Chapter 13: Nanotechnology Risk Governance

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Introduction

Purpose and Background

This final case study summarises the major findings of the IRGC's White Paper on "Nanotechnology Risk Governance" as prepared by the nanotechnology group lead by Mike Roco and Ortwin Renn (IRGC, 2006). Since its publication in June 2006, the white paper provoked reactions from members of the academic community as well as from risk managers, regulators and representatives of non-governmental organizations (NGOs). Further comments were collected during two IRGC workshops on the risk management of nanotechnology in April and July 2006 and are presented here. The chapter will conclude with a discussion of the application and future development of the IRGC Risk Governance Framework for Nanotechnology[1].

In contrast to most of the case studies described in this part of the volume, the risks from nanotechnology constitute a newly emerging field of research. Hence, the risk governance framework discussed in this article does not provide a lessons-learned perspective but a prospective and proactive one. Based on a careful assessment of nanotechnology's current status in the context of the regulatory environment, the level of science-policy interface and other aspects, IRGC's proposed framework presents decision-makers with a systematic and integrated approach to analysing and managing the anticipated risks, challenges and opportunities of nanotechnology.

The framework includes three major innovative concepts for the risk governance of nanotechnology:

- First, the risk governance strategies presented anticipate four generations of nanotechnology product development. Corresponding to the level of complexity of nanostructures and nanosystems, their behaviour dynamics and the level of knowledge about them, these four generations

[1] The "White Paper on Nanotechnology Risk Governance" is the product of a collaborate effort for which input was provided on two initial workshops in May 2005 and January 2006 and which was advised by the IRGC's Nanotechnology Working Group and a number of external experts. In addition, the results of four stakeholder surveys undertaken as part of the project in the second half of 2005 are incorporated The surveys were concerned with the role of governments, industry, research organizations and NGOs and have been published as separate volumes on the IRGC website http://www.irgc.org/irgc/projects/nanotechnology/. On the same page, the full white paper can be downloaded as well.

are divided into two levels of risk perception and represent two separate frames of reference: Frame 1: Passive Nanostructures (generation 1) – where complexity of a nanostructured component in a system is a typical characteristic, and Frame 2: Active Nanostructures and Nanosystems (generations 2-4) - where possible system uncertainty and a high degree of ambiguity are anticipated.

- Second, the framework integrates a scientific risk-benefit assessment (including environment, health, and safety and ethical, legal and other social issues) and concern assessment (an assessment of risk perception and the societal context of risk). The framework also includes the risk concerns about the educational gap issues, political and security issues and longer-term human development issues.
- Third, the authors elaborate risk management strategies that are based on a corrective and adaptive approach and take into account the level and extent of available knowledge and a societal balancing of the predicted risks and benefits. The proposed risk management escalator and stakeholder involvement are functions of the risk problem and quality of data and can be adapted to the level and nature of the risk situation.

Inherent in all three of these concepts and, indeed, throughout the whole risk handling chain is the need for all interested parties to be effectively engaged, for risk to be suitably and efficiently communicated by and to the different actors, for decision-makers to be open to public and expert concerns and, in cases of high ambiguity, for effective public engagement, and for anticipation of the need to build governance capacity early on in the process.

The final section of the chapter will conclude with high-level risk governance recommendations and suggestions for their implementation. The recommendations based on the IRGC framework are addressed to governmental, business, scientific, civil and communication actors who each share concerns about and responsibilities for the complex and interdependent field of nanotechnology governance. However, the focus of attention will be on governments, both individually and collectively, as they are responsible for developing and implementing the policies which will enable the maximum benefit to derive from nanotechnology with the minimum of risk. Before opening up the field of risk governance, a brief review of the promises of nanotechnology will follow.

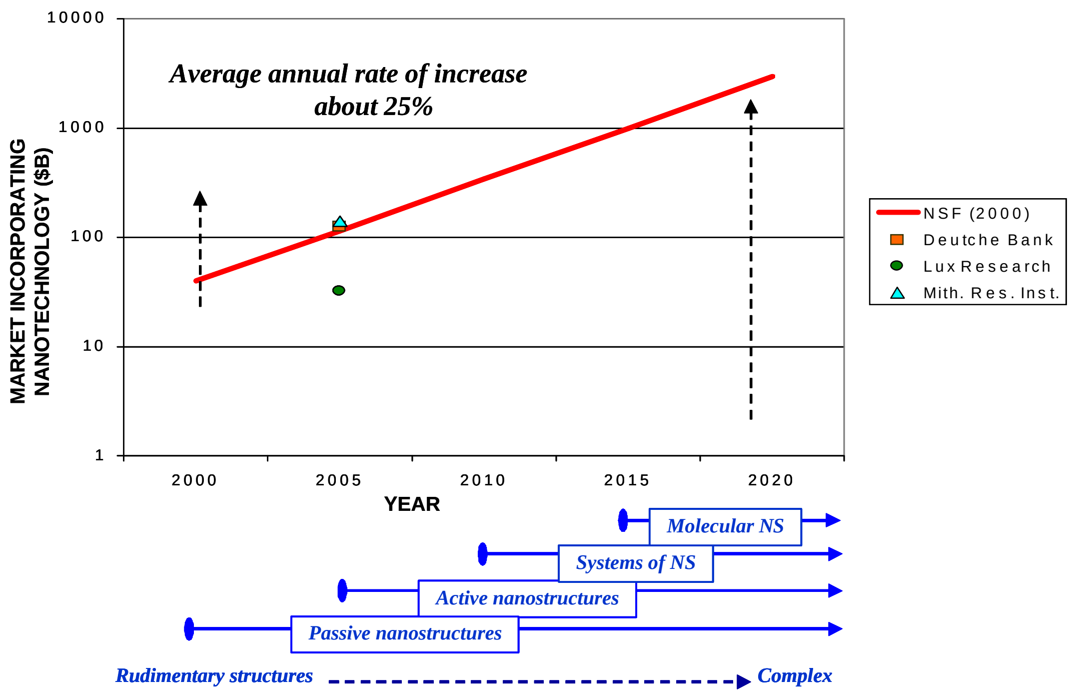
Promises of Nanotechnology

Nanotechnology refers to the development and application of structures, materials, devices and systems with fundamentally new and valuable properties and functions which derive from the size of their structure in the range of about 1 to 100 nanometres (nm) (Siegel et al. 1999). It involves the manipulation and/or creation of material structures at the nanoscale in the atomic, molecular and supramolecular realm. At the nanoscale the physical, chemical, and biological properties of matter can be significantly changed as compared to properties of individual atoms and molecules or bulk matter, particularly under 10-20 nm, because of properties such as the dominance of quantum effects, confinement effects, molecular recognition and an increase in relative surface area. Nanotechnology is still in an early phase of development analogous to the state of information technology in the 1960's and of biotechnology in the 1980's.

