

NANOTECHNOLOGY – HEALTH RISK AND SAFETY

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ABSTRACT

A top science field of the XXI century, promoting a new industrial revolution, nanotechnology deals with atoms and molecules. At this scale – a million times less than a millimeter – interactions are different. Nanoscience develops in parallel with nanotechnology, research develops immediately in technology and is commercialized in products. Often we work at the limit of knowledge, in a frontier climate with unknown risk. The paper points out principal risks and security issues.

KEYWORDS: nanotechnology, limit of knowledge, risk analysis, health safety

1. INTRODUCTION

Nanotechnology refers to the manipulation of living and non-living matter at the level of the nanometer (nm), one billionth of a meter. It is at this scale that quantum physics takes over from classical physics and the properties of elements change character in novel and unpredictable ways.

The societal impact of nanotechnology is enormous - better ways to prevent, detect and treat disease, faster and more efficient electronics, cleaner energy, more efficient manufacturing, and better systems to assess environmental risk. Major efforts are underway in both industry and government to realize the amazing promise of this technology. However, very little attention is devoted to assessment of health risks to humans or to the ecosystem. It is highly unlikely that all the materials used in construction of nanoparticles will be biologically inert. Furthermore, there is the still unsettled issue of "size matters" with respect to toxicity. The diversity of materials in constructing nanoparticles suggests that the universal safety of such systems cannot be taken for granted, and there will not be a single answer.

In summary, the toxicology of nanoparticles is poorly understood as there is no regulatory requirement to test nanoparticles for health, safety and environmental impacts. More research is

urgently needed as there are many indications that ultrafine particles could pose a human health hazard. The concern is that, as the industry grows, more and more people will be exposed to nanoproducts for which there is a paucity of toxicity information.

Occupational health risks associated with manufacturing and using nanomaterials are not yet clearly understood. Many nanomaterials and devices are formed from nanometer-scale particles (nanoparticles) that are initially produced as aerosols or colloidal suspensions. Exposure to these materials during manufacturing and use may occur through inhalation, dermal contact and ingestion. Minimal information is currently available on dominant exposure routes, potential exposure levels and material toxicity. What information does exist comes primarily from the study of ultrafine particles (typically defined as particles smaller than 100 nanometers).

Studies have indicated that low solubility ultrafine particles are more toxic than larger particles on a mass for mass basis. There are strong indications that particle surface area and surface chemistry are primarily responsible for observed responses in cell cultures and animals. There are also indications that ultrafine particles can penetrate through the skin, or translocate from the respiratory system to other organs. Research is continuing to understand how

these unique modes of biological interaction may lead to specific health effects.

Workers within nanotechnology-related industries have the potential to be exposed to uniquely engineered materials with novel sizes, shapes and physical and chemical properties, at levels far exceeding ambient concentrations. To understand the impact of these exposures on health, and how best to devise appropriate exposure monitoring and control strategies, much research is still needed. Until a clearer picture emerges, the limited evidence available would suggest caution when potential exposures to nanoparticles may occur.

All matter - living and non-living - originates at the nano-scale. The impacts of technologies controlling this realm cannot be overestimated: control of nano-scale matter is the control of nature's elements (the atoms and molecules that are the building blocks of everything). Biotech (the manipulation of genes), Informatics (the electronic management of information), Cognitive Sciences (the exploration and manipulation of the mind) and Nanotech (the manipulation of elements) will converge to transform both living and non-living matter. When gmos (genetically modified organisms) meet Atomically Modified Matter, life and living will never be the same [4].

2. RISK ANALYSIS

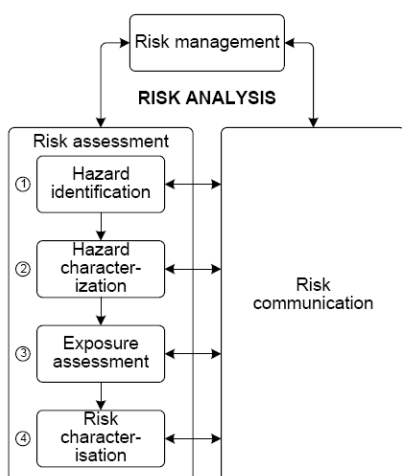


Fig. 1. The interconnected components of risk analysis identified and defined by the so-called “Food Law” [5]

