, he supposed, is also the point at which the structure of an object becomes simpler than the description of its properties. Soon, JVN prophesied, the builder of automata would find himself as helpless before his creation as we feel ourselves to be in the presence of complex natural phenomena.[12]

At any rate, JVN was thus founding the so-called *bottom-up approach* aka reverse engineering. In keeping with that philosophy, the engineers of the future will not be any more the ones who devise and design a structure capable of fulfilling a function that has been assigned to them. The engineers of the future will be the ones who know they are successful when they are surprised by their own creations. If one of your goals is to reproduce life, to fabricate life, you have to be able to simulate one of its most essential properties, namely the capacity to complexify itself always more.

Admittedly, not all of nanotech falls under the category of complexity. However, the scope covered by it, especially in the case of the NBIC convergence, is much wider and relevant than the implications of a possible Drexler-type molecular manufacturing. Even more importantly, the novel kind of uncertainty that is brought about by those new technologies is intimately linked with their being able to set off complex phenomena in the Neumannian sense.

3. Unchaining Complexity

It would be a mistake to think that, although novel, our current situation before the consequences of our technological choices is not the outcome of a long historical process. Discontinuities and ruptures must always be analyzed against the background of continuous dynamics. In her masterly study of the frailties of human action, *Human Condition*[13], Hannah Arendt brought out the fundamental paradox of our time: as human powers increase through technological progress, we are less and less equipped to control the consequences of our actions. A long excerpt is worth quoting here, as its relevance for our topic cannot be overstated – and we should keep in mind that this was written in 1958:

> [...] the attempt to eliminate action because of its uncertainty and to save human affairs from their frailty by dealing with them as though they were or could become the planned products of human making has first of all resulted in channeling the human capacity for action, for beginning new and spontaneous processes which without men never would come into existence, into an attitude toward nature which up to the latest stage of the modern age had been one of exploring natural laws and fabricating objects out of natural material. To what extent we have begun to *act into nature*, in the literal sense of the word, is perhaps best illustrated by a recent casual remark of a scientist who quite

[12] On all that, see my *The Mechanization of the Mind*, Princeton University Press, 2000.

[13] The University of Chicago Press, 1958.

> seriously suggested that "*basic research is when I am doing what I don't know what I am doing*." [Wernher von Braun, December 1957].
>
> This started harmlessly enough with the experiment in which men were no longer content to observe, to register, and contemplate whatever nature was willing to yield in her own appearance, but began to prescribe conditions and to provoke natural processes. What then developed into an ever-increasing skill in *unchaining elemental processes*, which, without the interference of men, would have lain dormant and perhaps never have come to pass, has finally ended in a veritable art of *'making' nature*, that is, of creating 'natural' processes which without men would never exist and which earthly nature by herself seems incapable of accomplishing [...].
>
> The very fact that natural sciences have become exclusively sciences of process and, in their last stage, *sciences of potentially irreversible, irremediable 'processes of no return'* is a clear indication that, whatever the brain power necessary to start them, *the actual underlying human capacity which alone could bring about this development is no 'theoretical' capacity, neither contemplation nor reason, but the human ability to act* – to start new unprecedented processes whose outcome remains uncertain and unpredictable whether they are let loose in the human or the natural realm.
>
>> In this aspect of action [...] processes are started whose outcome is unpredictable, so that *uncertainty rather than frailty becomes the decisive character of human affairs*[14].

No doubt that with an incredible prescience this analysis applies perfectly well to the NBIC convergence, in particular on two scores. Firstly, the ambition to (re-) make nature is an important dimension of what I called the metaphysical underpinnings of the field. If the NBIC converging technologies purport to take over Nature's and Life's job and become the engineers of evolution, it is because they have redefined Nature and Life in terms that belong to the realm of artifacts. See how one of their most vocal champions, Damien Broderick, rewrites the history of life, or, as he puts it, of "living replicators":

> *Genetic algorithms* in planetary numbers lurched about on the surface of the earth and under the sea, and indeed as we now know deep within it, for billions of years, replicating and mutating and being winnowed via the success of their expressions – that is, the bodies they *manufactured*, competing for survival in the macro world. At last, the entire living ecology of the planet has *accumulated, and represents a colossal quantity of compressed, schematic information*.[15]

Once life has thus been transmogrified into an artifact, the next step is to ask oneself whether the human mind couldn't do better. The same author asks rhetorically, "Is it

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14 P. 230-232. My emphasis.

15 Damien Broderick, *The Spike*, Forge, New York, 2001, p. 116. My emphasis.

likely that nanosystems, designed by human minds, will bypass all this ¨Darwinian wandering, and leap straight to design success?[16]"

Secondly, as explained before, it will be an inevitable temptation, not to say a task or a duty, for the nanotechnologists of the future to set off processes upon which they have no control. The sorcerer's apprentice myth must be updated: it is neither by error nor by terror that Man will be dispossessed of his own creations but by design.

There is no need for Drexlerian self-assemblers to come into existence for this to happen. The paradigm of *complex, self-organizing systems* envisioned by von Neumann is stepping ahead at an accelerated pace, both in science and in technology. It is in the process of shoving away and replacing the old metaphors inherited from the cybernetic paradigm, like the ones that treat the mind or the genome as computer programs. In science, the central dogmas of molecular biology received a severe blow on two occasions recently. First, with the discovery that the genome of an adult, differentiated cell can be "reprogrammed" with the cooperation of maternal cytoplasm – hence the technologies of nucleus transfer, including therapeutic and reproductive cloning. Secondly, with the discovery of prions, which showed that self-replication does not require DNA. As a result, the sequencing of the human genome appears to be not the end of the road but its timid beginning. Proteinomics and Complexity are becoming the catchwords in biology, relegating Genomics to the realm of passé ideas.

In technology, new feats are being flaunted every passing week. Again, the time has not come – and may never come – when we manufacture self-replicating machinery that mimics the self-replication of living materials. However, we are taking more and more control of living materials and their capacity for self-organization and we use them to mimic smart machinery or perform mechanical functions.

Examples are plenty. To name just a few: in December 2003, IBM managed to create silicon memory chips using a template provided by *a plastic polymer that organizes itself naturally*. One application of the technology could be to design flash memory chips with cells roughly 1/100th the size of the cells currently required to store a piece of data. More broadly, IBM said, "the successful research suggests that *polymer-based self-assembly techniques* could be used to build other kinds of microchips in the future, when more features shrink to such small scales that current production techniques become impractical[17]". On the same month, scientists from DuPont, the University of Illinois at Urbana-Champaign and the MIT used the self-assembly of DNA to sort carbon nanotubes according to their diameter and electronic properties. DuPont said, "spontaneous self-assembly of nucleic acid bases occurs on a variety of inorganic surfaces. This phenomenon, considered as an important prebiotic process relevant to the origin of life, has led us to seek a new function for nucleic acids in the manipulation of inorganic nanomaterials, where interfacial interactions dominate." The feat will have momentous applications, since "the separation of carbon nanotubes is

[16] Ibid., p. 118.

[17] See Barnaby Feder, "I.B.M. set to unveil chip-making advance", *New York Times*, December 8, 2003: http://www.siliconinvestor.com/stocktalk/msg.gsp?msgid=19572729.

the single greatest impediment to their technological application.[18]" Last November, scientists in Israel built transistors out of carbon nanotubes using DNA as a template. A Technion-Israel scientist said, "What we've done is to bring biology to *self-assemble an electronic device* in a test tube [...]The DNA serves as a scaffold, a template that will determine where the carbon nanotubes will sit. That's the beauty of using biology.[19]" Etc. etc.

4. A new kind of uncertainty and the irrelevance of the Precautionary Principle

Our tampering with, and setting off complex processes, in the technical, Neumannian sense of the word "complex", brings about a kind of uncertainty that is radically novel. In particular, it is completely alien to the distinctions upon which rests the Precautionary Principle.

The precautionary principle introduces what initially appears to be an interesting distinction between two types of risks: "known" risks and "potential" risks. It is on this distinction that the difference between prevention and precaution is made to rest: precaution would be to potential risks what prevention is to known risks.

A closer look reveals 1) that the expression "potential risk" is poorly chosen, and that what it designates is not a risk waiting to be realized, but a hypothetical risk, one that is only a matter of conjecture; 2) that the distinction between known risks and hypothetical risks (the term I will adopt here) corresponds to an old standby of economic thought, the distinction that John Maynard Keynes and Frank Knight independently proposed in 1921 between *risk* and *uncertainty*. A risk can in principle be quantified in terms of objective probabilities based on observable frequencies; when such quantification is not possible, one enters the realm of uncertainty.

The problem is that economic thought and the decision theory underlying it were destined to abandon this distinction as of the 1950s in the wake of the exploit successfully performed by Leonard Savage with the introduction of the concept of subjective probability and the corresponding philosophy of choice under conditions of uncertainty: Bayesianism. In Savage's axiomatics, probabilities no longer correspond to any sort of regularity found in nature, but simply to the coherence displayed by a given agent's choices. In philosophical language, every uncertainty is treated as an *epistemic* uncertainty, meaning an uncertainty associated with the agent's state of knowledge. It is easy to see that the introduction of subjective probabilities erases the distinction between uncertainty and risk, between risk and the risk of risk, between precaution and prevention. If a probability is unknown, a probability distribution is assigned to it "subjectively". Then the probabilities are composed following the computation rules of the same name. No difference remains compared to the case where objective probabilities are available from the outset. Uncertainty owing to lack of knowledge is brought down to the same plane as intrinsic uncertainty due to the random nature of the event under consideration. A risk economist and an insurance

18 Liz Kalaugher, "DNA sorts out nanotubes", *Nanotechweb.org*,, 3 December 2003: http://www.nanotechweb.org/articles/news/2/12/1/1.

19 Kenneth Chang, " Smaller Computer Chips Built Using DNA as Template", *New York Times*, November 21, 2003: http://www.nytimes.com/2003/11/21/science/21DNA.html?ex=1075525200&en=67948bd27029a142&ei=5070.

theorist do not see and cannot see any essential difference between prevention and precaution and, indeed, reduce the latter to the former. In truth, one observes that applications of the "precautionary principle" generally boil down to little more than a glorified version of "cost-benefit" analysis.

Against the prevailing economism, I believe it is urgent to safeguard the idea that *all is not epistemic uncertainty*. One could however argue from a philosophical standpoint that such is really the case. The fall of a die is what supplied most of our languages with the words for chance or accident. Now, the fall of a die is a physical phenomenon that is viewed today as a low-stability deterministic system, sensitive to initial conditions, and therefore unpredictable — a "*deterministic chaos*," in current parlance. But an omniscient being — the God of whom Laplace did not judge it necessary to postulate the existence — would be able to predict on which side the die is going to fall. Could one not then say that what is uncertain for us, but not for this mathematician-God, is uncertain only because of lack of knowledge on our part? And therefore that this uncertainty, too, is epistemic and subjective?

The correct conclusion is a different one. If a random occurrence is unpredictable for us, this is not because of a lack of knowledge that could be overcome by more extensive research; it is because only an infinite calculator could predict a future which, given our finiteness, we will forever be unable to anticipate. Our finiteness obviously cannot be placed on the same level as the state of our knowledge. The former is an unalterable aspect of the human condition; the latter, a contingent fact, which could at any moment be different from what it is. We are therefore right to treat the random event's uncertainty *for us* as an objective uncertainty, even though this uncertainty would vanish for an infinite observer.

Now, our situation with respect to the complex phenomena we are about to unleash is also one of objective, and not epistemic, uncertainty. The novel feature this time is that we are not dealing with a random occurrence either. Neither random, nor epistemically uncertain, the type of "risk" that we are confronting is a monster from the standpoint of classic distinctions. Indeed, it merits a special treatment, which the precautionary principle is incapable of giving it.

We know today that what makes a complex system, (e. g. a network of molecules connected by chemical reactions or a trophic system) robust is exactly what makes it exceedingly vulnerable if and when certain circumstances are met. As Albert-László Barabási puts it, this "coexistence of robustness and vulnerability plays a key role in understanding the behavior of most complex systems. [...] topology, robustness, and vulnerability cannot be fully separated from one another. All complex systems have their Achilles' heel.[20]" Complexity gives those systems an extraordinary stability and a no less remarkable resilience. They can hold their own against all sorts of aggressions and find ways of adapting to maintain their stability. This is only true up to a certain point, however. Beyond certain *tipping points*, they veer over abruptly into something different, in the fashion of phase changes of matter, collapsing completely or else forming other types of systems that can have properties highly undesirable for people. In mathematics, such discontinuities are called *catastrophes.* This sudden loss of

20 *Linked. The New Science of Networks*, Perseus Publishing, Cambridge (Mass.), 2002, p. 118 and 121-122.

resilience gives complex systems a particularity which no engineer could transpose into an artificial system without being immediately fired from his job: the alarm signals go off only when it is too late. And in most cases we do not even know where these tipping points are located. Our uncertainty regarding the behavior of complex systems has thus nothing to do with a temporary insufficiency of our knowledge, it has everything to do with objective, structural properties of complex systems.

On the other hand, this uncertainty is not of the kind that is attached to random events and it is not amenable to the concept of probability. The key notion here is that of informational *incompressibility*, which is a form of *essential unpredictability*. In keeping with von Neumann's intuitions on complexity, a complex process is defined today as one for which the simplest model is the process itself. The only way to determine the future of the system is to run it: there are no shortcuts. This is a radical uncertainty: in contrast with a deterministic chaos – the source of randomness –, perfect knowledge of the initial conditions would not be enough to predict the future states of the system. Its unpredictability is irremediable.

When the precautionary principle states that the "absence of certainties, given the current state of scientific and technical knowledge, must not delay the adoption of effective and proportionate preventive measures aimed at forestalling a risk of grave and irreversible damage to the environment at an economically acceptable cost", it is clear that it places itself from the outset within the framework of epistemic uncertainty. The presupposition is that *we know we are in a situation of uncertainty*. It is an axiom of epistemic logic that if I do not know p, then I know that I do not know p. Yet, as soon as we depart from this framework, we must entertain the possibility that we do not know that we do not know something. An analogous situation obtains in the realm of perception with the blind spot, that area of the retina unserved by the optic nerve. At the very center of our field of vision, we do not see, but our brain behaves in such a way that we do not see that we do not see. In cases where the uncertainty is such that it entails that the uncertainty itself is uncertain, it is impossible to know whether or not the conditions for the application of the precautionary principle have been met. If we apply the principle to itself, it will invalidate itself before our eyes.

Moreover, "given the current state of scientific and technical knowledge" implies that a scientific research effort could overcome the uncertainty in question, whose existence is viewed as purely contingent. It is a safe bet that a "precautionary policy" will inevitably include the edict that research efforts must be pursued — as if the gap between what is known and what needs to be known could be filled by a supplementary effort on the part of the knowing subject. But it is not uncommon to encounter cases in which *the progress of knowledge comports an increase in uncertainty* for the decision-maker, something that is inconceivable within the framework of epistemic uncertainty. Sometimes, to learn more is to discover hidden complexities that make us realize that the mastery we thought we had over phenomena was in part illusory.