However, because it allows fundamentally new characteristics and foresees almost unlimited applications, nanotechnology has the potential to become one of the defining technologies of the 21st century. It offers significant benefits to manufacturing, human health, energy conversion and to the environment and can act as a major driver of economic growth. In 2000, the US National Science

Foundation (NSF) estimated that $1 trillion worth of products worldwide would incorporate nanotechnology in key functional components by the year 2015 (Figure 2; Roco and Bainbridge 2001). The corresponding industries would employ about 2 million workers directly in nanotechnology, and about three times as many in supporting activities. These estimates were based on a broad industry survey and analysis in the Americas, Europe, Asia and Australia, and continue to hold in 2006. The scientific discoveries at the nanoscale and this economic potential has encouraged a dramatic rise in research and development (R&D) expenditure in over 60 countries. Government R&D investments in each of the US, Japan, EU and the “Rest of the world” (including Canada, China, Australia, Korea, Taiwan, and Singapore) totalled about or over $1 billion in 2005, with the fastest growth occurring in the “Rest of the world”. In 2006, industry R&D, with about $6 billion R&D investment, exceeded corresponding total government R&D expenditures of about $5 billion.

Figure 1: Worldwide Market Affected by Nanotechnology[a]



a) **NSF estimation made in 2000, the estimation holds in 2006.**

Nanotechnology has many characteristics which both increase its potential benefits while creating new issues for global risk governance. It:

- Offers a broad technology platform for industry, biomedicine and environment as well as an almost infinite array of potential applications.
- Holds promises for applications which have the potential to manage many technical, economic, ecological and social problems.
- Allows manipulation at the basic level of organisation of atoms and molecules, where the fundamental properties and functions of all manmade and living systems are defined.
- Has become one of the main drivers for technological and economic change and is already stimulating considerable industrial competition.

The implications of nanotechnology are broad because its applications are at the confluence of modern biology, the digital revolution and cognitive sciences.

Reflecting the specific characteristics of nanotechnology, national R&D programmes established during the last five years have become highly integrative, involving multiple funding agencies. However, risk governance approaches specific to nanotechnology seem to be lagging behind as it has happen in other emerging technologies and there is a perception that the present speed and scope of R&D exceeds the capacity of regulators to assess potential human and environmental impacts.

Risk Governance of Nanotechnology: An Application of the IRGC Risk Governance Framework

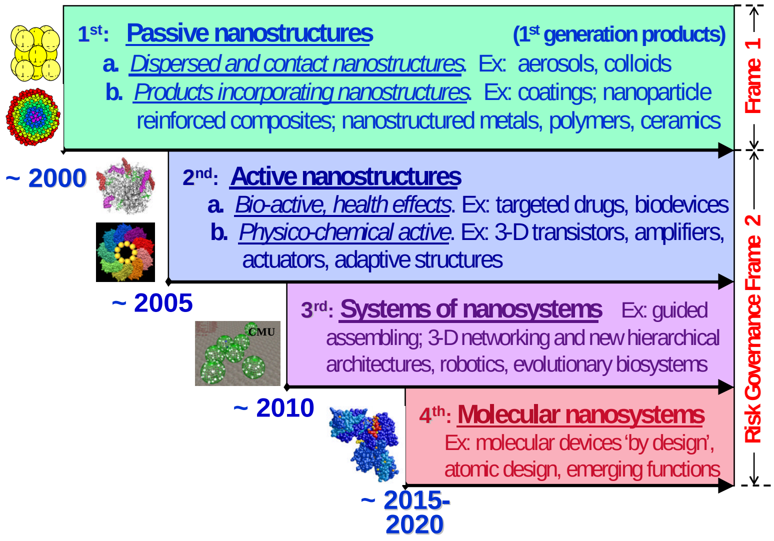
Pre-Assessment: Categorisation of Nanotechnology into Two Frames of Reference

The first phase of the IRGC risk governance framework, pre-assessment, constitutes a preliminary assessment of what major societal actors (such as governments, companies, the scientific community, NGOs, communication organizations and the general public) define as risk problems, either because of their anticipated impacts or because they are areas of concern for other reasons. For nanotechnology, risks and opportunities are commonly associated with changes in the chemical reactivity, mechanical, optical, magnetic and electronic properties of downsized material structures as compared to a bulk structure with the same chemical elements. Additionally, the potential for confluence with modern biology, the digital revolution and cognitive sciences means that we can expect nanotechnology to penetrate and permeate through nearly all sectors and spheres of life (e.g. communication, health, labour, mobility, housing, relaxation, energy and food) and to have implications for socio-economical development and the environment on a global scale.

These emerging and integrated characteristics of nanotechnology lead to a situation whereby the risk perception of one application may drive apprehension about other applications with the label, nanotechnology, that, in reality, require quite different risk governance strategies. For that reason, the white paper proposed that nanotechnology development not be viewed as a single consolidated concept but as comprising four overlapping generations of new nanotechnology products and processes, each generation having its own unique characteristics. We have defined these as 1) passive nanostructures, 2) active nanostructures, 3) complex nanosystems, and 4) molecular nanosystems (see Figure 2).

Furthermore, a second distinction can be made in terms of risk perception between the first generation and the following three generations. For the first generation of passive nanostructures, the ability to control nanostructure behaviour is easier to be done withing a system and more advanced than for the following three generations and it is therefore put in Frame 1. For generations two, three and four, potential social and ethical consequences are expected to be more transformative and they are put in Frame 2. Structuring nanotechnology risk governance into these two broad frames of reference allows for research and decision-making pathways to be adapted to the characteristics of each frame and, equally, for risks and concerns to be identified separately. Both, the categorization in four generations and into two frames are depicted in Figure 2.