The model used for risk analysis (Figure 1) by the EU scientists [5] is similar with that used in The Food safety laws, meaning the maximum level of contamination hazard. The principal terms used by this risk analysis model are:

- a. *Risk* means a function of the probability of an adverse health effect and the severity of that effect, consequential to a hazard;
- b. *Risk analysis* means a process consisting of three interconnected components: risk assessment, risk management and risk communication;
- c. *Risk assessment* means a scientifically based process consisting of four steps: hazard identification, hazard characterisation, exposure assessment and risk characterisation;
- d. *Risk management* means the process, distinct from risk assessment, of weighing policy alternatives in consultation with interested parties, considering risk assessment and other legitimate factors, and, if need be, selecting appropriate prevention and control options;
- e. *Risk communication* means the interactive exchange of information and opinions throughout the risk analysis process as regards hazards and risks, risk-related factors and risk perceptions, among risk assessors, risk managers, consumers, feed and food businesses, the academic community and other interested parties, including the explanation of risk assessment findings and the basis of risk management decisions;

- *Precautionary principle*:

1. In specific circumstances where, following an assessment of available information, the possibility of harmful effects on health is identified but scientific uncertainty persists, provisional risk management measures necessary to ensure the high level of health protection chosen in the Community may be adopted, pending further scientific information for a more comprehensive risk assessment.
2. Measures adopted on the basis of paragraph 1 shall be proportionate and no more restrictive of trade than is required to achieve the high level of health protection chosen in the Community, regard being had to technical and economic feasibility and other factors

regarded as legitimate in the matter under consideration. The measures shall be reviewed within a reasonable period of time, depending on the nature of the risk to life or health identified and the type of scientific information needed to clarify the scientific uncertainty and to conduct a more comprehensive risk assessment.

Linked to this model, some scientists argued that the use of the precautionary principle in the case of nanotechnology risk analysis may cause intolerable limitations of scientific research in the field.

The following risk analysis decision tree was proposed [5] for mapping out the nanotechnologies risks (figure 2).

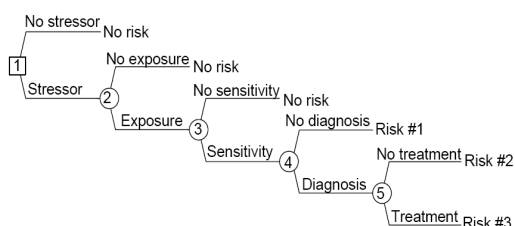


Fig.2. Risk analysis decision tree [5]

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 they respond to temperature and how do they behave in water? How do they react with inorganic vs. organic compounds? Which known natural and anthropogenic analogs, if any, will we be 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 nanoentities (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 nanoentities 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 there a way to fingerprint classes of nano-entities?

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

3. POTENTIAL RISKS

The present-day bulk production of materials and new forms of carbon with unknown and untested characteristics is a major concern. In the future, mass production of unique nanomaterials and self-replicating nanomachinery pose incalculable risks.

Nanoscale particles have distinctly different properties than their larger counterparts, so:

- Total surface area is larger
- Chemical reactivity is higher
- Smaller size facilitates cellular/organ uptake
- Tendency to agglomerate

- They may be more persistent (less biodegradable)

Nanoparticles may have physiological effects that their bulk counterparts:

- They may cross the blood-brain barrier
- They may cross the placental barrier
- They may have electronic effects that short-circuit metabolic processes in the cell

The requirements about nanotechnology safety must concern:

- Personal safety
- Effect on the environment
- Health and safety of workers in nanomanufacturing
- Health and safety of consumer

The global effects of nanoparticles over the environment may cause the following further risks:

- Enter the food chain
- Influence the biosphere
- Influence structural transition by liquids like water (biogenic nanoparticles)
- Chemical/physical transition by recycling (combustion) Nanomanufacturing will create new kinds and new classes chemical waste streams
- New, previously unconsidered, hazards may appear as different disciplines merge

4. KNOWLEDGE GAPS

UK scientist have identified substantial knowledge gaps in relation to key issues.. These are detailed below along with their view of how they may be addressed [6].