5. Toward a new science of the future

"We have met the Enemy and He is Us"

Pogo Possum

5.1. In Search of an Ethics of the Future

German philosopher Hans Jonas' fundamental book, *The Imperative of Responsibility*[21], cogently explains why we need a radically new ethics to rule our relation to the future in the "technological age". This "Ethics of the Future" [*Ethik **für** die Zukunft*] - meaning not a future ethics, but an ethics *for* the future, for the sake of the future, i.e. the future must become the major object of our concern – starts from a philosophical aporia. Given the magnitude of the possible consequences of our technological choices, it is an absolute obligation for us to try and anticipate those consequences, assess them, and ground our choices on this assessment. Couched in philosophical parlance, this is tantamount to saying that when the stakes are high, we cannot afford not to choose consequentialism[22], rather than a form of deontology[23], as our guiding moral doctrine. However, the very same reasons that make consequentialism compelling, and therefore oblige us to anticipate the future, make it impossible for us to do so. Unleashing complex processes is a very perilous activity that both demands foreknowledge and prohibits it. To take just an illustration:

> The unpredictable behaviour of nanoscale objects means that engineers will not know how to make nanomachines until they actually start building them[24].

Now, one of the very few unassailably universal ethical principles is that *ought* implies *can*. There is no obligation to do that which one can not do. However, in the technological age, we do have an ardent obligation that we cannot fulfill: anticipating the future. That is the ethical aporia.

Is there a way out? Jonas's credo, which I share, is that there is no ethics without metaphysics. Only a radical change in metaphysics can allow us to escape from the ethical aporia. The major stumbling block of our current, implicit metaphysics of temporality turns out to be our conception of the *future as indeterminate*. From our belief in free will – we might act otherwise – we derive the conclusion that the future is *not real*, in the philosophical sense: "future contingents", i.e. propositions about actions taken by a free agent in the future, e.g. "John will pay back his debt tomorrow", are held to have no truth value. They are neither true nor false. If the future

[21] Hans Jonas, *The Imperative of Responsibility. In Search of an Ethics for the Technological Age*, University of Chicago Press, 1985.

[22] Consequentialism as a moral doctrine has it that what counts in evaluating an action is its consequences for all individuals concerned.

[23] A deontological doctrine evaluates the rightness of an action in terms of its conformity to a norm or a rule, such as the Kantian categorical imperative.

[24] *The Economist*, March 2003.

is not real, it is not something that we can have cognizance of. If the future is not real, it is not something that projects its shadow onto the present. Even when we know that a catastrophe is about to happen, we do not believe it: we do not believe what we know. If the future is not real, there is nothing in it that we should fear, or hope for.

The derivation from free will to the unreality of the future is a sheer logical fallacy, although it would require some hard philosophical work to prove it[25]. Here I will content myself with exhibiting the sketch of an alternative metaphysics in which free will combines with a particularly hard version of the reality of the future.

Before I broach the metaphysical and final part of this discussion, I should like to add a further ethical reflection that compounds the need we are in to bestow some measure of reality onto the future.

I am referring to the concept of "moral luck" in moral philosophy. I will introduce it with the help of two contrasting thought experiments. In the first, one must reach into an urn containing an infinite number of balls and pull one out at random. Two thirds of the balls are black and only one third are white. The idea is to bet on the color of the ball before seeing it. Obviously, one should bet on black. And if one pulls out another ball, one should bet on black again. In fact, one should *always* bet on black, even though one foresees that one out of three times on average this will be an incorrect guess. Suppose that a white ball comes out, so that one discovers that the guess was incorrect. Does this *a posteriori* discovery justify a retrospective change of mind about the rationality of the bet that one made? No, of course not; one was right to choose black, even if the next ball to come out happened to be white. Where probabilities are concerned, the information as it becomes available can have no conceivable retroactive impact on one's judgment regarding the rationality of a past decision made in the face of an uncertain or risky future. This is a limitation of probabilistic judgment that has no equivalent in the case of moral judgment. Here we touch upon a second serious deficiency of the precautionary principle. As it is unable to depart from the normativity proper to the calculus of probabilities and the cost-benefit approach, it fails to capture what constitutes the essence of ethical normativity concerning choice in a situation of uncertainty.

A man spends the evening at a cocktail party. Fully aware that he has drunk more than is wise, he nevertheless decides to drive his car home. It is raining, the road is wet, the light turns red, and he slams on the brakes, but a little too late: after briefly skidding, the car comes to a halt *just past* the pedestrian crosswalk. Two scenarios are possible: Either there was nobody in the crosswalk, and the man has escaped with no more than a retrospective fright. Or else the man ran over and killed a child. The judgment of the law, of course, but above all that of morality, will not be the same in both cases. Here is a variant: The man was sober when he drove his car. He has nothing for which to

[25] See my *Pour un catastrophisme éclairé*, Paris, Seuil, 2002. See also Jean-Pierre Dupuy, "Philosophical Foundations of a New Concept of Equilibrium in the Social Sciences: Projected Equilibrium", *Philosophical Studies*, **100**, 2000, p. 323-345; Jean-Pierre Dupuy, "Two temporalities, two rationalities: a new look at Newcomb's paradox", in P. Bourgine et B. Walliser (eds.), *Economics and Cognitive Science*, Pergamon, 1992, p. 191-220; Jean-Pierre Dupuy, «Common knowledge, common sense», *Theory and Decision*, 27, 1989, p. 37-62. Jean-Pierre Dupuy (ed.), *Self-deception and Paradoxes of Rationality*, C.S.L.I. Publications, Stanford University, 1998.

reproach himself. But there is a child whom he runs over and kills, or else there is not. Once more, the unpredictable outcome will have a retroactive impact on the way the man's conduct is judged by others and also by the man himself.

Here is a more complex example devised by the British philosopher Bernard Williams,[26] which I will simplify considerably. A painter — we'll call him "Gauguin" for the sake of convenience — decides to leave his wife and children and take off for Tahiti in order to live a different life which, he hopes, will allow him to paint the masterpieces that it is his ambition to create. Is he right to do so? Is it moral to do so? Williams defends with great subtlety the thesis that any possible justification of his action can only be retrospective. Only the success or failure of his venture will make it possible for us — and him — to cast judgment. Yet whether Gauguin becomes a painter of genius or not is in part a matter of luck — the luck of being able to become what one hopes to be. When Gauguin makes his painful decision, he cannot know what, as the saying goes, the future holds in store for him. To say that he is making a bet would be incredibly reductive. With its appearance of paradox, the concept of "moral luck" provides just what was missing in the means at our disposal for describing what is at stake in this type of decision made under conditions of uncertainty.

Like Bernard Williams' Gauguin, but on an entirely different scale, humanity taken as a collective subject has made a choice in the development of its potential capabilities which brings it under the jurisdiction of moral luck. It may be that its choice will lead to great and irreversible catastrophes; it may be that it will find the means to avert them, to get around them, or to get past them. No one can tell which way it will go. The judgment can only be retrospective. However*, it is possible to anticipate, not the judgment itself, but the fact that it must depend on what will be known once the "veil of ignorance" cloaking the future is lifted.* Thus, there is still time to insure that our descendants will never be able to say *"too late!"* — a too late that would mean that they find themselves in a situation where no human life worthy of the name is possible.

Hence the bold metaphysical move advocated by Hans Jonas. The idea is to *project oneself* into the future and look back at our present and evaluate it from there. This temporal *loop* between future and past I call the metaphysics of *projected time*. As we are going to see, it makes sense only if one accepts that the future is not only real but also fixed.

5.2. *A Critique of the Scenario Approach*

For the last half century, futurology has been equated with the scenario approach. If some credit is granted the foregoing, it appears that this method is no longer appropriate to tackle the kind of radical uncertainty that we are confronting.

Ever since its beginnings the scenario approach has gone to great lengths to distinguish itself from mere forecast or foresight, held to be an extension into the future of trends observed in the past. We can forecast the future state of a physical system, it is said, but not what we shall decide to do. It all started in the 50s when a Frenchman, Gaston

[26] Bernard Williams, *Moral Luck,* Cambridge, Cambridge University Press, 1981.

Berger, coined the term "*Prospective*" – a substantive formed after "Retrospective" – to designate a new way to relate to the future. That this new way had nothing to do with the project or the ambition of anticipating, that is, *knowing* the future, was clearly expressed in the following excerpt from a lecture given by another Frenchman, Bertrand de Jouvenel, in 1964:

> The purpose is to generate a habit, the habit of forward-looking. We feel that as this grows into a habit, we, or our successors, shall develop in this exercise greater skill, thanks to self-criticism and mutual criticism. At the outset we encountered in the authors we solicited a great reluctance to embark upon such speculation. They said it was unscholarly, which of course it is, but it happens to be necessary. It is unscholarly perforce because there are no facts on the future. Cicero quite rightly contrasted past occurrences and occurrences to come with the contrasted expressions *facta* and *futura*: *facta*, what is accomplished and can be taken as solid; *futura*, what shall come into being, and is as yet 'undone,' or fluid. This contrast leads me to assert vigorously: *'there can be no science of the future.' The future is not the realm of the 'true or false' but the realm of 'possibles.'*

Another term coined by Jouvenel that was promised to a bright ... future was "*Futuribles*"[27], meaning precisely the open diversity of *possible futures*. The exploration of that diversity was to become the scenario approach.

Again, the premises on which the whole enterprise rests are at best arbitrary metaphysical presuppositions and ones, to repeat, that we can no longer afford to entertain. If we do not bring ourselves to believe in the reality of the future, we'll never be able to measure up to the challenges that lie ahead[28]. And those who claim that those presuppositions derive from the freedom of the will are just committing a serious philosophical blunder. Thus Michel Godet, one of the foremost among today's "prospectivists", could write

> All who claim to foretell or forecast the future are inevitably liars, for the future is not written anywhere – it is still to be built. This is fortunate, for without this uncertainty, human activity would lose its degree of freedom and its meaning – the hope of a desired future. If the future were totally foreseeable and certain, the present would become unlivable. Certainty is death. Because the future has to be built, it also cannot be conceived as a simple continuation of the past[29].

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27 The tradition launched by Bertrand de Jouvenel continues today in a journal called *Futuribles*, edited by his own son Hugues.

28 Another early proponent of "Prospective" was Robert Jungk. In 1960, as he was interviewing victims of the Hiroshima atomic bomb, he met a man under 50 who looked 80. That man said to him in a sedate manner: "How could all those intelligent people have dropped this bomb without thinking of the consequences?" That encounter was what prompted Jungk to devote his life to future studies.

29 Michel Godet and Fabrice Roubelat, "Creating the future: the use and misuse of scenarios", *Long Range Planning*, 29, 2, 1996.

This passage is also typical of a confusion that spoils much of what is being offered as a justification of the scenario approach. On the one hand, the alleged irreducible multiplicity of the "futuribles" is explained by the *ontological indeterminacy* of the future: since we "build", "invent" the future, there is nothing to know about it. On the other hand, the same multiplicity is interpreted as the inevitable reflection of our inability to know the future *with certainty*. The confusion of ontological indeterminacy with *epistemic uncertainty* is a very serious one, as explained above[30].

To underline the weaknesses of the philosophical foundations of the scenario method is not to deny its many virtues. There is no question that it has helped individuals, groups, and nations to find new ways to coordinate through a jointly worked-out image of the future shared by all. However that has been achieved in a paradoxical way. The method aimed at emphasizing the importance of the future while it denied its reality. Hence the essential question, is there a way to protect the democratic virtues of the scenario approach while jettisoning its unsuitable metaphysics?

5.3. *From Occurring Time to Projected Time*

If the future is ontologically indeterminate shouldn't we say the same about the past? After all, there was a time when our past was the future of its own past. French biographer André Maurois once went so far as to write:

> There is no privileged past (...) There is an infinitude of Pasts, all equally valid (...) At each and every instant of Time, however brief you suppose it, the line of events forks like the stem of a tree putting forth twin branches[31].

Dutch historian Johan Huizinga had already paved the way by writing:

> The historian must (...) constantly put himself at a point in the past at which the known factors will seem to permit different outcomes. If he speaks of Salamis, then it must be as if the Persians might still win; if he speaks of the coup d'Etat of Brumaire, then it must remain to be seen if Bonaparte will be ignominiously repulsed[32].

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30 The World Business Council for Sustainable Development (WBCSD) "Global Scenarios 2000-2050" Summary Brochure provides another illustration of this glaring confusion. On the one hand, we read that "Unlike forecasts, which impose patterns extrapolated from the past onto the future, scenarios are plausible, pertinent, alternative stories that are concerned more with strategic thinking than with strategic planning." We also read that "scenarios recognis(e) that possibilities are influenced by a wide range of people." Here we are clearly on the side of the indeterminacy of the future due to people's faculty to make (strategic) choices. On the other hand, we are also told that a crucial step in the making of scenarios is "to identify and analyse driving forces that will shape the environment. What will persist and can be forecast (for example, demography in many exercises), and what may change and is unknown? Following the identification of the driving forces, we can now contemplate a set of plausible storylines." The uncertainty is here clearly epistemic.

31 Quoted by Niall Ferguson in his *Virtual History*, Picador, London, 1997, p. 1.

32 Ibid.

The few historians who take this line of thought seriously are those who do not shy away from writing what goes today by the name of "Counterfactual History" or "Virtual History". Those "What if?" historians try and put forward more or less convincing answers to such questions as, What if there had been no French Revolution? What if Hitler had invaded Britain? What if the Soviets had won the Cold War? And, of course, the Pascalian one, What if Cleopatra's nose had been different?

Among professional historians, though, widespread is the opinion that this kind of exercise is a mere "parlour game" or a "red herring"[33]. From Marxists and other materialists this opinion doesn't come as a surprise but it is much more widely shared than that. It is worth quoting British idealist philosopher Michael Oakeshott on this:

> It is possible that had St Paul been captured and killed when his friends lowered him from the walls of Damascus, the Christian religion might never have become the centre of our civilisation. And on that account, the spread of Christianity might be attributed to St Paul's escape ... But when events are treated in this manner, they cease at once to be historical events. The result is not merely bad or doubtful history, but the complete rejection of history (...) The distinction (...) between essential and incidental events does not belong to historical thought at all[34].

The opposition between historians who see only historical necessity and those who are sensitive to the metaphysical postulation that things might be different from what they turned out to be, can and must be transcended. The metaphysical tools exist that allow us to carry out this *Aufhebung*. We owe them to French philosopher Henri Bergson and his brilliant student Jean-Paul Sartre. The idea is that as long as human beings live, they are absolutely free, and their freedom resides entirely in their capacity to choose, that is, to invent their lives. Future-oriented counterfactual propositions such as, "If I were to do this, the consequences would or might be that, and I am entirely responsible for them, whatever they turn out to be", make full sense. However, as soon as "death has turned life into destiny", to quote another famous existentialist, backward-looking counterfactual propositions such as, "Had I had more time to devote to my work, I would have written the novel of the century", are completely devoid of meaning and serve as mere alibis or cheap excuses – the stuff "bad faith" is made of[35].

In that kind of metaphysics, counterfactual propositions are admissible only when they are future-oriented. When we look back at the past, we see only necessity. There is nothing else than that which has happened, no possible that never came to actuality. When history unfolds, then, possibilities become actual, but something strange

33 These dismissive phrases are from E. H. Carr. Quoted by Niall Ferguson, p. 4.

34 Michael Oakeshott, *Experience and its Modes*, Cambridge, 1933; quoted by Niall Ferguson, p. 6-7.

35 In Sartre's plays, the dead keep talking to each other and even make definitive philosophical claims such as, "Hell is other people"! The only thing they wish to do, but can *no longer* do, is "choose their past". The latter has become inert, sentenced to be forever part of the "In itself".

happens to the branches that were not selected. It is not that they have become impossible: it turns out that they were never possible! As history proceeds in its course, it interjects necessity back into the past. Necessity is only retrospective.