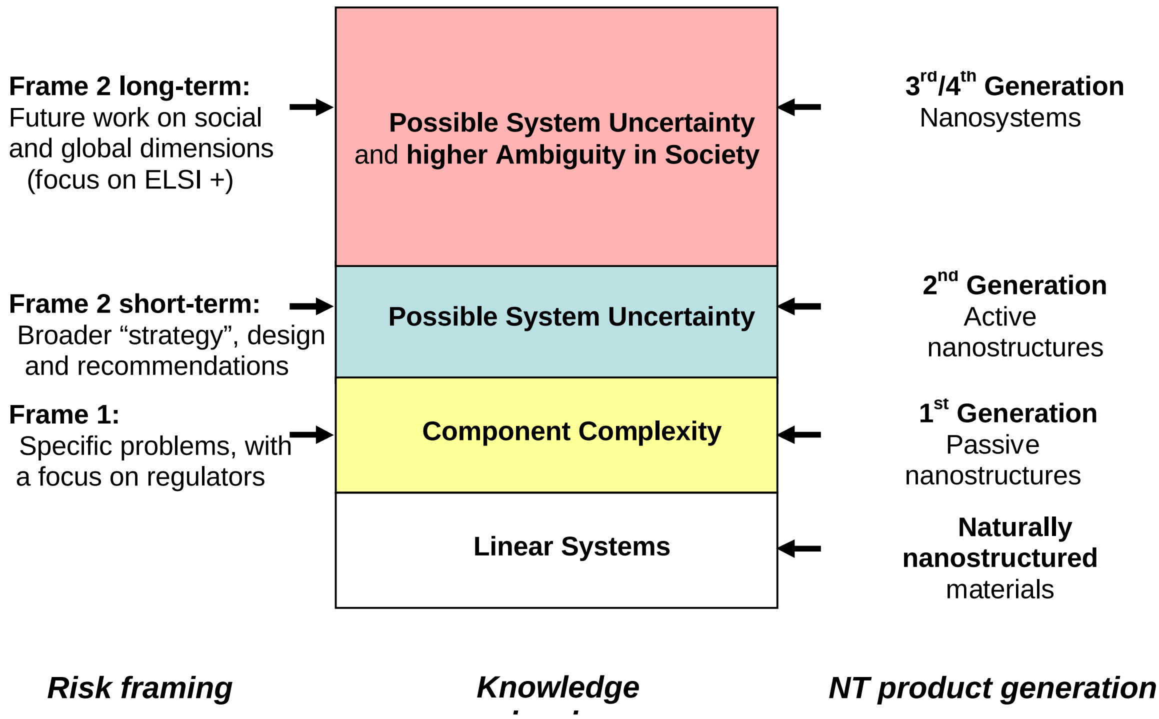
Figure 2: Timeline for the Beginning of Industrial Prototyping and Nanotechnology Commercialisation: Four Generations of Products and Production Processes



The distinction between Frame 1 and Frame 2 technologies is fundamental to the whole governance framework presented here and will further be elaborated in the following discussion of the current deficits of the nanotechnology risk governance, the risk appraisal and the risk management strategies.

On the basis of the Frame 1 and Frame 2 distinction it is possible to categorize the risk-related knowledge as part the IRGC Risk Governance Framework, namely: simple risk, component complexity, system uncertainty, and ambiguity. Risk-related knowledge for Frame 1 can be best characterised as complex for those system components which contain nanostructures with new physical, chemical and/or biological properties and functions while impacts on the societal system are expected to be less substantial. Risk-related knowledge for Frame 2 can be best characterised as uncertain for active system components (second generation) and nanosystems as a whole (third and fourth generations). For the more ambiguous large nanostructured systems (third generation) and molecular nanosystems (fourth generation), an appropriate evaluation will require the use of conflict resolution methods in order to resolve problems of perception and interpretation between stakeholder groups.

Figure 3: Strategies as a Function of the Generation of Nanoproducts: Application to Frame 1 and Frame 2



After framing the governance processes in the pre-assessment section of the framework, current deficits of the nanotechnology risk governance processes can now be identified.

Deficits in Nanotechnology Risk Governance Today

The main risk governance deficits for the Frame 1 (first generation of passive nanostructures: nanoparticles, coatings, nanostructured materials) are a relatively low level of understanding of the new properties and functions of toxicity and bioaccumulation, limited knowledge of nanomaterials exposure rates and gaps in regulatory systems at national and global levels. The main risk governance deficits for the second to fourth generations of nanoproducts (including active nanodevices, nano-bio applications and nanosystems) are the uncertain and/or unknown implications of the evolution of nanotechnology and its potential human effects (e.g. health, changes at birth, brain understanding and cognitive issues and human evolution), and the lack of a framework through which organisations and policies can address such uncertainties. In the following we list the main deficits anticipated for nanostructures. It is assumed that where deficits and recommendations are referred to as applying to first generation nanostructures these will also apply to later generations. However, there are specific deficits that are more unique to the second to fourth generations due to their expected complex and/or evolving behaviour and, where this is the case, it is specifically mentioned.

General deficits more specific for Frame 2 are:

- Uncertain or unknown implications mostly because the products are not yet fabricated
- Potential human effects of 2nd-4th generation nanoproducts
- Nanotechnology innovation proceeds ahead of the policy and regulatory environment: expected gaps in long-term for Frame 2

- Lack of a specific framework to address such issues

Technical and organizational (environmental health and safety):

- Limited knowledge on hazards and exposures, need for specific metrology, international transport, etc.

Institutional deficits (societal infrastructure, social and political):

- Relatively fragmented government institutional structure, relatively simple cause and effect approach, weak coordination among key actors, etc.

Risk communication deficits:

- Gap between science communities, between science communities and manufacturers/regulators/public/NGOs/industry/media/public.

Risk Appraisal for Nanotechnology

Risk appraisal is the second phase of the IRGC risk governance framework and comprises two elements: risk assessment and concern assessment. During risk appraisal, the classic risk assessment component - which includes generally hazard identification, exposure assessment and risk estimation - is particularly important for Frame 1 nanostructures where the speed of product development and application exceeds the ability of risk assessors to appraise any new risk. The concern assessment component - focused on risk perception and stakeholders' concerns - is particularly important for Frame 2 where less substantive knowledge is available and actors are more concerned with the social desirability of the anticipated innovations. The following two sections summarise the current levels of knowledge available and the key risk appraisal requirements for each frame.