Gap 1: The nanoparticle nomenclature is not sufficiently well described or agreed. The establishment of an agreed and unified nomenclature is widely recognised as an important step towards development in any field of scientific endeavour. Currently there are no agreed definitions for nanoparticles, nanoparticle aerosols, or for the various types of nanoparticles which are produced. The first aspect relates to particle size. A definition of a size range for nanoparticles needs to take account of the distribution in sizes likely to be present, and to define the size interval in relation to the distribution. Secondly, it is necessary to consider whether the definition should be based on physical dimensions (e.g.

length, diameter, surface area) or on some behavioural property such as diffusivity.

The definition of a nanoparticle aerosol needs to include some consideration of aggregation and agglomeration. For example, should an aerosol which is comprised of loosely bound agglomerates of primary nanoparticles, in which the agglomerates are a size or dimension larger than that normally regarded as a nanoparticle (e.g. 1000nm) be regarded as a nanoparticle aerosol?

Gap 2: There are no convenient methods by which exposures to nanoparticles in the workplace can be measured or assessed

There is a need for more research into the development of new improved methods, combinations and strategies to provide reliable assessments of exposure to nanoparticles and nanoparticle aerosols. For inhalation, the most appropriate metric for assessment of exposure to most nanoparticles is particle surface area. Currently there are no effective methods available by which particle surface area can be assessed in the workplace.

Failing the development of this measurement approach, two alternative strategies are available. One is to develop an appropriate exposure assessment approach which optimises information available from various sources. This could include using suitable instruments to measure mass and/or number, assessment of material bulk properties, identification of appropriate surrogate measures, use of appropriate models, and evaluating determinants of exposure in a structured way. Suitable combinations could include instrumentation to count and size particles, coupled with surface area measurements derived from BET measurements of bulk material. Surrogate measures could include measurements of chemical composition of the nanoparticle material or of trace elements or impurities. Various deterministic approaches are already in use to provide assessment of current and retrospective exposure levels in workplaces, (e.g. Cherrie, 1999) which offer the potential for use in the assessment of exposure to nanoparticles.

An alternative (or complementary) approach may be the development of biological assays which directly measure the toxic potential of collected samples. In principle, these could

be based on *in-vitro* methods currently used in toxicological studies to assess inflammatory response. More research is required to develop and evaluate approaches of this type. Development of appropriate methods to evaluate dermal and ingestion exposure is also necessary.

Gap 3: Insufficient information concerning nanoparticle exposure is available. Much more information is needed regarding the exposure of workers involved in the production of all of the various types of nanoparticles via all of the production processes. In the absence of suitable measurements systems coherent approaches as described above should be adopted. At this stage there is insufficient evidence to judge whether exposure to the various forms of nanoparticles is occurring at significant levels in nanoparticle production processes.

Gap 4: The effectiveness of control approaches has not been evaluated. Control methods are available which have the potential (at least for inhalation risks) to provide the basis for effective risk management. At this point, it is not easy to judge how effective control strategies need to be. For some specific nanoparticles it may be necessary to control to very low levels (e.g. ng m⁻³). There is almost no information available in the public domain to demonstrate that effective control of exposure to nanoparticles has been achieved. Better understanding is required relating to the effectiveness of control of nanoparticles. This will be better informed given the development of appropriate methods for assessment of exposure to nanoparticles and a better understanding on the levels of exposure which may be acceptable. This is true for both inhalation, dermal and ingestion risks.

Gap 5: Knowledge concerning nanoparticle risks is inadequate for risk assessments. Proper assessment of the risks associated with exposure to nanoparticles requires understanding of the toxicological hazard associated with these materials and of the levels of exposure, expressed in an appropriate metric, which are likely to occur. There is insufficient exposure information currently available to adequately assess the risks from exposure (by inhalation, dermal and ingestion) to nanoparticles in nanoparticle production processes. Given the

diversity of nanoparticle shape, size and function, risk assessments will by necessity be highly specific to particular groups or classes of nanoparticles. Risk assessment approaches will have to consider how best to use information which is currently available, and plan to collect new information. Methodological approaches are available which may be used in new studies.