In the framework of this metaphysics the parties to the debate about the meaning of virtual history appear to suffer from symmetrical blind spots. The "What if?" historians argue as if the possibilities that did not become actual kept existing forever, in a kind of eternal limbo. The mainstream historians who refuse to ascribe any meaning to counterfactuals reason as if agents endowed with free will didn't make any difference in the way events occur.

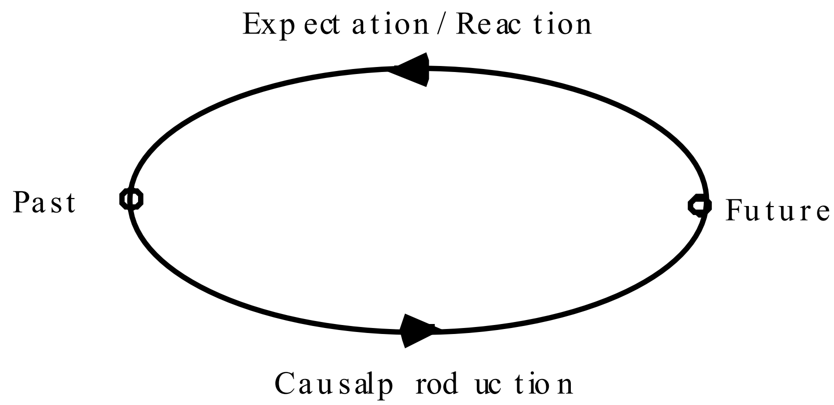
Back to the future. Following Hans Jonas, as explained before, my task has been to reestablish the future in its ontological status of a *real* entity. Bergsonian – Sartrean metaphysics permits exactly that: project yourself into the future and look back from there at the present. Seen from the present the future was open, but seen from the vantage point of the future, the path that led to it appears to have been necessary. We were free to choose, to be sure, but what we chose appears to have been our destiny[36].

At this stage non-philosophers are probably thinking that this is all speculative bla-bla-bla that has no bearing whatsoever on the real world. One couldn't be more plainly wrong.

The temporal experience I am trying to describe – and which, again, I call "projected time" -, is ours on a daily basis. It is facilitated, encouraged, organized, not to say imposed by numerous features of our social institutions. All around us, more or less authoritative voices are heard that proclaim what the more or less near future will be: the next day's traffic on the freeway, the result of the upcoming elections, the rates of inflation and growth for the coming year, the changing levels of greenhouse gases, etc. The *futurists* and sundry other prognosticators, whose appellation lacks the grandeur of the prophet's, know full well, as do we, that this future they announce to us as if it were written in the stars is a future of our own making. We do not rebel against what could pass for a metaphysical scandal (except, on occasion, in the voting booth). It is the coherence of this mode of coordination with regard to the future that I have endeavored to bring out.

A sine qua non must be respected for that coherence to be the case: a *closure condition*, as shown in the following graph. Projected time takes the form of a loop, in which past and future reciprocally determine each other.

[36] This is a famous Heideggerian *philosopheme*.



Projected time

To foretell the future in projected time, it is necessary to seek the loop's *fixed point*, where an expectation (on the part of the past with regard to the future) and a causal production (of the future by the past) coincide. The predictor, *knowing that his prediction is going to produce causal effects in the world*, must take account of this fact if he wants the future to confirm what he foretold. Traditionally, which is to say in a world dominated by religion, this is the role of the prophet, and especially that of the biblical prophet.[37] He is an extraordinary individual, often excentric, who does not go unnoticed. His prophecies have an effect on the world and the course of events for these purely human and social reasons, but also because those who listen to them believe that the word of the prophet is the word of Yahveh and that this word, which cannot be heard directly, has the power of making the very thing it announces come to pass. We would say today that the prophet's word has a *performative* power: by saying things, it brings them into existence. Now, the prophet knows that. One might be tempted to conclude that the prophet has the power of a revolutionary: he speaks so that things will change in the direction he intends to give them. This would be to forget the fatalist aspect of prophecy: it describes the events to come as they are written on the great scroll of history, immutable and ineluctable. Revolutionary prophecy has preserved this highly paradoxical mix of fatalism and voluntarism that characterizes biblical prophecy. Marxism is the most striking illustration of this.

However, I am speaking of prophecy, here, in a purely secular and technical sense. The prophet is the one who, more prosaically, seeks out the *fixed point* of the problem, the point where voluntarism achieves the very thing that fatality dictates. The prophecy includes itself in its own discourse; it sees itself realizing what it announces as destiny. In this sense, as I said before, prophets are legion in our modern democratic societies, founded on science and technology. What is missing is the realization that this way of relating to the future, which is neither building, inventing or creating it, nor abiding by its necessity, requires a special metaphysics.

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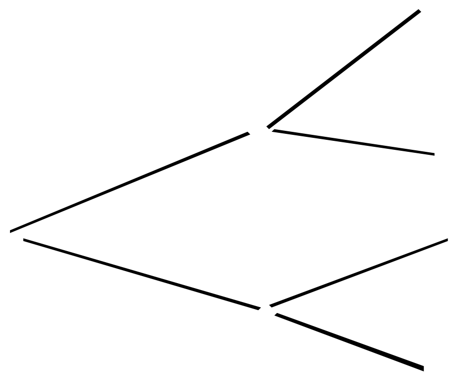
[37] To his misfortune and above all that of his compatriots, the ancient prophet (such as the Trojans Laocoon and Cassandra) was not heeded; his words were scattered by the wind.

Perhaps the best way to bring out the specificity of the metaphysics of projected time is to ponder the fact that there is no such closure or looping condition as regards our "ordinary" metaphysics, in which time bifurcates into a series of successive branches, the actual world constituting one path among these. I have dubbed this metaphysics of temporality "occurring time"; it is structured like a decision tree:



Occurring time

Obviously the scenario approach presupposes the metaphysics of occurring time. But that is also the case of the metaphysical structure of prevention. Prevention consists in taking action to insure that an unwanted possibility is relegated to the ontological realm of non-actualized possibilities. The catastrophe, even though it does not take place, retains the status of a possibility, not in the sense that it would still be possible for it to take place, but in the sense that it will forever remain true that it could have taken place. When one announces, *in order to avert it,* that a catastrophe is coming, this announcement does not possess the status of a *prediction,* in the strict sense of the term: it does not claim to say what the future will be, but only what it would have been had one failed to take preventive measures. *There is no need for any loop to close here*: the announced future does not have to coincide with the actual future, the forecast does not have to come true, for the announced or forecast "future" is not in fact the future at all, but a possible world that is and will remain not actual.[38]

By contrast, in projected time, the future is held to be fixed, which means that any event that is not part of the present or the future is an impossible event. It immediately follows that in projected time, prudence can never take the form of prevention. Once again, prevention assumes that the undesirable event that one prevents is an unrealized possibility. The event must be possible for us to have a reason to act; but if our action is effective, it will not take place. This is unthinkable within the framework of projected time.

Such notions as "anticipatory self-defense", "preemptive attack", or "preventive war" do not make any sense in projected time. They correspond to a paradox exemplified by a classic figure from literature and philosophy, the killer judge. The killer judge "neutralizes" (murders) the criminals of whom it is "written" that they will commit a

[38] For an illustration, one may think of those traffic warnings whose purpose is precisely to steer motorists away from routes that are otherwise expected to be clogged with too many motorists.

crime, but the consequence of the neutralization in question is precisely that the crime will not be committed![39] The paradox derives from the failure of the past prediction and the future event to come together in a closed loop. But, I repeat, the very idea of such a loop makes no sense in our ordinary metaphysics.

5.4. Conclusion. Exploring the set of projected equilibria as a substitute for the scenario approach

We should take very seriously the idea that there is a "co-evolution of technology and society" (Arie Rip). The dynamics of technological development is embedded in society. The consequences of the development of nanotechnology will concern society as well as technology itself. Technology and society shape one another.

The future of nanotechnology, therefore, depends on the way society is going to react to the anticipations that are being made of this future. If those anticipations are produced through the scenario method, they will be of no help in the resolution of the ethical problem. They won't restore the future in its status of a real entity of which our knowledge must be as precise as possible. I have argued that the most effective way to ascribe reality to the future is to reason in the framework of projected time. But, then, we are confronted with a problem of reflexivity. This "we" refers to all groups, lobbies, expert groups, administrations, institutions that purport to shape the future through its anticipation, anticipation made public. We are the "prophets" of today, in the technical sense explained above. We have to explore the fixed points of the temporal loop that links the future to the past and then to the future again. Those fixed points I have called "projected equilibria".

Alexei Grinbaum and I have called "*ongoing normative assessment"* the methodology that corresponds to the determination of these projected equilibria. One can succinctly capture the spirit of this approach with the following words: it is a matter of obtaining through research, public deliberation, and all other means, an image of the future sufficiently optimistic to be desirable and sufficiently credible to trigger the actions that will bring about its own realization. It is easy to see that this definition can make sense only within the metaphysics of projected time, whose characteristic loop between past and future it describes precisely. Here coordination is achieved on the basis of an *image* of the future capable of insuring a closed loop between the causal production of the future and the self-fulfilling expectation of it.

I have said before that prevention made no sense in projected time. What can take its place then? Are there projected equilibria that may protect us against a major disaster, if such a denouement is in the offing? The search for an answer to that question I have called "enlightened doomsaying".

From the outset it appears that this search is bound to run into an irremediable paradox. It is a matter of achieving coordination on the basis of a negative project taking the form of a fixed future that *one does not want.* One might try to transpose the above characterization of the methodology of ongoing normative assessment into the

[39] Here I am thinking of Voltaire's *Zadig.* The American science fiction writer Philip K. Dick produced a subtle variation on the theme in his story "Minority Report." Spielberg's movie is not up to the same standard, alas.

following terms: "to obtain through scientific futurology and a meditation on human goals an image of the future sufficiently catastrophic to be repulsive and sufficiently credible to trigger the actions that will block its realization" — but this formulation would fail to take account of an essential element. Such an enterprise would seem to be hobbled from the outset by a prohibitive defect: self-contradiction. *If one succeeds in avoiding the undesirable future, how can one say that coordination was achieved by fixing one's sights on that same future?* The paradox is unresolved.

In order to spell out what my solution to this paradox is, it would be necessary to enter into the technical details of a metaphysical development, and this is not the place to do so.[40] I will content myself with conveying a fleeting idea of the schema on which my solution is based. Everything turns on a random occurrence — but one whose nature and structure defy the traditional categories that I discussed in the first sections of this work.

The problem is to see what type of fixed point is capable of insuring the closure of the loop that links the future to the past in projected time. We know that the catastrophe cannot be this fixed point: the signals it would send back toward the past would trigger actions that would keep the catastrophic future from being realized. If the deterrent effect of the catastrophe worked perfectly, it would be self-obliterating. For the signals from the future to reach the past without triggering the very thing that would obliterate their source, there must subsist, inscribed in the future, an *imperfection in the closure of the loop.* I proposed above a transposition of our definition of ongoing normative assessment, in order to suggest what could serve as a maxim for a rational form of doomsaying. I added that as soon as it was enunciated, this maxim collapsed into self-refutation. Now we can see how it could be amended so as to save it from this undesirable fate. The new formulation would be: "to obtain… an image of the future sufficiently catastrophic to be repulsive and sufficiently credible to trigger the actions that would block its realization, *barring an accident.*"

One may want to quantify the probability of this accident. Let us say that it is an epsilon, **e**, by definition weak or very weak. The foregoing explanation can then be summed up very concisely: it is because there is a probability **e** that the deterrence will not work that it works with a probability 1-**e**. What might look like a tautology (it would obviously be one in the metaphysics of occurring time) is absolutely not one here, since the preceding proposition is not true for **e** = 0.[41] The fact that the deterrence will not work with a strictly positive probability **e** is what allows for the inscription of the catastrophe in the future, and it is this inscription that makes the deterrence effective, *with a margin of error **e**.* Note that it would be quite incorrect to say that it is the *possibility* of the error, with the probability **e**, that saves the effectiveness of the deterrence — as if the error and the absence of error constituted two paths branching out from a fork in the road. There are no branching paths in projected time. The error

40 I will take the liberty of referring the interested reader to my *Pour un catastrophisme éclairé*.

41 The discontinuity at **e** = 0 suggests that something like an uncertainty principle is at work here, or rather an indeterminacy [*Unbestimmtheit*] principle. The probabilities **e** and 1-**e** behave like probabilities in quantum mechanics. The fixed point must be conceived here as the *superimposition* of two states, one being the accidental *and* preordained occurrence of the catastrophe, the other its non-occurrence. I cannot pursue this line of reasoning any further here.

is not merely possible, it is actual: it is inscribed in time, rather like a slip of the pen. In other words, the very thing that threatens us may be our salvation.

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Nano Ethics Primer

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For the conference Mapping out nano risks
Brussels, March 1, 2004

The problem with mapping out nano risks is that this mapping is difficult or (in some areas) impossible to carry out in a non-arbitrary way, at least at the present time, for reasons to be given shortly. But particularly important are probably the following four areas: possibilities for surveillance (raising confidentiality and privacy issues), possible health hazards of nano technology (raising security and safety issues), impact of nano waste on environment (raising issues about our responsibilities to future generations) and access to the benefits in a global perspective (raising issues of equity and justice between developed and developping countries).

Ethical problems

Ethical problems of the sort we are concerned with here presuppose that we are faced with a choice between different possible alternatives of action – where naturally to do nothing is one of these alternatives. The alternatives may include not just whether particular actions ought to be done or not, but also whether an area should be regulated or not, and in the former case, whether this should be done in this, that or the other way.

Besides, different stakeholders, agents and others concerned are involved, and what is good for one is not necessarily good for others. The problem can then be described in terms of conflicting interests, values, norms or rights – depending on the ethical point of departure chosen. A choice has then to be made, which will favour certain interests (values, rights, …) at the expense of others. By whom is this choice to be made, and in accordance with what principles? If there are no conflicts between interests, values, norms or rights, there is no ethical problem.

Ethical principles and traditions

Ethical traditions in condensed form can be used as normative starting points. But also ideas about the goals of medicine, technology and health care can function in this may, just as more overarching views of man and social ideals – or all of this in combination.

One group of ethical theories are the *consequentialist* ones. According to them the criterion of the moral value of an action is determined by the value of the consequences of that action. Utilitarianism is a well-known form of such a theory, but not the only one – and besides there are several versions of utilitarianism.

Another main group of ethical traditions is called *deontological.* According to them the moral value of an action depends on whether it is compatible or incompatible with certain rights or duties, which can be based on religion, social contracts or so-called natural rights. Kant's ethical theory is a well-known deontological theory.

The strong and weak points of these two traditions have been extensively discussed in the literature.

There are also *causuistic traditions* and *virtue ethics*. The former stress the importance of the situation and that two situations are never alike; the circumstances in the case at hand will decide what is right or wrong. The latter focus not on finding and clarifying criteria of which actions are right or wrong, but on what virtues should be promoted by moral education. Instead of asking "Which action is the right one in this situation?" it focuses on the question "What sort of person ought I to be?"