Risk Appraisal of Frame 1 Nanotechnology Applications: A focus on Risk Assessment

Only a limited understanding exists of the potential environmental, health and safety risks of nanomaterials. Further studies are required for: 1) hazard identification, in areas such as toxicity, ecotoxicity, carcinogenicity, volatility, flammability, persistence and accumulation in cells; and 2) exposure, including the potential for oral, cutaneous and inhalation uptake of nanomaterials during production, transport (in air, water, soil and biosystems), decomposition and/or waste disposal. Some of these risks are:

- Human health risks. Several studies have shown that: 1) due to the high surface-area-to-volume ratio and frequently higher reactivity of nanostructures, large doses can cause cells and organs to demonstrate a toxic response (in particular inflammation) even when the material itself is non-toxic 2) some nanosized particles are able to penetrate the liver and other organs and to pass along nerve axons into the brain; 3) nanomaterials may combine with iron or other metals, thereby increasing the level of toxicity and presenting unknown risks; 4) engineered nanomaterials raise particular concerns because of the unknown characteristics of their new properties and their potential use in concentrated amounts; and 5) some nanomaterials may have similar characteristics to known high-risk materials at the microscale.
- Explosion risks. The higher surface reactivity and surface-area-to-volume ratio of nanopowders increases the risk of dust explosion and the ease of ignition.
- Ecological risks. The impact of nanostructures on the environment may be significant because of the potential for: 1) bioaccumulation, particularly if they absorb smaller contaminants such as pesticides, cadmium and organics and transfer them along the food chain; and 2) persistence, in

effect creating non-biodegradable pollutants which, due to the small size of the nanomaterials, will be hard to detect in situ in the environement.

In addition to the EHS risks the following societal impacts of nanotechnology development have been raised for Frame 1:

- Political and security risks. Decisions taken about the direction and level of nanotechnology R&D may result in: 1) insufficient investment in key areas to benefit future economic development; 2) an uneven distribution of nanotechnology risks and benefits among different countries and economic groups; 3) use in criminal or terrorist activity; and 4) a new military technology race.
- Educational gap risk. If the knowledge within professional communities is not appropriately shared with regulatory agencies, civil society and the public, and, consequently, risk perception is not based on the best available knowledge, innovative opportunities may be lost.

As we will see, the societal impacts described for Frame 1 are also, in part, valid for Frame 2.

Risk Appraisal of Frame 2 Nanotechnology Applications: A Focus on Concern Assessment

As already mentioned, the risk appraisal of Frame 2 is more concerned with the social desirability of the anticipated innovations. Several characteristics of the risk appraisal for Frame 2 are:

- Inclusion of the societal context from the risk pre-assessment to risk management is needed: risk-benefit analysis of what is a desirable investment; increased science–society interactions because societal implications are broad and political involvement is necessary
- Capabilities to safely use converging technologies must be developed since nanotechnology is applied in conjunction with other technologies
- Anticipatory and integrative measures based on both scenarios development and building capacity are needed to address them in an corrective, adaptive system; evaluation criteria coming form various communities

The potential for environmental health and safety risks identified in Frame 1 are also relevant to Frame 2 where one expects a large impact and there is a lower level of knowledge and understanding of the nanostructures and nanosystems and their behaviours (see Figure 3). The risks requiring further study in Frame 2 are primarily related to the assessment of the more complex behaviors and prioritisation of stakeholder concerns which in part rest on different value-judgements. In the white paper the following most significant potential risks were identified:

- Risks to human biological and societal development. Societal apprehension exists about the use of nanotechnology to change biological and socioeconomic dimensions. Examples include: 1)) economic impact of mass application of nanotechnology; 2) changes to the environment, human safety and quality of life; 3) genetic modification to control factors such as sex or eye colour; 4) devices to control the human brain and body; and 5) new technological and cultural environment based on the ability to purchase new revolutionary products and access cognitive technologies and life extension promises.
- Society structural risks. Risks may be dampened but also induced and amplified by the effect of social and cultural norms, structures and processes, such as: 1) the inability of the regulatory environment to react rapidly to new technologies; 2) the unintended availability to the mass market

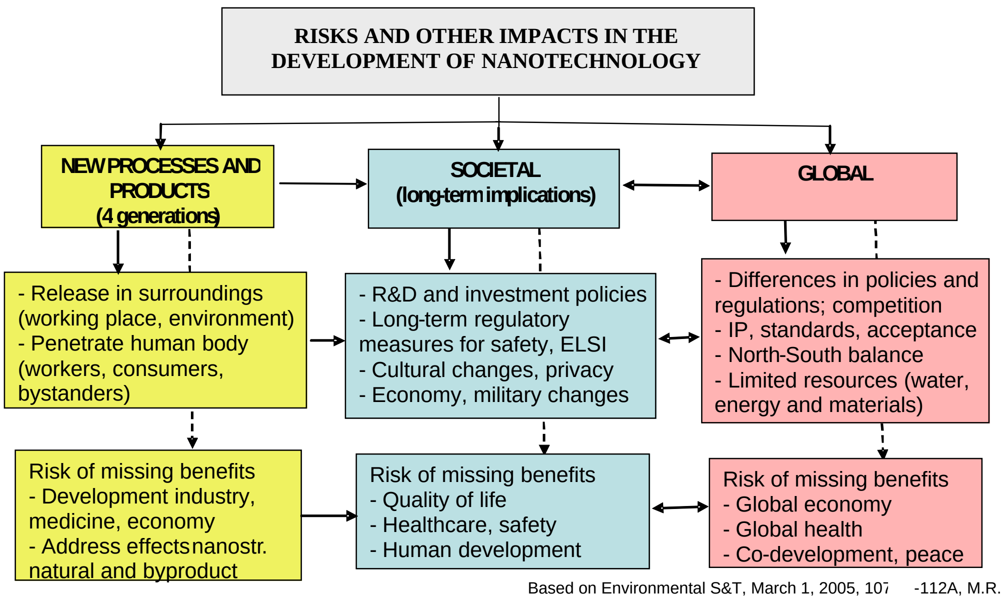
of products based on applications developed by and for the military (e.g. tiny airborne surveillance devices); and 3) lack of propr educational and communication organizations to address development of nanotechnology and unexpected events.

- Public perception risks. Recent surveys have shown that public concern is currently less linked to any particular application or risk but rather to the capacity for human misuse, to unexpected technological breakouts, or to nanotechnology's potential to exacerbate existing social inequalities and conflicts. This situation may change if nanotechnology becomes associated with specific incidents and, meanwhile, there remains a deep suspicion of the motives of industry and doubts regarding government's ability (or desire) to act if required. The increasing impact of the mass media on risk perception (such as in movies and books) need to be fully considered.
- Transboundary risks. The risks faced by any individual, company, region or country depend not only on their own choices but also on those of others. Evidence that control mechanisms do not work in one place may fuel a fierce debate in other parts of the world about the acceptability of nanotechnology in general.

Risk Appraisal of Nanotechnology: A summary

An overview of the various potential risks and other impacts in the development of nanotechnology is provided in Figure 4. The potential risks may be caused either by new processes and products (marked with yellow in Figure 4), by societal implications (green), and/or global interactions (pink). The negative consequences may be directly related to harm by unintended effects (first row in Figure 4) or by the risk of missing the benefits (bottom row).