Appropriate and useful studies would include investigation of material properties (e.g. dustiness), exposure assessment and toxic potential within a structured risk assessment framework. These studies are unlikely to proceed without Governmental encouragement and support.

An effective strategy for storing and sharing this information is also necessary. Development of appropriate databases, and other information resources which can be used to collect and disseminate information on studies to investigate exposure or toxicological assessment of nanoparticles would be a key element in this.

Information resources of this type are already available to collect and disseminate information about exposure studies. One model is the HEROX database (www.herox.org) which contains information concerning exposure assessment studies for chemicals. This is a managed resource, with information concerning the studies being submitted by the researchers. This or other similar information resources could provide the basis for collection and storage of information about nanoparticle studies.

There is a strong case for placing more emphasis on issues of risk assessment and management than has been placed thus far. Development of new materials and products should not take place in the absence of consideration of the risks associated with their development, manufacture, use and ultimately disposal. Even though there are gaps in available approaches, a start can and should be made on the collection, dissemination and analysis of information relating to risks of these materials.

5. NEW TECHNOLOGY INTRODUCTION

The Action Group on Erosion, Technology and Concentration, formerly RAFI, nowadays ETC, is an international civil society

organization headquartered in Canada. The ETC group is dedicated to the advancement of cultural and ecological diversity and human rights. (www.etcgroup.org). The ETC group is also a member of the Community Biodiversity Development and Conservation Programme - CBDC (www.cbdcprogram.org).

The ETC group proposed [4], in order to avoid negative impacts of technology on the planet ecological balance, the following laws of new technology introduction:

1 It takes a full human generation to comprehend the ramifications of a new technology. Therefore, decisions about whether or not or how to use a new technology will necessarily be ambiguous. Society must be guided by the Precautionary Principle.

2 In evaluating a new technology, the first questions must be: Who owns it? Who controls it? By whom has it been designed and for whose benefit? Who has a role in deciding its introduction (or not)? Are there alternatives? Is it the best way to achieve a particular goal? In the event of harm, with whom does the burden of liability rest and how can the technology be recalled?

3 The extent to which a new technology may be beneficial to society will be in proportion to the participation of society in evaluating the technology - including and especially those people who are most vulnerable.

4 A new technology cannot definitively be assessed as positive, negative or neutral, although certain technologies - in an equitable environment - may be intrinsically decentralizing, democratizing and helpful.

5 For every so-called Luddite attempting to establish social controls over the introduction of a technology, there is powerful elite using social controls to impose new technologies on society.

6 The introduction of a new technology is not inevitable.

7 Any new technology introduced into a society that is not itself a just society can exacerbate the gap between rich and poor - and may even directly harm the poor.

8 A new technology cannot be a "silver bullet" for resolving an old injustice. Hunger, poverty, social disablement and environmental degradation are the consequences of

inequitable systems - not of inadequate technologies.

9 The leaders of a society who permit injustice are the least likely to introduce a new technology that will correct injustice.

6. CONCLUSIONS

The rapid growth of nanotechnology is leading to the development of new materials, devices and processes that lie far beyond our current understanding of environmental and human impact.

Emerging technologies require scientific, socioeconomic and societal evaluation in order for governments to make informed decisions about their risks/benefits and ultimate value.

REFERENCES

- [1] The National Nanotechnology Initiative Strategic Plan: December 2004
www.nano.gov/NNI_Strategic_Plan_2004.pdf
- [2] NNI, The National Nanotechnology Initiative
www.nano.gov.
- [3] NIOSH nanotechnology topic page at
www.cdc.gov/niosh/topics/nanotech/
- [4] The Big Down: *From Genomes to Atoms*,
www.etcgroup.org
- [5] 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; 2004;
http://europa.eu.int/comm/health/ph_risk/events_risk_en.htm.
- [6] RJ Aitken, KS Creely, CL Tran,
Nanoparticles: An occupational hygiene review, Institute of Occupational Medicine, Research Park North, Riccarton Edinburgh 2004
- [7] L. Gibb, M. Tang, *Nanotechnology: Safety and Risk. Management overview*, NNIN Nanotechnology Safety Workshop, 2 Dec 2004.

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