The ethical points of departure chosen may make a difference as to the relative importance attached to certain concerns. But whatever ethical point of departure chosen, it is easy to agree that the following concerns are all ethically relevant and need to be addressed, also in the area of nanotechnology:

- Risk – benefit assessment
- Information and consent
- Privacy and integrity
- Costs and research priorities
- Commersialisation of research
- Equity and fairness
- Public trust and transparency

Ethical analysis

An often used model for the analysis of ethical problems is the following one:

(1) Information

(2) Normative points of departure

(3) Conclusion

The important point is that both premises (1) and (2) are needed for the conclusion. If an ethical problem is to be analysed, the relevant background information and the normative points of departure have to be made explicit. Ideally, it is then demonstrated how you go step by step from these premises to the conclusion.

The first premise may include information about the current state of the art, the predictable consequences of the available alternatives of action, as well as information about the preferences of those involved and about relevant laws and guidelines.

The normative points of departure can be the goals and values of the parties involved, or of their culture, ethical principles of different sort, as well as ethical traditions at a more general and abstract level of the kind just mentioned, of which there are many varieties. Thus explicitness and consistency are essential.

I will here use as normative starting points some middle-range principles, on the relevance of which there is a fair amount of agreement in our culture – though the precise ranking order of the principles may be a bone of contention. They include human dignity (or integrity), autonomy, the obligation not to harm and to do good, especially in the area of health care, as well as fairness or justice. Each of them can be supported both by consequentialist and by deontological arguments.

A fundamental problem

The first obvious difficulty is to describe the state of the art of nanotechnology accurately, and to distinguish between science and science fiction or between the state of the art today, what may be around the corner tomorrow – and in a more distant future.

The ethical problems are likely to be very different, depending on whether we discuss what was done yesterday, what is done today, and what may be done tomorrow.

Already today, "nano-technology is part of everyday life. Clay nano-particles make plastic beer bottles less likely to shatter and help seal in carbon dioxide to keep carbonated drinks fresh. Nano-composites strengthen plastic running boards in automobiles. Nano-coatings make eyeglasses scratchproof. Sunscreens with titanium oxide nanopowder reflect ultraviolet light without being visible on the skin." (Putman [2])

In the near or more distant future many fascinating applications are foreseen.

Risk – benefit assessment

The potential *risks* may include that artificial nano-entities be used by terrorists as massive chemical and biological weapons, that their application may create unintended health-hazards, that they may be used in ways that violate our rights tgo integrity and privacy, and that their reaction with other things can be harmful.

Taking risks seriously will help to foster public support. If billions are invested, the development of many nanotech products must be foreseen. So what happens to the waste? Will nano-particules move up through the food chain? If they do, will this create any health risks to humans?

The *benefits* may include: Effective delivery systems for drug and gene therapies, novel means for body and organ imaging, surgical tools only a few nanometers thick are already in development. Nano-probes may be able to add diagnostic specificity to biopsy studies. Perhaps nanorobots will be able to travel through the body searching out and clearing up diseases. (Lancet [1])

Nanotechnology offers a range of potential benefits for developing countries, as has recently been stressed by a group of bio-ethicists from Toronto [4]. Nanotech could possibly bring better, cheaper disease diagnostics for people and crops, provide safer and affordable vaccines and improve water purification. It could also, as the ETC group recently added [3], "significantly improve solar cells offering major benefits to remote communities, reduce raw material demands, increase recycling and slash transport and energy costs."

In view of the above, the problem is to assess the risks and benefits of the new technology in a non-arbitrary way. There is little scientific evidence in terms of relative frequencies, but there are some historical analogies (as to what happened with the promises offered by other new technologies (nuclear, chemical – including DDT – and biotech), and plenty of guesses and wishful thinking. Since the various stakeholders have very different perspectives, and the risks and benefits are difficult to estimate and to compare (comparing apples and pears is much easier than the comparisons that have to be done here), what is needed is a continuous dialogue where different voices are heard – as well as an international instrument for assessing risks and benefits of the new technology.

We need to distinguish the following four situations:

	Risks	benefits
Immediate	1	2
Long term	3	4

Who weighs the risks and benefits – and who decides? And what do we know today in our multi-cultural societies

- about how different groups value various benefits and risks?
- about how they rank different values?

Crucial questions include:

- Which are the benefits?
- When can we expect them?
- How likely are they?
- What will they cost?
- Who will benefit from them?

Problems

We may distinguish between two concepts of risk, one based on relative frequencies (the standard notion), and the other on gaps in our knowledge – sometimes in the literature called "epistemic risk".

The standard notion of 'risk' contains two conceptual components: the probability of a certain outcome, based on knowledge of relative frequencies, and a negative evaluation of this outcome. But epistemic risks cannot be quantified in a non-arbitrary way precisely because of the gaps in our present knowledge. Perhaps then focus on procedures, monitoring, a precautionary approach and underlying value-issues is more fruitful than legal regulation which is not very flexible and soon may be out-dated.

An additional challenge is to maximize the benefit. The problem is: who weighs the risks and benefits – and who decides?

Information and consent

The information problems are likely to be different depending on whether we talk about nanotechnology today, tomorrow or in the future.

How is this information to be stated (a) to be correct and not misleading, and (b) to be understandable by people, given the present gaps in our knowledge?

The idea is not that people need to be told everything. Then we would never be able to decide. Saturation in a certain sense is the ideal. The idea is that they need to told so much that further information will not make a difference for their decision – or, somewhat weaker, that there are no good reasons to believe that further information would make such a difference.

Privacy and integrity

How will privacy and integrity be protected from invisible molecular devices? How could invasions of privacy or violations of integrity occur in this context? They could occur, for instance, if it is true that current work on nano-tags will lead to production and use of devices that can be inserted into our bodies for identification.

If nano-particles can be made to invade human bodies without free and informed consent from the persons invaded, or if mental capacities can be manipulated, we have clear cases of violations of integrity. Moreover, if nano identification tags can be implanted into criminals in order to track them against their will, this could be extended to other groups and other purposes.

Cost and research priorities

How much is invested in research in various nano-technologies? And what is the future market expected to be worth? The figures are staggering.

The EU's FP6 has set aside 1300 million Euros for nanotechnology research between 2003 and 2006. In the US, 288 billion USD was spent on research and technological development in 2000, compared to "only" 164 billion USD in the EU. But the member states have increase their R&D budgets to minimise the gap between the US and the EU. Incidentally, the ETC group estimates that corporations and governments around the world invest "upwards of USD 6 billion *per annum* to develop nanotech" [3].

The use of these millions will then have to be compared to alternative uses of the same amount of money, and what we get for each invested dollar. For instance, US National Science Foundation estimates that the nanotechnology market will be worth 700 billion USD by 2008 and exceed one trillion USD annually by 2015. (Putman)

Equity and fairness

New technologies cannot solve old injustices, as the ETC group stressed in a very recent (Feb 13, 2004) publication [3], and is not an alternative to sound social policies. Put differently, if new patented drugs and improved methods for disease diagnostics for people as well as crops are made possible by nanotechnology, this will be of little help to poor countries if they cannot afford them.

Which needs, and whose needs, will the new technology meet? Will industrialised nations continue to invest in scratch-proof sunglasses coated by nano-particles, stain-resistant nano-pants, nano-technology cosmetics, flat big-screen televisions using carbon nano-tubes, sunscreens with titanium oxide nano-powder reflecting ultraviolet light without being visible on the skin and other products for wealthy customers, or will nano research be directed at addressing the needs of the developing countries?

If the development of nano technology speeds up the growing gap between developed and developing countries we may have yet another divide, a widening "nano-divide" (in addition to the IT-divide and others), as many have warned.

Public trust and transparency

The different perspectives of the developed and developing world could also be reflected in different ranking orders of values. If people are starving and plagued by epidemics, then meeting basic needs related to survival would most likely be ranked higher than individual self-determination and promoting free enterprise.

A deeply polarised debate is a warning signal. Clearly, transparency is important for public acceptance and trust. Transparency presupposes in its turn openness and information about risks and benefits, methods and aims, successes and failures in research

This information has not only to be

- correct and
- not misleading

It is also essential that it is

- easily accessible
- understandable
- relevant to public concerns

Which are the public concerns?

This is something we have to study, and it is possible to design studies that would help us to know more about this. Who should set the agenda for the discussion – the industry, the researchers, those with the concerns or someone else?

One-way information has to be replaced by dialogue and communication; scientists have to understand the concerns of the general public, what their concerns are, and why they have these concerns. Is the political and social resistance only an information problem? Certainly not. Also in this respect, a great deal can be learnt from the reception of GM-food in Europe.

Commercialisation of research

Without the involvement of industry in research it may not be possible to carry out front line research and to achieve a number of important goals. But it raises ethical concerns, including … controversies over access to data, non-publication or publication bias, conflicting loyalties, controversial broad patents, developments of research to areas which may generate profit.

Underlying values

Of course, both the positive and the negative implications of the technology need to be studied. This also requires a sincere discussion about ethics, and such a discussion presupposes that the underlying values and value-conflicts are made explicit.

The particular way in which these problems are handled in specific situations will depend on which values are recognised, how they are interpreted and how they are ranked. "What we must avoid at all cost is determined by what we must preserve at all cost" (Hans Jonas). Consider the following values, all of which are perfectly legitimate in our contemporary culture:

- Freedom of research
- Economic growth
- Health: longer life expectancy for future generations
- Well-being for future generations
- Individual self-determination
- Safety and security

Compare the ranking order above with the reversed one, and the differences will soon be obvious:

- Safety and security
- Individual self-determination
- Well-being for future generations
- Health: longer life expectancy for future generations
- Economic growth
- Freedom of research

- Which restrictions do such ranking orders imply for the values at the bottom of the hierarchy?
- Which are the implications of the ranking order above for the limits of autonomy?
- Who decides? What are the power implications of these ranking orders?
- For the conditions for acting in somebody's "best interest" without having explicit free and informed consent?

This suggests that no value or normative principle has unlimited validity; they will have to be balanced against each other and against other valid concerns and interests.

In fact, the two different ranking orders mirror two different types of societies; thus here there is a connection between ethics, political philosophy and social ideals.

Needless to say, many of these values can be interpreted in more ways than one.

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Nanotechnology – From the insurers' perspective

Submitted by Annabelle Hett, Risk Engineering Services, Swiss Re, for "Mapping out Nano Risks", 1-2 March, European Commission, Brussels, 1-2 March 2004

The core business of the insurance industry is the transfer of risk. Thus the insurance business identifies, evaluates and diversifies risk in order to minimise the total capital cost of carrying it. However, the traditional means of diversification reach their limits when:

- it is no longer possible to assess the probability and severity of risks
- many companies, industry sectors and geographical regions are affected simultaneously
- the magnitude of a possible event exceeds the capacities of the private insurance industry

As one of the major risk takers, the reinsurance business must have a clear picture of the risk landscape to avoid cumulative and serial loss exposures that may exceed the capacity of the private insurance industry. The insurability depends on:

- accessibility (probability and severity of losses must be quantifiable to allow pricing)
- randomness (time of the insured event must be unpredictable and occurrence independent of the will of the insured)
- mutuality (exposed persons must join together to build a community in which the risk is shared and diversified)
- economic feasibility (private insurers must be able to charge a premium which is commensurate with the risk, giving them a fair chance to write the business profitably in the long run)

Nanotechnology, as an emerging risk, challenges the insurance industry because of the high level of uncertainty in terms of potential nanotoxicity or nanopollution, the ubiquitous presence of nano-products in the near future (across industry sectors, companies and countries) and the possibility of long latent, unforeseen claims.

The insurance industry is concerned because scientific evaluations of potential risks for human health and the environment are few and remain inconclusive. Nor are there regulatory guidelines that address potential risks in an adequate manner. The industry community has only begun to evaluate potential "nano-risks" and there is no global approach towards finding a solution satisfactory to business, scientists and regulators alike. Given the complexity of nanotechnology and the magnitude of capital at stake, no single authority or country can find answers to the questions at hand within an entirely acceptable period of time.

Currently there is no common terminology for the great variety of nanotechnological substances, products or applications. Any structured scientific approach towards evaluating potential risks would require a standardisation of these materials and applications. Only a common language would allow a comparison of scientific knowledge across industries and countries. It would also be the precondition for labelling requirements which may prove necessary for the insurance business in order to differentiate and insure certain exposures originating from different products or applications.

To make any progress in these issues, it is essential to start a risk dialogue which includes regulators, business and science, as well as the insurance industry. Risk communication efforts should also include the broad public. In contrast to the debates on nuclear power and genetic engineering, the public does not yet view nanotechnology as a noteworthy hazard. Many are still quite unaware of the introduction of this new technology. The increase in media interest since the beginning of 2003 could change that, however, and lead to more lively debate on the benefits and risks. Whether the public accepts the new technology and sees in it advantages for itself, or whether it rejects it, will largely depend on how well informed it is and to what degree it is able to make objective judgments.

The assessment of risks associated with nanotechnology – as well as risk communication efforts – should concern all involved stakeholders: industry, scientists, regulators, consumer organisations and the insurance industry. The only way to prevent a polarized debate about nanotechnology, which may slow down future research and economic growth in this field, is to find a common approach to lessen the uncertainty and to provide some answers for pressing questions concerning potential nanotoxicity and pollution issues.

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9 February 2004

A briefing note on Nanoparticles

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Nanoparticles are particles smaller than 100 nanometres in size, i.e. on average less than a thousandth of the width of a human hair. The nano-technology industry is starting to produce nanoparticles on a large scale, for applications in a range of products. Examples include:

- The use of nanoparticles as a vehicle to transport drugs more easily around the body
- The use of nanoparticle titanium dioxide in sunscreens,
- The use of nano-powders as colourants in cosmetics,
- The making of fullerenes, known as 'bucky balls', which are 'footballs' one nanometre in diameter, the most common being made of 60 carbon atoms
- The production of carbon 'nanotubes', which are of fibres one nanometre in diameter but up to several micrometres (millionths of a metre) in length and are a technological development arising from 'bucky balls'.

Consideration of the types of particle that our ancestors were exposed to throughout human evolution is illuminating. These mainly consisted of suspended sand and soil particles and biological products such as pollens. Most of these are relatively coarse and become trapped before getting deep into the lung. There have always been nanoparticles in our environment, mainly consisting of minute crystals of salt, which become airborne through the action of the waves of the sea [1]. These are not normally toxic as they are soluble salts. What seems clear is that there were few particles smaller than 70 nanometres in diameter in the air throughout our prehistory, until we harnessed fire to our uses.

When ordinary materials are made into nanoparticles, they tend to become more chemically reactive - this is how heterogeneous catalysts are made for the chemical industry. For example, gold and platinum (which are normally chemically inert) are able to catalyse chemical reactions when converted into nano-powders.

There is considerable experimental evidence that nanoparticles are toxic in people and animals and the toxicity increases as the particle size decreases. This has been shown to be true for very different types of material, such as titanium dioxide, carbon black and latex [2]. Thus nanoparticles appear to have a toxicity which is primarily a property of their small size rather than the type of material from which the particles are made, although research into this question is incomplete. The basis of this toxicity is not fully established, but a prime candidate for consideration is the increased reactivity associated with very small size. The toxicity is primarily expressed through an ability to cause inflammation. There is strong evidence that recurring exposure to ultrafine particulates through polluted air can affect human health [3].