Figure 4: Risks and other Impacts in the Development of Nanotechnology (negative implications, including not taking advantage of the benefits)

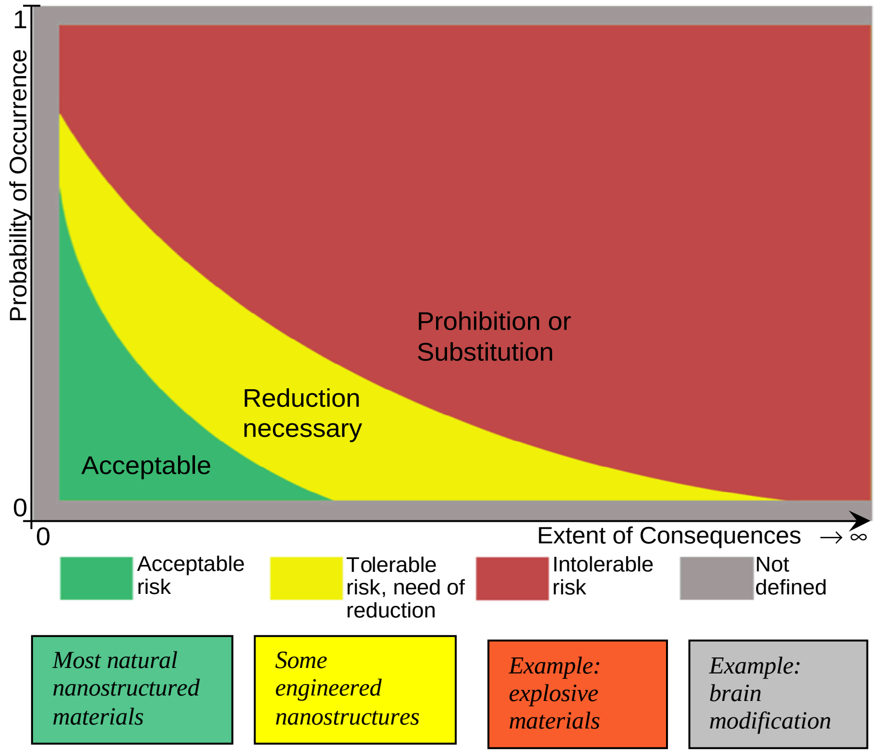


Based on Environmental S&T, March 1, 2005, 107 -112A, M.R.

Characterisation and Evaluation of the Benefits and Risks

Arriving at a balanced judgement about the acceptability or tolerability of nanotechnology means that nanotechnology will deliver sustainable added value for society, economy and industry only if it is possible to achieve an acceptable balance between its projected benefits and the management of its unintended impacts and risks at a societal level. It is not sufficient to focus only on the physical, chemical or biological risks of nanotechnology, because they address only part of what is at stake within culturally plural, morally concerned and educated societies (AEBC 2001; Grove-White et al. 2000). Stakeholders play an important role in defining acceptable to intolerable by considering among other factors the balance between risk and benefits and the probability of extreme events. Figure 5 brings together the findings of the previous sections in the traffic light model of the IRGC Risk Governance Framework (chapter X). As in the general IRGC Framework on Risk Governance, 'acceptable' – attributed to most naturally nanostructured materials - refers to an activity where the remaining risks are so low that additional efforts are not necessary. 'Tolerable" – attributed to engineered nanostructures – refers to a technology worth pursuing yet requiring additional efforts for risk reduction. Intolerable risks would, for example, be constituted by explosive nanomaterials designed for other purposes.

Figure 5: Acceptable, Tolerable, Intolerable and Undefined Risks Relative to Benefits (Traffic Light Model, a Stakeholder Perspective)



Risk Management Strategies for Frame 1 and Frame 2

Risk management, the final phase of the risk governance framework, comprises the selection of a strategy or strategies designed to avoid, prevent, reduce, transfer or contain risks. For both frames there are factors particular to nanotechnology that will impact on the choice of measures. These include: 1) its multidisciplinary, cross-sectoral and multiple stakeholder nature; 2) its characterisation as more-or-less complex, uncertain or ambiguous (depending on the specific development or application under consideration); and 3) the need to ensure the consistent participation in the risk management process of key stakeholders including all countries concerned in nanotechnology research, development and application.

The white paper proposes a risk management strategy based on adaptive and corrective measures rather than a simple cause-and-effect approach, as well as coordination at the international level. Furthermore, it is recommended that risk management strategies include contingency plans for dealing with a wide variety of risk scenarios, so as to prepare for changes in the economy, the societal and political arena or in the available levels of knowledge. Decision-makers also need to distinguish between Frame 1 and Frame 2, designing risk management and communication programmes that provide adequate and effective strategies for the particular characteristics of each frame. Table 1 and 2 provide detailed proposals of the risk management recommendations for Frame 1 and Frame 2. Both tables already contain information on stakeholder participation and risk communication that will be dealt with in the following paragraphs. The first part of recommendations addresses the classical risk assessment components – hazard, exposure and risk –, the second part focuses on institutional, communication and transboundary issues.

Table 1: Risk Government Recommendations for Frame 1 Passive Nanostructures

Risk Management Recommendations for Frame 1			
	Hazard Recommendations	**Exposure Recommendations**	**Risk Recommendations**
Classical Risk Assessment	– Testing strategies for assessing toxicity and eco-toxicity. – Best metrics for assessing particle toxicity and eco-toxicity. – A nomenclature which includes novel attributes, such as surface area. – Pre-market testing, full lifecycle assessment and consideration of secondary risks. – Disposal and dispersion methods for nano-engineered materials. – Development of waste treatment strategies.	– Exposure monitoring methodologies. – Methods for reducing exposure and protective equipment.	– Risk assessment methodologies. – Guidelines and best practices available internationally. – Evaluation of the probability and severity of risks, including loss of benefits. – Balanced knowledge-based communication and education of EHS and ELSI, including uncertainties and ambiguities.

Risk Management Recommendations for Frame 1	
ExtendedRisk Assessment	**Institutional Recommendations** – Systematic liaison between government and industry. – Sufficient resources and capabilities for conducting concern assessments along with risk assessments. – Information for consumers enabling them to make informed choices. – Transparent decision-making processes for R&D and investment. – Non-proprietary information on test results, impact assessments and their interpretations on the internet. – Systematic feedback about the concerns and preferences of the various actor groups and the public at large. – Incentives for promoting and sustaining international cooperation. – Critical examination of intellectual property rights for basic natural processes and structures. **Risk Communication Recommendations** – Information about the benefits and non-intended side effects. Communication tools include: internet-based documentation of scientific research, product labelling, press releases and consumer hot lines. – Public information on the principles and procedures used to test nanotechnology products, to assess potential health or ecological impacts and to monitor the effects. – International disclosure of risk information by large transnational companies (not competitive information). – Risk communication training courses and exercises for scientists. – Integrated risk communication programmes for scientists, regulators, industrial developers, representatives of NGOs, the media and other interested parties. **Transboundary Recommendations** – Incentives for all countries to participate in risk governance. Possible tools include: policies by insurance companies, certification programmes, education programmes, R&D programmes, response to disruptive technological and economical developments, and international studies on cost and benefit/risk analysis. – Explore the role of international organisations, international industry and academic organisations and NGOs. – Public-private partnerships when participants are reluctant to adopt protective measures. Possible method include: government standards and regulations coupled with third party inspections and insurance. – Global communication of international standards and best practices to both developing and developed countries in a reasonable timeframe.

Given the lack of nanotechnology-specific regulation, one of the most promising management strategies for Frame 1 is to establish internationally-applicable voluntary codes or rules for ensuring safety and risk control in the short term, allowing time for the necessary development and establishment of formal norms. The risk management strategies identified for Frame 1 will also be applicable for Frame 2. In addition, given the ambiguity and lack of substantive knowledge associated with Frame 2 technologies, a more discursive and participatory approach is required in which all actors, including industry and NGOs should be involved from the beginning. Table 2 provides a more detailed proposal of risk management recommendations for Frame 2.

Table 2: Risk Government Recommendations for Frame 2 Active Nanostructures and Nanosystems

Risk Management Recommendations for Frame 2 (in addition to those listed for Frame 1 in Table 2)			
Classical Risk Assessment	**Hazard Recommendations** – Identifying hazards using scenarios. – Matrix for assessing the identified hazards.	**Exposure Recommendations** – Estimation of exposure for events with great uncertainties using methods such as casual chain.	**Risk Recommendations** – Identifying, communicating and educating others on environmental health and safety, ELSI, Human Development Implications and Political and Security Issues. – Developing capacity to address uncertain/ unknown and ambiguous developments at national and global levels. – Identifying and analysing highly controversial developments.

<table>
<tr><th colspan="2">Risk Management Recommendations for Frame 2 (in addition to those listed for Frame 1 in Table 2)</th></tr>
<tr><td>Extended Risk Assessment</td><td>Institutional Recommendations
– Communication platforms that help address the purposes for future technologies.
– Common scenario development exercises for future applications of nanotechnology.
– Common rules and standards for potentially high-impact, long-term projects for nanotechnology.
– A process of periodic review of national and international institutional frameworks.
Risk Communication Recommendations
– Debate on the desirability of special applications of nanotechnology in the light of ethical and social issues.
Transboundary recommendations for Frame 2
– Use corrective, adaptive approach
– Use integrative methods for converging technologies
– Consider the co-evolution NT-ethics
– Create incentives for all countries to participate in RG of emerging technologies in Frame 2 (certification programs, policies for insurance, research and education programs, and responses to disruptive technological and economical developments
– Address ELSI + : ELSI, EGI, PSI, HDI
– Increased role of risk communication between all stakeholders, from manufacturers to regulators and public; a special role of media and Internet
– Responsible innovation: Include ELSI in training; Incentives in industry using certification; ELSI criteria in evaluating value of IPO</td></tr>
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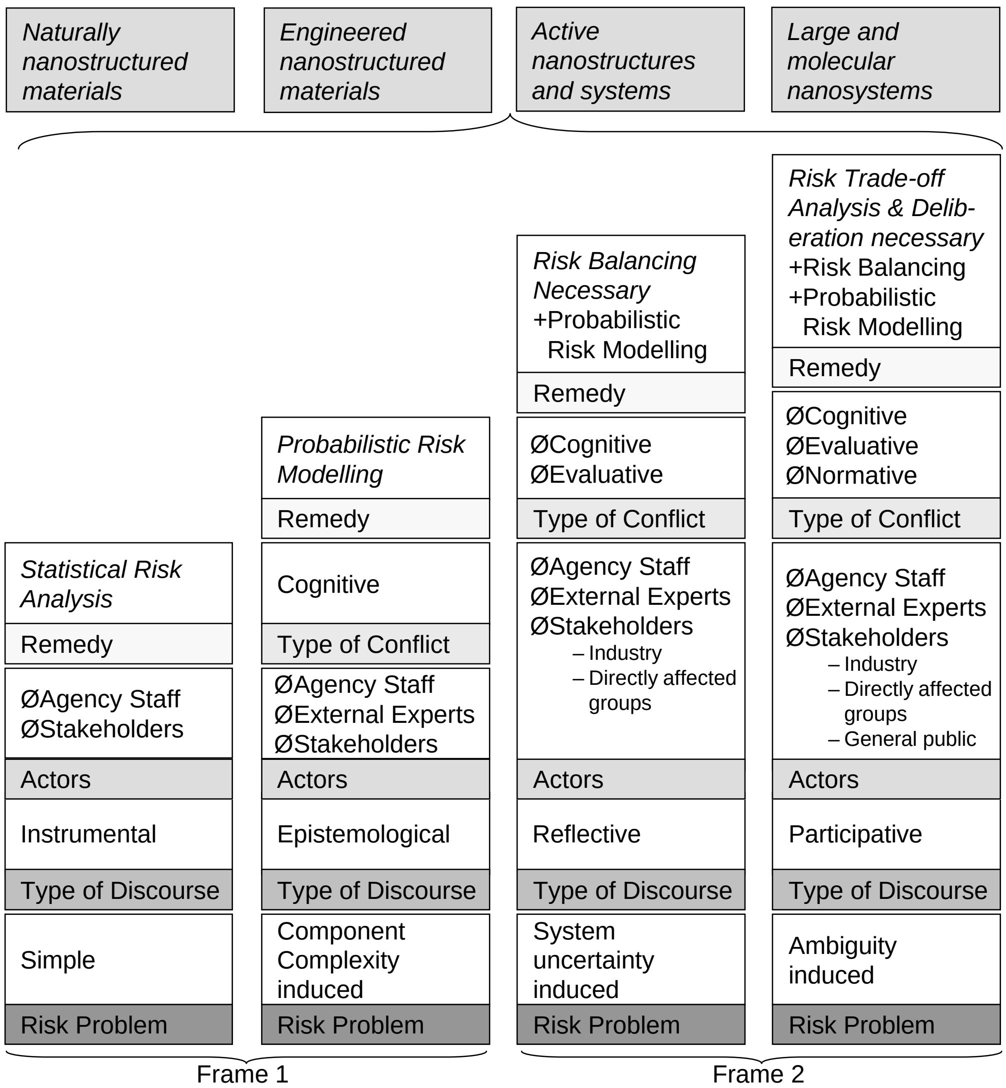
Risk Management Strategies for Stakeholder Participation

A central aim of applying the IRGC model is to stimulate participatory innovation in anticipatory debates about emerging technologies, and to generate better and neutral platforms for stakeholder involvement. For this, it is again helpful to distinguish between simple, complex, high uncertainty and high ambiguity risk problems. In the case of nanotechnology, the four single levels of risk related knowledge and the respective technologies lead to the involvement of different types of actors and anticipate particular types of discourses see Figure 6).