Drugs are very difficult to deliver across certain protective membranes, such as the blood-brain barrier. Research has shown that drug penetration across these membranes can be increased by 'piggybacking' the drug as a coating on nanoparticles, which cross these barriers with relative ease. There are many examples [4, 5, 6]. These benefits, e.g. to increase drug penetration into the brain, should also warn us that this is a technology that must be treated with care. If 'beneficial' nanoparticles, introduced into the body under informed consent, can penetrate into organs such as the brain, then it is quite likely that other 'uninvited' nanoparticles may be also able to do so.

While there are mechanisms in the throat and lung (the muco-ciliary escalator in the trachea and bronchi) which trap many of the larger inhaled particles, nanoparticles seem able to penetrate deep into the lungs very efficiently [7]. The body is not well equipped to cope with inhaled nanoparticles, because alveolar macrophages (the scavenging cells that 'mop up' particles arriving in the depths of the lung) do not easily recognise nanoparticles and in addition, they can be overwhelmed by too many particles (a condition termed 'overload') [3].

Another possible portal of entry into the body is via the skin. A number of sunscreen preparations are now available which incorporate nano-particle titanium dioxide (TiO2). Recent studies [8] have shown that particles of up to 1 micron in diameter (i.e. within the category of "fine" particles) can get deep enough into the skin to be taken up into the lymphatic system, while particles larger than that did not. The implication is that nanoparticles can and will be assimilated into the body through the skin. The exact proportion absorbed remains unknown.

Once in the body, nanoparticles appear to be able to penetrate more rapidly in between cells than larger particles and therefore to move more easily to distant sites within the body [3]. There appears to be a natural 'passageway' for them to travel around the body. This is through openings (known as 'caveolar' openings) in the natural cell membranes which separate the body compartments. These openings are tiny (between 40 and 100 nanometres in size) and are thought to be involved in the transport of substances such as proteins, including viruses. They also happen to be about the right size for transporting nanoparticles. Most of the research on this topic has been performed by the pharmaceutical industry, which is interested in finding ways of improving drug delivery to target organs such as the brain. The subject area has been reviewed by Gumbleton [9].

Although there are clear advantages to the intentional and controlled targeting of 'difficult' organs, such as the brain, with nanoparticles to increase drug delivery, the other side of this particular coin needs to be considered. When environmental nanoparticles (such as from traffic pollution) gain unintentional entry to the body, it appears that there is a pre-existing mechanism which can deliver them to vital organs [9]. The body is then 'wide open' to any toxic effects that they can exert. The probable reason why we have not built up any defences is that any such toxic nanoparticles were not part of the prehistoric environment in which we evolved and therefore there was no requirement to develop defensive mechanisms.

There is considerable evidence to show that inhaled nanoparticles can get into the blood stream and are then distributed to other organs in the body [10, 11, 12]. This has also been shown for synthetically produced nanoparticles such as 'bucky-balls' [13], which appear to accumulate in the liver.

A major, and as yet unanswered, question is whether nanoparticles can pass from a pregnant woman's body into the baby in her womb, and if so, what the consequences might be.

We should not necessarily assume that, because experiments to date have been carried out with 'high dose' exposures, that we therefore only need to worry about high dose exposure of humans. The asbestos story reminds us that, for certain toxicological effects, a single low-dose exposure can be sufficient.

Conclusion

In conclusion, there is evidence that nanoparticles can gain entry to the body by a number of routes, including inhalation, ingestion and across the skin. There is considerable evidence that nanoparticles are toxic and therefore potentially hazardous.

We are defenceless against the assimilation of nanoparticles by swallowing, inhalation or absorption through the skin. While it is easy to appreciate how this can be harnessed to positive pharmaceutical purposes, there is an urgent need to curb the generation of unnecessary nanoparticles, particularly of the insoluble variety. There is already enough evidence available, to demonstrate that nanoparticles are likely to pose a health hazard and that human exposure in general, and in particular exposure of pregnant women and in the workplace, should be minimised on a precautionary basis. We are dealing with a potentially hazardous process. Full hazard assessments should be performed to establish the safety of each type of nanoparticle before manufacturing is licensed.

These are my personal views, and do not reflect any policy of the University of Liverpool.

Glossary

Alveoli small cells deep in the lungs, where the air passes into the bloodstream

Micron= 1 micrometre = one millionth of a metre i.e. 0.000001 metre

Nm = Nanometre = 1 micromillimetre = one billionth of a metre i.e. 0.000000001 metre

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Mapping Out Nano Risks

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About 60% of the products made by major industries such as Dupont, Dow or ICI are either made as particles or involve significant particle technology in their manufacture. Particle science and engineering is already central to the environment (air pollution, climate change, ozone hole, green house effect), energy utilization (fossil fuel combustion, engine fuel injection, turbine combustion, fly ash) and medicine (virus and bacteria transport, medicine delivery, allergies). Our program in ETH focuses on (nano)particle formation in manufacture of catalysts, ceramics, dental composites and metallic powders by aerosol processes. Their characterization as aerosols and powders is one of our key competences enabling targeted manufacturing and modelling of those processes. In addition, particle suspensions in liquids are studied for their applications in drinking or wastewater treatment as well as in processing of pharmaceuticals and food products.

Aerosol technology is used routinely today to make a variety of (nanoparticle) commodities: more than 8 Mt/year carbon blacks are produced for tires (70%) and rubber (20%); titania (about 2 Mt/year) is mainly used for pigments, zinc oxide (0.6 Mt/year) as activator of rubber vulcanization (50%) and pigment or pharmaceutical additive, fumed silica (about 0.2 Mt/year) as a powder flowing aid, in cosmetics and in fabrication of optical fibers for telecommunications. The use of these processes date back to the late 1940s to mid-1950s where for example Degussa and Carbot developed flame processes resulting in products such as Aerosil and Carbosil with particles sizes down to 5 nm. Since then there is a track record (more than 50 years) of production and handling of nanoparticles in those industries which has to be carefully studied in order to identify already known risk and safety measures developed independently from governmental laws or instructions.

Characterization of nanoparticles plays an important role for mapping out their potential risks. As it is well known form many applications that the size of the primary particles is only one of many decisive properties of nanoparticles. Aggregates of nanoparticles, surface functionalization including coatings or reactive groups and morphology (fibers, nanotubes), to name just a few, are equal aspects to be considered. Furthermore, risk assessment should be based on detectable particle properties which can be reproducibly measured.

In particle technology only a single process step is needed to change the nanoparticle characteristic tremendously. Activation and deactivation of catalyst is one example while surface treatment can change for example a silica filler from hydrophilic to hydrophobic. Therefore, the question arises which properties have to be evaluated and which assessment criterion will be applied to classify the commodity as new product with its own material safety regulations.

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Social Imagination for Nanotechnology

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Films like *Hulk*, books like *Prey* can impact, perhaps shape how the public perceives the risks of nanotechnology. One might therefore look to popular culture in order to study the "emerging risks of nanotechnology." I propose a different perspective by viewing a book like *Prey* not as cause but as symptom of the way in which we conceive of risks. Considered as a symptom, books like *Prey* teach us that one can't have it both ways, conceive of nanotechnology in visionary terms and complain about those who take these visions to dystopian extremes. They also teach us that we have to consider the risks not of nanotechnology but of particular nanotechnologies. What is true of airborne nanoparticles does not apply to nanostructured circuits or to surfaces in which nanoparticles are embedded. Taking nanotechnologies one at a time may diminish the glamour of "nanotechnology" but is the only way of keeping science honest and of gaining public support for specific, socially beneficial research programs that can be monitored for risk.

Unimaginative Visionaries

When Richard Feynman presented in 1959 his visionary lecture about "Plenty of the Room at the Bottom" that established the very possibility of nanotechnology, he simultaneously proved to be surprisingly unimaginative. When it came to describing what one might do with all this space at the bottom, he considers how much information it can accommodate. By envisioning the Library of Congress on the tip of a pin, Feynman remains firmly entrenched in the familiar paradigm of miniaturization.

From a science fiction author one might expect more than from a theoretical physicist, and so it is all the more surprising that the most famous nanotechnology novel to date proves equally unimaginative. Falling far behind the example of less famous, but more inventive authors like Kathleen Goonan or Neal Stephenson, Michael Crichton's *Prey* stays firmly entrenched in the familiar paradigm of the Frankenstein story. Once humans have developed addressable nanoparticles, what else might these do but band together to form macroscopic entities that undergo evolution, develop superhuman strength, and use it merely to seek out and destroy their makers?

Feynman and Crichton both lack imagery that is specific to nanoscience and nanotechnology, for example, that speaks of the fears and risks related to the scale of nanotechnical artifacts, the unsettling nervousness that attends to things unseen and unfelt which may yet be actively present in some way or another. To be sure, this lack of imagination is due to the very novelty of the nanotechnical possibilities: Of course, most of us haven't quite learned to imagine these possibilities in the first place and know no better than to project our conventional, old-fashioned fears onto the new nanotechnology. There is an illuminating paradox in this: Since we are more familiar with those fears and worries than we are with the new technologies, the stories by Crichton *et al.* in an odd way familiarize us with the unfamiliar. While conjuring catastrophic dangers to humankind, they also give us a false sense of security, namely that we know already what we need to be afraid of. I am not sure which is worse—the disproportionate and inadequate fears that become associated with an as of yet mostly non-existing technology, or the false sense of security and ignorance regarding the real character of the risks.

When, in contrast, we consider the risks not of “nanotechnology” but of artificially created nanoparticles, the situation changes entirely. On the one hand, there is no temptation anymore to conflate the fear of autonomous robots with the toxicological risk of airborne nanoparticles to the health of biological systems and of humans, in particular. On the other hand, we become confronted with very real limits of knowledge that may be insurmountable in the near and medium term. In the face of possible, even plausible risks to human health, are the promises of this research such that for the time being and while exposure levels are low we should support this research and permit the use of nanoparticles in aerosols and cosmetics? I submit that this specific problem is far more difficult and pressing than Bill Joy’s and Michael Crichton’s question whether or not the future still needs us.

From Nanotechnology to Nanotechnologies

The fear that pervades Michael Crichton’s novel *Prey* is a vaguely generalized fear of nature itself. Especially his introduction makes clear that he is concerned with the dangerous instability of nature, a tendency toward chaos that is barely contained by the evolved order. On this view, nature produces perversions of nature that threaten the foothold of our species (as science fiction scholar Steve Lynn pointed out in a panel discussion, it appears that the career woman is for Crichton one such “perversion of nature”). Accordingly, what we have to fear most of all is a technology that becomes itself natural and, for example, subject to an evolutionary process.

There are equally generalized fears also about multinational corporations and the hegemony of the United States, about the mechanization and dehumanization inherent in technological progress, about technologically super-empowered individuals who can abuse technologies for purposes of terrorism, etc. While the fears associated with GMOs allowed themselves to be tied into the designs of particular companies such as *Monsanto*, it is characteristic of “nanotechnology” that it cannot be tied to any particular social or economic agenda and that the public is confronted with an amorphous technology that promises to change everything but nothing, in particular.

Accordingly, generalized fears are matched by vague promises of a better life, a clean environment, plenty of space in an overcrowded world, global abundance, etc. These promises represent the flipside of Crichton’s doomsday scenario and they are due to another illuminating paradox, namely the impossibility to extrapolate social visions for a technology that is thought to be radically novel and discontinuous with all that came before.

Again, I am not sure what is worse – the vaguely generalized fears or the equally general promises. It appears that both will distract us in coming to terms with the risks and benefits of specific innovations. At the same time, if we cannot extrapolate benefits and risks or even the particular applications of nanotechnology, how can we even envision and evaluate specific innovations?

The Liability and Opportunity of "Nanotechnology"

We are accustomed to speaking of "nanotechnology" in general terms as a radically novel enabling technology, one that can dramatically change every aspect of our lives. This characterization may well be adequate – as it is, for example, of "biotechnology." When we speak in these terms, however, we cannot claim that Michael Crichton's scenario is irrational as opposed to the credible visions of Mihail Roco, the chief propagandist for the US Nanotechnology Initiative, who promises mind-machine interfaces, new sports and art forms, and the cure for cancer within the next 10 to 15 years. On the contrary, any talk of a radically novel, deeply transformative enabling technology must open the floodgates of the imagination, and it would be foolish to believe that one can steer this outpouring of visions in a particular direction. The trenches for this outpouring are already dug by generations of technophiles and technophobes who stand ready to bring their intellectual resources to bear on any program for universally transformative technologies. As long as nanotechnology trades in visions to obtain funding, it invites the company of visionaries.

Just like "biotechnology", nanotechnology may therefore be better off as a plural of technologies, each of which posing its own opportunities and risks. Society wouldn't know how to handle "biotechnology" as such, but it can engage in specific debates regarding GMOs and their regulation, the permissibility of stem cell research and human cloning, the benefits of tissue engineering and in vitro fertilization. As long as there is no similarly delimited list of particular nanotechnologies, however, the vagueness of "nanotechnology" presents not only a liability, but also an opportunity. If the future of vaguely defined nanotechnology is wide open, then there is time and space for deliberation and choice. Since "nanotechnology" radically underdetermines technological development, we can mobilize social imagination to determine it. Natural and social scientists, industry and consumers, engineers and policy makers can work together to develop social imagination not about nanotechnology in the singular and how it might radically affect a distant future. Instead, in a public process, the task is to identify social needs, economic benefits and cultural values for nanotechnology and with nanotechnologists in order to influence what particular nanotechnologies shall come out of generic nanotechnology. If the task is too big for specialists and disciplinary specialties, then it is cut out for a collaboration that spans from research communities to civil society.

To be sure, such common work may have a sobering effect. Once assessments of benefits and risk shift from the unbounded promise of nanotechnology at large to particular short-term research projects, smoother billiard-balls, tighter tennis-rackets, scratch-free sunglasses or better sunscreens can no longer serve as evidence for the progress and utility of nanotechnology. If nothing else, our discontent with such new and improved products for a familiar life of leisure must challenge the social imagination for nanotechnology's potential.

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Emerging Concepts in Nanoparticle (NP) Toxicology

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Although exposures to airborne nano-sized particles (particles <100 nm) have been experienced by humans throughout their evolutionary stages, it is only with the advent of the industrial revolution that such exposures have increased dramatically due to anthropogenic sources such as internal combustion engines, power plants, and many others. And, most recently, the rapidly developing field of nanotechnology is likely to become yet another source for human exposures to nano-sized particles – engineered NP – by different routes, *i.e*., inhalation, ingestion, dermal or even injection. At this point in time, we do not know the extent of expected exposure to engineered NP by any of these routes, whether inadvertent or controlled. Likewise, information on potential adverse effects is very limited at best. However, although potential adverse effects of engineered NP have not been systematically investigated, there are a number of studies that were performed in the area of inhalation toxicology and also human epidemiology from which some preliminary conclusions about effects of nano-sized particles can be drawn. These studies have tested the hypothesis that airborne ambient ultrafine particles (particles <100 nm) emitted from many anthropogenic sources (thermal degradation) contribute causally to increased morbidity and mortality in susceptible parts of the population. These effects have been observed in numerous epidemiological studies and have been attributed to particulate air pollution.