Figure 6: The Risk Management Escalator and Stakeholder Involvement (from Simple Systems via Complex and Uncertain to Ambiguous Phenomena) with reference to Nanotechnology



Function:	Allocation of risks to one or several of the four routes
Type of Discourse:	Design discourse
Participants:	A team of risk and concern assessors, risk managers, stakeholders and representatives of related agencies

In Figure 6, the first two categories – naturally nanostructured materials/simple risk problems and engineered nanostructured materials/component complexity – are part of Frame 1, whereas the latter two categories – active nanostructures and systems/systems uncertainty induced and large and molecular nanosystems/ambiguity induced are part of Frame 2. In accordance to the risk related knowledge, specific types of conflicts can be identified that ask for appropriate ways to involve stakeholder groups. In the case of nanotechnology, the risk management escalator shows four different routes to which a particular technology may be allocated which then offer approaches to adequate stakeholder involvement. Each and one of the routes depict separate situations and remedies and do not build upon another.

Risk Management Strategies for Risk Communication

In a society with multiple or plural values, risk communication is needed between key staholders throughout the risk handling chain, from the framing of the issue to the monitoring of the potential impacts of risk management strategies themselves. Risk communication is a means to ensure that:

- those who are central to risk framing, risk and concern assessment or risk management understand what is happening, how they are to be involved, and, where appropriate, what their responsibilities are ("open" communication), and,
- others outside the immediate risk appraisal or risk management process are informed and engaged ("transparent" communication).

In designing the risk communication strategies for nanotechnology, it is essential to distinguish between the two frames (Frame 1 and Frame 2 as defined earlier). Risk communication should avoid the strategic mistake of grouping all applications of nanoscale technologies under the single descriptor "nanotechnology". This approach would blur the distinction between the two frames and their subcategories and runs the risk of discrediting nanotechnology development as a whole, for example, if a serious incident related to a specific application within one frame or the other were to occur.

The first communication strategy (for both Frames 1 and 2) should be designed to enlighten the discussion about the benefits and non-intended side effects and the methods to identify and quantify those effects. The first task should be to facilitate an exchange of information among risk professionals, a task that has often been underestimated in the literature. A close communication link between risk and concern assessors and risk managers, particularly in the phases of pre-assessment and tolerability/acceptability judgement, is crucial for improving overall governance. Similarly, co-operation and communication among natural and social scientists, between legal and scientific staff and between policy makers and scientific staff are all important prerequisites for enhancing the risk management performance.

The second communication strategy, particularly for Frame 2, requires communicating risk appropriately to the outside world, and should be directed towards a broader debate on the desirability of special applications of nanotechnology in the light of ethical and social issues. The main message here could be that it is not nanotechnology that creates the problem but rather the use of this technology in a controversial application. It may certainly be legitimate to reject special applications (such as using neurochips in the human brain for control of its functions without a medical justification) without having to oppose the technology that makes such an application technically feasible.

This second strategy is very challenging to implement. Many representatives of stakeholder groups, particularly members of the affected and non-affected public, are often unfamiliar with the approaches used to assess and manage risks. They may find it difficult to differentiate between the potentially harmful properties (i.e. hazards) of a nanotechnology product and the estimates of risk that depend not just on the hazards but on the scenarios that describe the ways in which the products might be used and on the potential for exposure to humans associated with those scenarios (Morgan et al. 2002). They may try to pursue their own specific agendas, trying to achieve extensive consideration of their own viewpoints.

Nonetheless, it is critical to provide public information on the principles and procedures used to test nanotechnology products, to assess their potential health or ecological impacts, and to monitor their effects. Candid discussions on the role of investment policies in research, development and production can also be helpful. If people have the reassurance that public authorities are taking special care to protect the population against unintended consequences of this new technology, they may be able to develop more trust than they demonstrate today in the capacity of society to control the risks and acknowledge and plan for remaining uncertainties. This is true for both the public and the private sector.

After diagnosing the needs of the two major audiences, the main form(s) of communication must be chosen. There are four basic forms of communication:

- **Documentation.** In a democratic society, it is absolutely essential that documentation in the field of nanotechnology products marketed to the consumers (such as sun creams) should more accurately reflect risks, show how and why decisions in risk management were made, which arguments were considered and what scientific bases were used. This serves transparency. Even if explanations are comprehensible only to a few, like with package inserts that describe the potential side effects of medicines that are understandable often only to the medically trained, they illustrate that nothing is being withheld.

- **Information.** Information should be prepared and compiled in such a way that it addresses key concerns of target groups and so that individuals within target groups can comprehend it and can integrate its message into their everyday lives.

- **Two-way communication or dialogue.** This form of communication aims at an exchange of arguments, experiences, impressions and judgements. There must be willingness on both sides to listen to and learn from the other.

- **Participation in risk analyses and management decisions.** In a pluralistic society people expect to be included adequately, directly or indirectly, in decisions which concern their lives. Not all affected people can participate in the risk governance, but it must be ensured that the concerns of the stakeholders will be represented in the decision-making process and that the interests and values of those who will later have to live with the risk effects will be taken up appropriately and integrated into the decision-making process. The previous section on stakeholder involvement provided some insights into this aspect of risk communication.

We acknowledge that public engagement does not necessarily solve all problems; it does, however, enlighten the public debate and provide incentives for mutual learning, gaining and sustaining trust. It also helps individuals to be more attentive to both benefits and risks. We believe that the present platform could act as a catalyst for achieving these goals.

IRGC recommends that the risk communication strategy be developed carefully within the context of the risk handling chain:

As part of the risk appraisal phase, in of risk assessment, risk management agencies should be encouraged to undertake an exercise to develop and characterize potential scenarios that might describe the diffusion of nanotechnology in their own countries and the likely social reactions to it. Academic researchers, developers, potential users and important other actors should be actively involved in the scenario workshops in order to get a adequate representation of societal forces that ultimately shape the future of nanotechnology in the world. The scenarios suggested in the IRGC White Paper on Nanotechnology (IRGC, 2006) may serve as default options for designing more specific scenarios that relate to specific uses and contextual conditions in each participating country.