In addition, there are some decades-old — mostly forgotten — studies with nano-sized particles which shed light on the biokinetics of such particles once introduced into the organism. Although there are differences between monodispersed engineered and polydispersed thermally-generated nano-sized particles, there are many similarities as well, and the same toxicological principles appear to apply. Collectively, therefore, from results of these older and new studies some emerging concepts of nanotoxicology can be identified:

(i) When inhaled, NP have a high probability to deposit by diffusional mechanisms in all regions of the respiratory tract: In particular, the smallest particles (1-5 nm) will target the olfactory mucosa of the nose, and particles around 20 nm have a very high deposition in the alveolar region of the lung. Importantly, the agglomeration state (singlets *vs*. aggregates) has a major impact on where inhaled NP deposit and what their fate is after deposition.

(ii) In contrast to larger particles, nano-sized particles can translocate across epithelia and along axons and dendrites of neurons.

(iii) Nano-sized particles have a greater inflammatory and oxidative stress generating potential than larger particles per given mass; however, mass may not be the appropriate dosemetric but particle surface area and number appear to be better predictors for their biological activity.

(iv) It appears that mitochondria are preferred subcellular structures where nano-sized particles localize.

(v) A key notion is that in addition to particle size, there are other important particle parameters which will modify effects and translocation: chemistry, biopersistence, surface properties, agglomeration state, shape.

Although some of these emerging principles of nano-toxicology are specific for exposure *via* the respiratory tract (*e.g.*, deposition of airborne NP), the fate and effects of NP once taken up into the organism by different routes are likely to be governed by the same mechanisms. For example, following inhalation exposure, local portal of entry effects as well as effects in extrapulmonary organs (*e.g.*, cardiovascular, liver, CNS) due to the propensity of NP to translocate can be expected, depending on modifying particle parameters outlined above.

Specific examples of translocation and effects of nano-sized particles and presumed mechanisms will be highlighted. They illustrate, on the one hand, that we need to be aware of possible acute adverse effects and potential long-term consequences; on the other hand, the findings also give us ideas about the intriguing possibilities that NP offer for potential use as diagnostic tools or as therapeutic delivery systems. Obviously, a thorough evaluation of desirable *vs*. adverse effects is required for the safe use of engineered NP. Thus, a major challenge lies ahead to answer key questions of nanotoxicology, foremost being the assessment of human and environmental exposure, the identification of potential hazards (toxicity *vs*. benefit), the biopersistence in cells and subcellular structures, the correlation between physicochemical and biological/toxicological properties and defining the appropriate dosemetric, the translocation pathways to sensitive structures within organs (biokinetics) as well as the mechanisms of uptake and translocation, and the mechanisms of effects at the organ/cellular/molecular level.

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“Mapping Out Nano Risks”
Dr. M.A.Pierotti
contribution

THEME 1: “Untangling science and science fiction in assessing the potential risks of nanotechnology”

Subject: Michael Crichton’s **“Prey”** best seller.

I believe that we should at first to distinguish between nanotechs employing nanoparticles which contain or not organic material, in particular nucleic acids (RNA or DNA).

In the case of inorganic compounds I do not see any possible or potential danger such as that described in the book. In the other case, although what described in the book appears unlikely at the light of our knowledges, the possibility of recombinational events between nucleic acids contained in the nanoparticles and those of the host (vegetal,animal or human) should be taken into consideration.In addition , in biology it is now emerging the concept of RNA interference by which small fragments of RNA (15-25 base pairs, designated as siRNA) complementary to a given gene can bind by complementarity to it and promote its degradation.Since the dimension of siRNAs is compatible with their inclusion in nanoparticles, this latter product should be treated with caution because it could be used as a potential weapon to silence relevance genes whose inactivation is incompatible with life.Of course,the other side of the coin are its extraordinary therapeutic applications!!

To summarise: it is science fiction to belive that **inorganic nanoparticles** could invade, become parasitc and reproduce themselves in an host but it has some scientific foundations to belive that **nanoparticles containing nucleic acids** ,once injected in an organism are at danger in causing genetic mutations or recombinations that could hamper even human health.

THEME 3: “Reflecting about the potential risks of nanotechnology with respect to ethics, privacy and security”

My contribution is limited to the security issue,in particular the potential danger for the workers in the plans which produce nanoparticles.

I have some information about the biologic properties of solid lipid nanoparticles that are now in a pre-clinical experimental phase as innovative drug delivery system.

The most impressive observation is that,most likely due to their dimensions, these nanoparticles are internalized into cells in few minutes.In the particular case, this occurrence is an advantage if we want to bring the drug into the cell and are using nanoparticles made up of biocompatible materials which is immediately degraded inside the cell.

A different situation could occur with nanoparticles made of not biologically degradable material (e.g. titanium dioxide).In this case it is predictable that if these particles become inhaled or (less likely) injected they will cause major problems by loading and perhaps killing a variety of cells (including macrophages etc).causing severe obstructions of both respiratory and circulatory tracts.

In conclusion, it is recommendable that during the process of nanoparticles production very tight procedures of containment should be applied to protect the workers from a potential exposure eventually resulting in inhalation /injection of these products.

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Mapping out Nano Risks

Jos Put

Nanotechnology has become a container concept, covering various structures, phenomena and technologies at the nano length scale. This makes it very difficult to map out or describe the risks, associated with these various technologies that in some way are associated with "Nano". It will be necessary to make very clear distinctions and to formulate accurate definitions or descriptions about what we mean with various terms. For some people "nanotechnology" seems to be synonymous with "nanoparticles", in this way creating a lot of confusion.

Nanotechnologies are technologies that are based on structuring of matter on the nano length scale. In fact they are based on new achievements of science that allow for creating such structures, as well in down sizing from the macroscopic world as in building up such structures in a controlled way starting from the atomic or molecular level. It is typically an interdisciplinary field, were physics, chemistry and biology meet.

Creating nanostructures in matter can be done in various ways and can lead to very different results. One can think of creating nano-patterns at the surface of a material, creating nano-ordening in a material, creating nanoparticles of various natures and by various methods, building up supramolecular nano-sized structures by self assembly, etc…. One really has to distinguish between all these technologies if one wants to come to a realistic mapping out of risks.

For the purpose of mapping out risks, the following classification could be used for the time being:

1. Nanostructures from whatever nature (nanopatterns, nano-ordering, nanoparticles) that are immobilized at the surface or in the bulk of a matrix material
2. Nanoparticles that are free and can become airborn to form an aerosol.
3. Supramolecular nanosystems, built up via self assembly, mimicking natural systems
4. Nanosystems of natural origin

Ad 1.

This kind of nanostructuring, applied to generate electrical, optical, barrier and other properties, creates very little risk, as the nanostructures or nanoparticles are fixed in a matrix.

Ad 2

Nanoparticles that are not fixed in a matrix can become airborn and can form an aerosol. Depending on the shape of the particles, they can be breathable. Upon inhalation they can have possible adverse effects.

These effects are related to the enormously enhanced surface to mass ratio. All properties related to surfaces: adsorption, reactivity, catalytic activity, etc… will be multiplied with a huge factor.

For these nanoparticles, two measures should be taken:

a. As long as the effects are unknown, containment is necessary until they are fixed in a matrix

b. A consortium of labs has to be set up to measure properties and toxicity of these particles and to create a database

These particles might keep some possible toxicity when dispersed in a liquid. The chance of becoming airborn however is reduced in that case.

Ad 3

Although these nanosystems might look like natural systems, there is one essential difference: they are not self-replicating and it is unlikely that self-replicating systems will be built up on short notice.

"Living" systems on the contrary are self-replicating or belong to organisms that are self-replicating.

Although self-replication is perceived as an additional risk, it has the advantage that only a small amount is needed as these systems can multiply via fermentation. Synthetic systems have to be synthesized in the amounts needed.

The idea that systems of this kind can turn into self-replicating nanobots is pure science fiction. However, these systems can be designed to have very specific catalytic activity, comparable to enzymes. As a consequence they can be harmful, but this risk is comparable to that of existing systems and can be controlled.

Ad 4

Natural nanosytems can be extremely dangerous or poisonous. As these systems are self-replicating or belong to self-replicating organisms and moreover as some of them are continuously modifying themselves via exchange of genetic material (e.g. viruses), these nanosystems have to be considered as the most dangerous ones on this planet, although this is not perceived as such.

Genetic modification of certain natural systems is done because it can enhance certain beneficial properties (e.g. enzymatic catalysis) substantially. However, the new insights in genetics (the existence of complex epigenetic networks and a much more complex than anticipated translation of genomics into proteomics) led to the conviction that not all consequences of even simple genetic modifications can be predicted.

As a consequence, genetic modification should be limited to micro-organisms for which containment is possible. Genetic modification on larger organisms (plants or animals) for which containment is not possible, should be avoided.

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<u>Public Perception of Nanotechnology</u>

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February 2004

1. As any new technology, nanotechnology evokes enthusiasm and high expectations with respect to new progress in science and technology, new productive applications and economic potentials on one hand side, and concerns about risks and unforeseen side effects on the other hand (NSF 2000; Roco et al. 2000; cf. Roco & Tomellini, 2002). As many new technologies experienced a strong public opposition after their often euphoric introduction (nuclear technology, bioengineering, genetic modifications), it is important to understand in advance potential public reactions and potential mobilization effects by relevant social groups.

2. For improving our understanding one needs to investigate the evolving socio-cultural context in which research at the nanoscale is funded, the societal needs that nanotechnology may satisfy, and the popular images that experts, politicians, and representatives of the various publics associate with nanoscience and nanotechnologies. The past research on public attitudes and political mobilization has demonstrated that the effectiveness of public protest does not depend so much on the number of people concerned about a technology but rather on the composition of the groups that are willing to act publicly in favor or against the implementation of such technologies (Hampel et al. 2000).

3. Public perception of technological risks depends on two sets of variables: the first set includes the well-known psychological factors such as perceived threat, familiarity, personal control options, and positive risk-benefit ratio. The second set includes political and cultural factors such as perceived equity and justice, visions about future developments and effects on one's interests and values. While the first set of components can be predicted to some degree on the basis of the properties of the technology itself and the situation of its introduction, the second set is almost impossible to predict. The social, political and cultural embedding of a new technology is always contingent on situational, randomly assorted combination of circumstances that impedes any systematic approach for anticipation.

4. The psychological associations linked to nanotechnologies can be and are studied empirically (cf. Bainbridge 2003). The main problem here is that for more than 90 percent of the respondents in European as well as U.S. surveys the term nanotechnology has no meaning and evokes educated guesses at best (Rocco and Bainbride 2001). Even if the term is explained to the interview partners, the response is a direct reaction to the verbal stimulus and thus more an artefact of the questionnaire than a valid representation of a person's attitude. A more promising method would be to conduct focus groups in which proponents and opponents of nanotechnology would be given the opportunity to develop their arguments in front of representatives of the general public or selected groups and then ask the respondents to share their impressions and evaluations.

5. Looking at the empirical results so far, it is interesting to note that the concern about the science-fiction notion of self-reproducing nano-robots or other more exotic applications of nanotechnology that could harm humans directly has been rarely found in the few surveys conducted until today (the theses of Joy, 2000, and others have no found much resonance in the public). Rather, critical remarks center around the concern that nanotechnology would be misused by some people to harm other people, exacerbating existing social inequalities and conflicts. In contrast, most respondents associated quite a number of direct but non-specific benefits and found a number of ways to express confidence that nanotechnology would help human beings achieve legitimate goals (Bainbridge 2003).

6. The social and cultural aspects of perception can be investigated by a combination of theoretical concepts (for example reflexive modernization approach) and empirical illustrations (we are far from empirical validation). On the basis of sociological theory one can deduct potential interest violations, mobilization potentials and societal opportunities or constraints for political action. For this purpose, it is important to analyze the motives, interests and resources of social player and simulate their influence on the policy process. Such a study will not be able to predict the exact development of the controversy over time, but may help decision makers to prepare themselves for what they could expect in the future. It is more a contingency analysis than a prediction.

7. An alternative route to understanding the more complex social and cultural responses is to organize public participation forums that simulate a microcosm of what one could expect in society as a whole (Renn 1999). Such forums are worthless if the outcome has no political impact. Only if these forums are constructed to enlighten policy makers or even co-determine public policies, can they fulfill their mandate to provide a public platform that simulates and precedes a similar debate in the wider society. Such forums will and should not replace the wider debate in society but it may pre-structure this debate and provide policy makers with suggestions and policy recommendations that they can successfully use in the wider debate that follows.

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Risks and Ethical Challenges of Nanotechnology in Healthcare

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Introduction

The convergence and integration of nanotechnology, biotechnology, information technology and cognitive science is expected to lead to advances in many different areas, including human health and healthcare technology. It is essential that these new developments take place with due respect for human welfare and dignity. Until the present, however, studies of the ethical, environmental, economic, legal and social implications of nanotechnology have generally tended to be lag behind the scientific and technological advances, with the risk that the current rapid progress in this field might be slowed down or even entirely halted due to the increasing degree of public concern regarding the introduction of the new technology.

Any technology, irrespective of whether it is established or innovative, has the potential for misuse and evaluation of the benefits to society of the application of a given technology must incorporate evaluation of this risk into the ethical consideration, though technologies themselves in general are inherently ethically neutral. Many of the ethical questions that are raised by nanotechnology are closely linked to the related disciplines of biology and biotechnology. Public anxieties are focussed mainly on fears that the introduction of nanotechnology could lead to an invasion of privacy as a result of the creation of genetic databanks, the prospect of runaway proliferation of self replicating systems and the possibly toxic nature of nanoparticles dispersed in the environment. Developments in nanobiotechnology pose particularly significant ethical, safety and social questions.

Applications of nanotechnology in healthcare

Broadly speaking, one can classify the biomedical applications of nanotechnology into several main categories: diagnostic systems, including biochips and nanoarrays; biomaterials, including tissue engineering; therapeutic systems, including targeted drug delivery and gene therapy. Current fields of research include the synthesis of nanostructures, biomimetic nanostructures based on naturally occurring biological structures, the electronic-biological interface, methods for early detection of disease, molecular biotechnology and scaffolds for tissue engineering. Potential applications of nanotechnology in the healthcare sector include biosensors for diagnosis and patient monitoring, the synthesis of new pharmaceutical products, development of improved biocompatible materials for medical implants of increased durability, organ and tissue regeneration and replacement and genetic based diagnostic and therapeutic methods. These advances can expected to lead to improved health even at advanced age and longer life expectation compared with present-day standards.

The field of nanobiotechnology deals with biological and chemical systems from the cellular to the molecular level, biological-material interfaces, hybrid bio-electronic systems and nanofabrication techniques. Currently available types of biomaterials consist of metallic alloys, ceramics, polymers and composites that may also incorporate biological molecules such as peptides and proteins. They find an extremely varied range of applications that includes orthopaedic and dental implants, lab-on-a-chip diagnostic devices, biosensors, tissue engineering and organ replacement, materials for cardiovascular surgery and advanced drug delivery systems. Natural body tissues are made up of complex architectures of differentiated cells in an extracellular matrix. Nanotextured surfaces are being developed to allow the controlled growth of cells reproducing as closely as possible these natural structures. The potential applications include the growth of nerve cells for neural implants, orthopaedic implants with increased biocompatibility, and substrates for tissue and organ growth.

Targeted drug delivery techniques involve the use of nanopowders to deliver drugs to specific sites within the body. Nanoparticles and nanotubes have high surface-to-volume ratios, which increases the drug uptake. One highly successful technique uses hydrogel spheres that allow controlled time release of the medication encapsulated inside. These may be coated with a biocompatible compound in order to allow penetration of cancerous cells without triggering a response from the patient's immune system. Because the drug is delivered to the specific site of action lower doses are required, undesirable side effects are greatly reduced and the treatment is more efficacious. Specific targeting and intracellular delivery by means of nanoparticles is especially advantageous in gene therapy. Implantable biosensors may be incorporated into therapeutic systems to control the administration of the drug by continuously monitoring the response of the patient in real time.

Biosensors are devices that can be used to determine the concentration of analytes in body fluids. They may be based on optical phenomena (such as absorption or emission of light or photochemical reactions), electrochemical reactions, or the piezoelectric effect. Their most common application at present is in minimally invasive blood glucose measurements, though other types of sensor are used for blood gas analysis and metabolic function. Research is also in progress to develop biosensors to perform cancer screening tests and sensors that use antigen-antibody reactions to detect viruses. The incorporation of DNA chips as components of biosensor systems is likely to revolutionize clinical diagnostics and allow the use of personalized gene therapies specifically designed for the individual patient. Biochip technology utilizing microarrays or microfluidic devices is currently emerging as a new tool in diagnosis and drug discovery.

The molecular components of living organisms, such as proteins, lipids and nucleic acids, possess properties that are determined at the nano level and cellular processes are fundamentally nanoscale phenomena. Genetic information is encoded on the DNA molecules within the individual cells and an increased knowledge of the patient's genetic makeup will allow the tailoring of therapies to the individual. The introduction of gene and antisense therapies will allow the treatment of viral and other diseases by modifying aberrant gene expression, or by preventing the translation of genetic information to protein. The use of genetic screening techniques will enable the identification of those individuals who may be predisposed to particular diseases and allow improvement of drug targeting. Research into human genomics attempts to develop an understanding of the underlying genetic factors that are responsible for or contribute to the susceptibility to disease. Applications of molecular medicine and molecular diagnostics are expected to increase in the future as the results of this research come to fruition. The ultimate aim is to shift the emphasis from curing disease to its earlier detection and prevention before health has deteriorated to a significant extent.

Ethical and regulatory considerations

The application of clinical genomics in epidemiological studies requires the accumulation of large quantities of data to determine the combined influence of genotype, lifestyle and environment on risk of contracting conditions such as cancer, cardiovascular disease and diabetes. Bioinformatics is the branch of information technology concerned with the processing and utilisation of genetic and other information stored in databases for the prevention, diagnosis and treatment of disease. Due to the confidential nature of the information being handled it is essential that both the information and the clinical samples are processed in an ethically responsible as well as a scientifically correct way. Complex bioethical questions are posed by the establishment and maintenance of genetic databases and an adequate system of safeguards will therefore be necessary to guarantee data confidentiality and to ensure respect for the principle of informed consent and to prevent discrimination based on genetic factors.

Technology transfer from pure research to commercial applications requires appropriate regulatory procedures to ensure that the products are properly approved and certified for use. This is especially important in cases where there is a high degree of public concern regarding the ethical, legal and social consequences of the introduction of a new technology. The existing regulatory framework for the medical device industry in Europe is based on three European Commission Directives. These are the Medical Devices Directive, the Active Implantable Medical Devices Directive, and the In Vitro Diagnostic Directive. Within the scope of these current regulations no distinction is made between medical devices and diagnostic systems based on conventional technology and those based on nanotechnology. Technological progress needs to be closely linked to the re-examination of the existing framework of laws, regulations and standards so that revisions can be made where appropriate. New scientific developments must therefore be closely reviewed in order that the regulatory framework can be updated when needed.

An improved understanding of the interactions within complex systems will required in order to anticipate and avoid unforeseen negative effects due to the introduction of these new technologies. Action also needs to be taken to address fears that the introduction of nanotechnology might lead to invasion of the individual's right to privacy or to the uncontrollable propagation of self-replicating systems in the environment. Relatively little research has been undertaken to ascertain the effects of nanomaterials on living organisms or to investigate whether nanoparticles might be capable of penetrating the defences of the body's immune system. Important legal issues arise concerning the rights to ownership and patenting of biological molecules and genes by individual companies and organisations. Examination of these considerations needs to take into account both the short term and the long term potential impact of nanotechnology.

The precautionary principle has been commonly invoked as a method of minimising the hazards, especially those to the environment, associated with the introduction of new technologies. In its most stringent interpretation application of the precautionary principle would require no action ever to be taken where the results of that action might potentially be harmful. Applying the principle in this form would however clearly limit scientific and economic progress very severely, so that a less restrictive version, which requires the use of reliable scientific data to minimise the level of risk, is generally used. It is necessary that the precautionary principle be incorporated within a structured approach to the analysis of risk.

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Towards an appropriate corporate and public governance of Nano Risks : Promoting and strengthening a multilateral approach

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As a matter of fact, there is no need to refer to the mass medias hype surrounding the nanotechnologies to understand industrial realities. The patent offices statistics, the amounts invested by venture capitalists, public spending in fundamental as well as applied research throughout the world close to the market, speak for themselves : yes, nanoscience has already left the sheltered confines of the labs to enter the marketplace.
I shall adopt a specific vision of this reality, focusing on the economic and legal matters opened by such a quick evolution, as it expands on a worldwide basis.

Institutional investors, insurances, shareholders and national financial authorities have the right and/or duty to assess the financial risk of their contractual relationships with entreprises involved in the production, or incorporation, or dissemination of nanoelements and structures.

They need to act on the basis of financial risk assessment models. Legislation can oblige the president of a board to declare on annual basis the potential negative impact of the firm's activities on the environment and the financial risks incurred in case of a legal action to seek redress of a damage occurred at a large scale. The European Parliament recently adopted (12.02 2004) a resolution related to corporate governance and supervision of financial services, who supports the European Commission's proposal to tighten up the collective board members responsibilites in the short run, and calls a new proposal in order to create an individual responsibility

But as far as environmental risk assessments are concerned by financial annual reports, one has to admit that we collectively need a learning process in order to obtain actual implementation of the law...

There is a need to accelerate the risk assessment process initiated at the european level for nanotechnologies and to extend it quickly to converging technologies at the nanoscale, if we want to be in a position to discuss the rules and the price to be payed for, in case they would be broken on a deliberate basis.

This point is of a paramount importance, as regards the sincere evaluation of assets in the balance sheets, and the value shareholders would give to firms acting in the field of nanotechnologies.

The set of governance rules, ideally, would be settled at the most appropriate level, which is related to the relevant markets and areas of concern.

* The text is presented under the author's responsibility.

Multilateral / Intergovernmental agreements may provide a helpful framework to nano risks assessment.

There are voices expressed in transatlantic relationships whose aims seem to advocate in favor of soft law and self-regulation of the industrial and economic activities related to converging technologies at the nanoscale. The explicit goal is to avoid a reluctant approach at the european level, because it would lead to unacceptable trade and investment regional restrictions, based on the precautionary principle, following the GMO's track.

The « cultural » difference between US and UE would be, as ever, the positive « if you don't know it, just try it » american way, versus the negative «first to go, last to know » or in french « dans le doute abstiens-toi » european drive.

There should be a pragmatic way to bridge the emerging gap, provided that there is a common will to let it happen : it is a transparent, democratic and multilateral way to address public concerns about the actual knowledge of direct and cumulative impacts of nanoscale productions on the environment and the human beings.

Where there is a call for public governance, relevant public authorities should first take the lead.

Four questions can be expressed at this stage :

☙1. How to avoid environmental dumping by entering, at an early stage, a fruitful dialogue of mutual interest with Asia and Americas ?

☙2. How to use the specific existing multilateral / intergovernmental tools (hortatory and mandatory ones) and, possibly, amend them to adapt to nano realities :

Ex.a) : Nano-biotechnology : Extension of the « Biosecurity Protocole », also known as « Protocole de Carthagène » to the nanoscale, including self-assembly (103 countries signed, but the US).

Ex.b) : Nano-chemistry : Applying the REACH future European union regulatory framework being under discussion on chemistry, to manufactured goods including nanoelements (REACH stands for Registration, Evaluation, Autorisation and Restriction of Chemicals)

Ex. c) : Nano-information technologies : Promotion of a European union approach through the CEN initiative to create a working group dedicated to nanotechnologies no later than the end of 2004. (CEN stands for Centre Européen de Normalisation)

Ex.d) : Cognitive sciences and NBIC convergence : Revisiting the European charter of human rights in order to considering, on a constitutional basis, human dignity and privacy concerns due to the progressively strengthening speech in defense of huge and sometimes unbelievable human performance enhancements (whatever the ultimate goals) related to brain/machine and brain-to-brain communications...

ↀ3. How to promote transparency and citizens commitment to the debate, on an improved and available knowledge basis, through consumers associations, amongst other relevant levers of action. Embedded nano-elements or structures should become neither a nightmare nor a dream.

ↀ4. Last but not least : how to enter a dialogue with all stakeholders to determine the right burden sharing between public and private responsibilities related to Nano Risks.

The experience of the recently opened multilateral dialogue on the worldwide Internet public/private governance, provides a good basis to understand the difficulties, but nonetheless the social utility, to address seriously, and in due time, this kind of planetary problem. Under the United Nations Secretary general authority, a group of stakehoders representatives, including governments, NGO's and private sector has been created by a commonly agreed action plan of the first World Summit on Information Society (WSIS), precisely to define and make proposals to address internet governance issues (either « technical » and public ones)

If convergence of technologies at the nanoscale and at the femtosecond timescale is to bring such universal issues as the internet already provided, it would not be so unrealistic to impulse a WSIS-like dynamic to assess nano risks...and review all opportunities to bridge the emerging « nano » economic divide.

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<u>Nanotechnology and its implications</u>

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Neal Lane, then Assistant to the President of the USA for Science and Technology said "If I were asked for an area of science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering." This statement epitomises the view of Governments worldwide and indicates precisely why so much financial investment in both nanoscience and nanotechnology is being made. It doesn't explain why nanoscience and nanotechnology are the subject of such debate in terms of potential drawbacks or even show stoppers whether environmental, societal or ethical. To understand this more fully it is important to understand what nano<u>science</u> is, what nano<u>technology</u> offers in terms of commercial opportunities and what role nanotechnology will have in amidst of all the other technologies that shape our lives.

The prefix nano- has two meanings. In an exact sense it means a factor of one thousandth of a millionth, 10^{-9}, and hence a nanometre (5 atom diameters) as a length measurement and a nanosecond as a time measurement. In its popular use the nano- prefix normally refers to the length scale. The more imprecise definition of nano is 'extremely small'. Hence a nanosatellite is simply a satellite that is extremely small compared to a conventional satellite, and not a satellite that is a few atoms in size – in fact it is more likely to be the size of a football. The interest surrounding nanoscience and nanotechnology is associated with the exact definition and the fact that both science and engineering are now possible on the nanometre length scale. To put this into perspective, engineering at the nanometre scale with respect to a metre length is the equivalent of being able to position a single eye of a common house fly to an accuracy of less than 1/10th of its diameter in the distance between Paris and Rome.

The fact that science and engineering on the nanometre scale is now ubiquitous is predominantly a natural consequence of miniaturisation that has been constantly evolving over the last few centuries: we are simply used to having smaller and more complex machines. Two obvious examples of this are how the sizes of watches and clocks has decreased in the past 500 years and how, in the 15 years, the size of mobile phones has shrunk even though their complexity has increased. Miniaturisation by itself does not however explain the nano- boom. There are at least three unique factors that combine to explain the real potential, and ultimately the concerns, around nanoscience and nanotechnology:

1. *The end of the road for miniaturisation*. The atoms and molecules of everything around us represent the fundamental building blocks of nature that we can currently explore <u>and</u> exploit. In this sense miniaturisation has come to a natural limit. The importance of this is best summed up in a quote from Horst Stormer, a Nobel Laureate who said "Nanotechnology has given us the tools…to play with the ultimate toy box of nature – atoms and molecules. Everything is made from it….The possibilities to create new things appear limitless."

2. *Nano is different*. As an object is shrunk in size there is a length scale beyond which the physical properties of the object itself can start to change. This is not because the laws of physics have changed it is simply because the size and shape of the object now play a role in defining the objects' physical property. Thus, for example, magnetic properties of magnets smaller than a few hundred nanometres in size become increasingly dependent upon size and shape – a fact that will be exploited in future computer hard disk drives. Engineering at the nanometre scale therefore provides an opportunity to make new types of materials and devices with unique properties. Nanoparticles such as carbon nanotubes are good examples of this. As a tool however it is important to recognise that it is not a technology it its own right. It is simply an enabling technology that will allow one or more elements of a material, product or process to be done differently; energy efficiently, uniquely or through the use of fewer raw materials. It is just one of the plethora of technologies that are available and therefore used only where appropriate.

3. *Nano is ubiquitous*. Since atoms and molecules are nanometre size objects it is not surprising that nanoscience has relevance to a range of scientific disciplines and nanotechnology is important across technology sectors. It also explains why nano- can so easily become a catch-all prefix. Since nature is constructed from atoms and molecules, a nanometre or so in size, it is possible to claim that nano- is therefore everything. Chemists have been making and measuring molecules for over 100 years, does this mean they are suddenly all nanoscientists? In a sense the nomenclature doesn't really matter. What is actually important is that the nanometre is a unit of length of fundamental importance to many disciplines so that advances in science and technology in any one area can have an immediate impact on another. A prominent example of this is how an imaging tool, the scanning tunnelling microscope, designed to image single atoms, is now applied to problems in nearly every area of science that range from understanding how crystals grow to watching DNA molecules at work.

Nanoscience and nanotechnology, as both Neal Lane and Horst Stormer say, has the potential to impact almost every aspect of our lives. It has the potential to have a positive impact on our lives and, like every other technology, could have a negative effect. Making the right choices in respect of both outcomes requires a co-ordinated and inclusive approach where societal, ethical and environmental issues are balanced against technical and commercial pressures.

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2. Terms of Reference

Background

The Directorate-General for Health and Consumer Protection (DG SANCO)[92] of the European Commission is responsible for Consumer policy (Treaty Articles 95 and 153), Public health (Treaty Articles 95, 152 and 300), and Food safety, animal health, animal welfare and plant health (Treaty Articles 37, 95 and 152).[93]

One of the mandates of the "Risk Assessment" Unit of the "Public Health and Risk Assessment" Directorate of DG SANCO concerns in-house risk assessment. Specifically, the "Risk Assessment" Unit should in particular contribute to

- identifying emerging risks in the non food areas, establishing a procedure for early identification of risks in the non food areas and in new technologies;
- providing DG SANCO with preliminary risk assessments on an ad hoc basis, offering an in house analytical facility to characterize risks in support of SANCO;
- ensuring, in support of the first two items, co-operation with national, Community and international bodies on risk assessment, facilitating co-operation on risk assessment of subjects of mutual interest with national, Community and international bodies as appropriate with a view to sharing information and to avoid diverging scientific opinions.

Therefore, by necessity, the Unit must take a proactive stance.

Why single out nanotechnology and hold a scoping workshop on "Mapping Out Nano Risks"?

First, if chemists, solid state physicists, and condensed matter physicists rightfully argue that nanoscience has existed for a long time and that its theoretical underpinnings—quantum mechanics—while still baffling can make no claim of novelty, STMs (Scanning Tunneling Microscopes), AFMs (Atomic Force Microscopes), and other workhorses of nanotechnology have recently become relatively affordable, opening the ground for scientific investigation and commercial innovation.

Second, scientists in general (e.g., Bill Joy[94]) and risks analysts in particular (e.g., summary of the "Societal and Communication Aspects" session at the EuroNanoForum, in Trieste, Italy, on 10 December 2003[95]), activists (e.g., ETC Group[96], Greenpeace[97]), military analysts (e.g., Gsponer[98]), ethicists, science fiction writers (e.g., Michael Crichton with his bestselling novel *Prey*) have identified nanotechnology as a potential emerging risk and the public has taken

[92] http://europa.eu.int/comm/dgs/health_consumer/index_en.htm
[93] http://europa.eu.int/eur-lex/en/search/search_treaties.html
[94] http://www.wired.com/wired/archive/8.04/joy.html
[95] http://ica.cordis.lu/search/index.cfm?fuseaction=news.simpledocument&N_RCN=21330&CFID=5333&CFTOKEN=94512958
[96] http://www.etcgroup.org/documents/TheBigDown.pdf
[97] http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/5886.pdf
[98] http://www.acronym.org.uk/dd/dd67/67op1.htm

notice, in particular, of its potential public health, environmental, ethics including privacy, and military implications. In response to this, the UK government has asked its national science and engineering academies to undertake a study into nanotechnology and, as part of this study, they are consulting with interested parties including the public.[99]

Third, massive funding in the US, Europe, and Japan is fueling R&D and innovation in nanotechnology[100].

Fourth and finally, nanoscience has already left the sheltered confines of the lab as nanotechnology to enter the market as the following products attest.

- wrinkle- and stain-resistant cotton fabrics (e.g., Nano-Tex, subsidiary of Burlington Industries and provider of Eddie Bauer's "Nano-Care" stain-resistant pants[101]);
- tennis rackets (e.g., Babolat[102, 103]);
- tennis balls (e.g., Wilson Double Core tennis balls with InMat[104] nanoparticles);
- non-stick coating for glass and anticorrosion linings for metals (e.g., Nanogate[105]);
- sunscreen (e.g., using silica coated nano titanium dioxide,TiO_2, manufactured by Chengyin Technology Co. Ltd.[106]);
- ultraviolet screening material (e.g., using silica coated nano titanium dioxide manufactured by Chengyin Technology Co. Ltd.[107]);
- topical treatment of Herpes, skin de-germing, and nail fungus treatment (e.g., NanoBio Corp[108])
- anti-bacterial powder (e.g., Chengyin Technology Co. Ltd.[109]);
- medical applications including wound care (bandages and adhesives), catheters of all types including CVC, CVP's, urinary catheters, heart valves, pacemaker leads, suture rings, feeding tubes, orthopaedic implants, and small joint replacements (e.g., AgION™[110])
- contaminants cleanup products (e.g., Chengyin Technology Co. Ltd.[111]);

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99 http://www.nanotec.org.uk/
100 http://www.nano.gov/
101 http://www.eddiebauer.com//Search/Controller.asp?f=m&Nty=1&N=0&Ntk=All_Search&Ntt=Nano%2DCare&D=Nano%2DCare&Fs=1&lp=h4&Ne=200000&s=s&referringurl=http%3A%2F%2Fwww%2Eeddiebauer%2Ecom%2Feb%2Fdefault%2Easp
102 http://www.babolat.com/english/tennis/technology/index.php?src=tennis (see NCT= Nano Carbon Technology)
103 http://www.tennis-warehouse.com/descpageRCWILSON-TRIAD4.html
104 http://www.inmat.com/
105 http://www.nanogate.com/_english/homepage_html.htm
106 http://nanodot.org/article.pl?sid=02/08/02/0752217
107 http://www.chengying.com/doce/products-01.htm
108 http://www.nanobio.com/emulsion.html
109 http://www.chengying.com/doce/products-06.htm
110 http://www.agion-tech.com/applications.html
111 http://www.chengying.com/doce/products-03.htm

− beautification products (e.g., L'Oréal[112, 113, 114]);

− home-pregnancy test (e.g., Carter-Wallace[115]);

− air-filtration systems (e.g., Emergency Filtration Products[116]).

Examples of products that may incorporate nanotechnology tomorrow range from molecular computers based on spintronics; cancer-fighting molecules; non-polluting automobile engines; sensors that help the food industry detect suspected pathogens; delivery systems that embed nutrients in foods that do not naturally have them; to drug delivery systems in the blood stream.

What does the workshop aim to achieve?

In terms of substance, the workshop aims to produce (a) a preliminary mapping of risks (or a small set of them) and (b) a documented mapping strategy (or a small number of them).

In terms of products, (a) a collection of short contributions from each participant and (b) short workshop proceedings. Both will be put on the web.

A classical decision tree for risk analysis (Fig. 1) helps highlight possible different foci of the mapping.

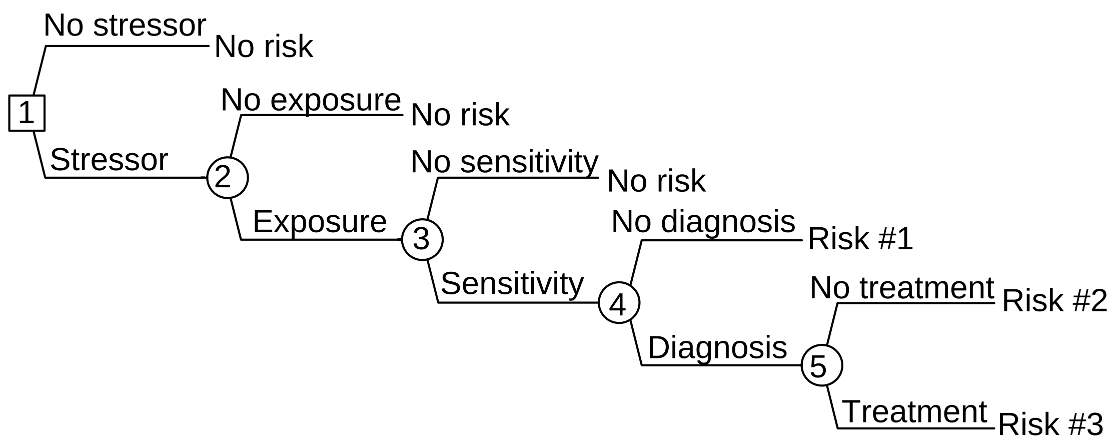

Figure 1: Classical decision tree for risk analysis

[112] http://www.loreal.de/press-room/full_article.asp?id_Art=1770&id_sousrubrique=1
[113] http://www.loreal.com/us/group/world/loreal-japon.asp
[114] http://www.loreal.it/press-room/full_article.asp?id_Art=1596&id_sousrubrique=1
[115] http://pubs.acs.org/hotartcl/ac/98/may/nano.html
[116] http://www.emergencyfiltration.com/Product%20Page/Products.htm

Looking at each node in turn,

1. *Nanotechnology as a stressor:* What kinds of nano-entities can we find today, what kinds will we encounter within the next ten years, and what kinds of nano-entities will we meet beyond ten years from now? Can we cluster nano-entities into classes? If yes, using which rationale? What are their characteristics in terms of numbers; mass; interactive or reactive surface; distribution; mechanical, chemical (in particular, colloidal), and radiative properties; foreseen functions; undesirable but likely capacities; etc.? In particular, how do their respond to temperature and how do they behave in water? How to their react with inorganic vs. organic compounds? Which known natural and anthropogenic analogs, if any, will we able to use to predict their behavior, their mechanical, chemical, and radiative properties, their longevity; or their controllability? When can these minute particles create a waste problem? Can ensembles of nano-entities (cf., “grey goo” and “green goo”) behave in a coordinated manner? Which emerging properties could they acquire when they interact with each other, when controlled and when uncontrolled? How will nano-entities interact with other objects and how could they make them toxic? Etc.

2. *Exposure to nanotechnology:* In which circumstances will citizens find themselves in contact with nano-particles? When will this contact be chosen? When will it be fortuitous? How can nano-entities move? When will movement be passive and when will it be active? Which energy sources can active nano-entities tap in? Which differences will matter between different carriers such as air, water, food, manufactured products, animals, and plants? Which parts of the body are most likely to be in contact? The epidermis? The respiratory tract? The nasal cavity and the brain? The digestive tract? Which will the modes of action and the target organs be? In which context, under what circumstances, and with which time horizon can the molecular manufacturing or self-assembly of nano-entities become an issue? Can organically-based self-replication become an issue? When? Etc.

3. *Sensitivity to nano-entities:* Which classes of sensitivities can we identify today in humans, in domestic animals, in the environment including the flora, the fauna—in particular decomposing microbes, and soil? How could sensitivity vary with different populations? Which environmental factors affect these sensitivities?

4. *Diagnosis:* Can we foresee ways to diagnose contamination by nano-entities? Is their a way to finger print classes of nano-entities?

5. *Treatment:* Can we foresee ways to treat contamination by nano-entities?

HOW DO WE PLAN TO DO THAT?

1. We ask each participant to send us a short (2–3 pages) contribution by 15 February 2004 so that these contributions may be collated and circulated before the meeting—contributions received after 15 February will not be included. Participants are welcome to submit any background information that they deem useful, preferably in electronic form so that it may be easily circulated.

2. At the meeting, in terms of organization, we will open each session with a short (15–20 min.) presentation. After that we will open the floor for discussion. See agenda.

3. After the meeting, we will produce draft proceedings, circulate them for comments, suggestions, and approval, and put a final version on the web along with the contributions communicated before the meeting.

DRAFT AGENDA

The scoping/brainstorming workshop will comprise four half day sessions (see Table below).

Time	Monday, 1 March 2004	Tuesday, 2 March 2004
10:00	Introduction	Summary of previous day
	Theme 1: "Untangling science and science fiction in assessing the potential risks of nanotechnology"	**Theme 3: "Reflecting about the potential risks of nanotechnology with respect to ethics, privacy, and security"**
10:45	Discussion primer by Prof. Alfred Nordmann (Technische Universität, Darmstadt)	Discussion primer by Dr Jürgen Altmann (Ruhr-Universität Bochum)
11:05	Session 1.1	Session 3.1
11:55	*Coffee break*	*Coffee break*
12:10	Session 1.2	Session 3.2
13:00	Conclusion	Conclusion
13:20	*Lunch*	*Lunch*
	Theme 2: "Using data and analysis to quantify and qualify the potential risks of nanotechnology"	**Theme 4: "Identifying emerging patterns and methodological keys to monitor the potential risks of nanotechnology"**
14:20	Discussion primer by Prof. Vicki Colvin (Rice University)	Discussion primer by Prof. Jean-Pierre Dupuy (École Polytechnique)
14:40	Session 2.1	Session 4.1: Break-up in subgroups
15:30	*Coffee break*	*Coffee break*
15:45	Session 2.2	Session 4.2: Plenary
16:35	Conclusion	Conclusion
17:00	End of 1st day	End of workshop

The first session will concern itself with untangling science and science fiction in assessing the potential risks of nanotechnology taking Michael Crichton's *Prey* bestseller as starting point. Prof. Alfred Nordmann from Technische Universität, Darmstadt, will prime the discussion.

The second session will focus on using data and analysis to quantify and qualify the potential risks of nanotechnology. Dr. Vicki Colvin, Director of the Center for Biological and Environmental Nanotechnology (CBEN) and Associate Professor at Rice University, will start the discussion with a presentation of her work and that of her colleagues in environmental nano-ecotoxicology.

The third session will propose a reflection on the potential risks of nanotechnology with respect to ethics, privacy, and security. Dr. Jürgen Altmann from Ruhr-Universität Bochum will open the discussion with remarks on a scientific approach to science-policy and science-society issues.

The fourth and last session will place itself at a higher level of abstraction. It will examine how we can apprehend the vastness, diversity and resulting complexity of nanotechnology, trying to identify key aspects, emerging patterns, and methodological angles to facilitate the understanding and monitoring of this dynamic field and the potential risks associated with it. Prof. Jean-Pierre Dupuy from CREA (Centre of Research in Applied Epistemology of the École Polytechnique) will launch this last session.

The group will break up into four subgroups and reconvene for a plenary during which results will be shared.

TIME, DATE, PLACE, AND PUBLIC TRANSPORT

Date	Monday, 1 March and Tuesday, 2 March 2004
Time	10 am to 5 pm
Location	Room 36 1st floor 1, rue de Genève (main entrance at 3, rue de Genève) B-1140 Brussels BELGIUM
Public transport	− Brussels Airport bus 12 stop: “rue de Genève”[117] − NATO bus 21 stop: “rue de Genève”[118] − Hal/Halle-Maline/Mechelen or Hal/Halle-Vilvorde/Vilvoorde train line 26 stop: “Evere”[119]

ORGANIZATION

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[117] http://www.stib.irisnet.be/40000NF/Actuel/012(B)/Index.html
[118] http://www.stib.irisnet.be/40000NF/Actuel/021(B)/index.html
[119] http://www.b-rail.be/rnvn/pdf/p2_28fr.pdf

3. Agenda

"Mapping Out Nano Risks" Workshop Agenda (2004/02/04)

Schedule	1st day: Monday, 1 March 2004
10:00	Introduction
	Theme 1: "Untangling science and science fiction in assessing the potential risks of nanotechnology to human health"
10:45	Opening discussion primer by Prof. Alfred Nordmann (Technische Universität, Darmstadt)
10:55	Open discussion
11:45	*Coffee break*
12:00	Toxicological discussion primer by Prof. Günther Oberdörster (University of Rochester, NY)
12:10	Open discussion
13:00	Conclusion
13:20	*Lunch*
	Theme 2: "Using data and analysis to quantify and qualify the potential ecotoxicological risks of nanotechnology"
14:20	Ecotoxicological discussion primer by Prof. Vicki Colvin (Rice University and Centre for Biological and Environmental Nanotechnology)
14:30	Open discussion
15:20	*Coffee break*
15:35	Ecotoxicological intervention by Prof. Paul Borm (Centre of Expertise Life Sciences (CEL), Heerlen, and University of Düsseldorf)
15:45	Open discussion
16:35	Conclusion
17:00	End of 1st day
	2nd day: Tuesday, 2 March 2004
10:00	Summary of previous day (especially pending issues and questions)
	Theme 3: "Reflecting about the potential risks of nanotechnology with respect to ethics and security"
10:45	Ethics discussion primer by Prof. Gören Hermerén (Lund University and European Ethics Group)
10:55	Open discussion
11:45	*Coffee break*
12:00	Security discussion primer by Dr. Jürgen Altmann (Ruhr-Universität Bochum)
12:10	Open discussion
13:00	Conclusion
13:20	*Lunch*
14:20	**Theme 4: "Identifying emerging patterns and methodological keys to monitor the potential risks of nanotechnology"**
14:20	Break-up in subgroups: -subgroup 1: toxicology -subgroup 2: ecotoxicology -subgroup 3: ethics and security
15:10	*Coffee break*
15:25	Plenary
16:15	Synthesis by Prof. Jean-Pierre Dupuy (École Polytechnique)
16:35	Conclusion
17:00	End of workshop

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