The second key component of the risk appraisal step is the concern assessment in which it is essential to investigate and explore the social and cultural frames and the individual risk and benefit perception patterns in the respective countries or cultures. The relevant actors in each country need to be informed about the structure and strength of the various frames that individuals and groups associate with nanotechnologies. For this purpose, interviews should be conducted with the leading individuals of civil society groups such as consumer unions, environmental groups, religious communities, and others. On the basis of these empirical results, one can compare insights from one country with similar studies in different other countries and conduct a systematic evaluation in terms of intensity of concerns, types of concerns and willingness to act.

Such an analysis is not only a means for identifying potential barriers and obstacles to the diffusion of the technology, but it is also an important input for refining potential scenarios and for the identification of potential opportunities based on revealed preferences.. In addition, both risk management agencies and corporations would understand better the factors that govern the perception process for each nanotechnology frame and would be better equipped to design appropriate risk management and risk communication strategies.

Together, the scenario exercise and the concern study and can provide input to a targeted and effective communication program designed to foster public understanding of technical issues and to address the perceptions and concerns of the key actors. The program for Frame 1 could include internet presentations, brochures, press releases, consumer product labels and others. If the concern assessment concludes that the Frame 2 is also quite relevant, other communication means will be needed such as an open forum on the use and abuse of nanotechnology for medical, military or other controversial purposes. In addition, citizen panels or joint action committees (including consumer associations, unions, employers, etc,) could be convened to draft legislation that would inhibit the potential misuse of nanotechnologies. All these activities would be able to preserve or even restore trust in the risk managing agencies.

Risk Governance Strategies and the Potential Future Role for International Bodies

To summarize insights provided by the prior analysis, Table 3 gives an overview of the characteristics and the risk governance context of the four generations of nanotechnology developments put in Frame 1 and Frame 2:

Table 3: The Different Generations and Frames of Nanotechnology Development

	Four Generations	Generation Characteristics	Risk Governance Context
FRAME 1	**First Generation** – passive (steady function) nanostructures e.g. nanostructured coatings and non-invasive; invasive diagnostics for rapid patient monitoring *From 2000 -*	***Behaviour:*** inert or reactive nanostructures which have stable behaviour and quasi-constant properties during their use. ***Potential risk:*** e.g. nanoparticles in cosmetics or food with large scale production and high exposure rates.	***Current context for Frame 1 products and processes:*** interested parties are seeking to develop knowledge about the properties of nanomaterials and their EHS implications so that risks can be characterised internationally. Debates are focused on the design and implementation of best practices and regulatory policies. ***Risk characterisation:*** the nanoscale components of the nanoscale products and processes result in increased system component complexity. ***Strategies:*** the establishment of an internationally reviewed body of evidence related to toxicological and ecotoxicological experiments, and simulation and monitoring of actual exposure. ***Potential conflict:*** the question of how much precaution is necessary when producing the nanomaterials (focusing on changes to best practices and regulation) and over their use in potential applications.
FRAME 2	**Second Generation** – active (evolving function nanostructures) e.g. reactive nanostructured materials and sensors; targeted cancer therapies *From 2005 -*	***Behaviour*:** the structure, state and/or properties of 'nanostructures' are designed to change during use so behaviour is variable and possible unstable. Successive changes in state may occur, either intended or as an unforeseen reaction to the external environment. ***Potential risk**:* e.g. nanobiodevices in the human body; pesticides engineered to react to different conditions.	***Current context for Frame 2 products and processes:*** interested parties are considering the social desirability of anticipated innovations. Debates are focused on the process and speed of technical modernisation, changes in the interface between humans, machines and products, and the ethical boundaries of intervention into the environment and living systems (such as possible changes in human development and the inability to predict transformations to the human environment).

Four Generations	Generation Characteristics	Risk Governance Context
Third Generation – integrated nanosystems (systems of nanosystems) e.g. artificial organs built from the nanoscale; evolutionary nanobiosystems *From 2010 -*	***Behaviour*****:** passive and/or active nanostructures are integrated into systems using nanoscale synthesis and assembling techniques. Emerging behaviour may be observed because of the complexity of systems with many components and types of interactions. New applications will develop based on the convergence of nanotechnology, biotechnology, information technology and the cognitive sciences (NBIC). ***Potential risk:*** e.g. modified viruses and bacteria; emerging behaviour of large nanoscale systems.	***Risk characterisation****:* the nanoscale components and nanosystems of the Frame 2 products and processes result in knowledge uncertainty and ambiguity. ***Strategies:*** stakeholders must achieve understanding, engage in discussion about ethical and social responsibility for individuals and affected institutions and build institutional capacity to address unexpected risks. Projected scenarios need to be explored that show plausible (or implausible) links between the convergence of technologies and the possible social, ethical, cultural and perception threats. A major challenge is that decisions need to be undertaken before most of the processes and products are known. ***Potential conflicts****:* the primary concern of Frame 2 is that the societal implications of any unexpected (or expected but unprepared for) consequences and the inequitable distribution of benefits may create tensions if not properly addressed. These concerns about technological development may not be exclusively linked to nanotechnology but are, at least partially, associated with it and will impact upon stakeholder perceptions and concerns.
Fourth Generation – heterogeneous molecular nanosystems e.g. nanoscale genetic therapies; molecules designed to self-assemble *From 2015/2020 -*	***Behaviour*****:** engineered nanosystems and architectures are created from individual molecules or supramolecular components each of which have a specific structure and are designed to play a particular role. Fundamentally new functions and processes begin to emerge with the behaviour of applications being based on that of biological systems. ***Potential risk*****:** e.g. changes in biosystems; intrusive information systems.	

On the base of the detailed analysis, the following general risk governance strategies can be recommended:

- Distinguish between Frame 1 and Frame 2 debates and design corresponding risk management and communication programs
- Ensure that the interests of all those potentially affected by nanotechnology are addressed and understood by decision makers
- Be cognisant of and where appropriate, responsive to other global governance systems
- Adaptive and corrective approaches need to be applied to societal system
- Develop an inclusive risk governance framework addressing both short and long-term applications of nanotechnology

However, it is clear that a reasonable risk governance framework needs a number of motivated and concerned stakeholders that put the recommendations into practice. The IRGC White Paper on Nanotechnology (IRGC, 2006) has presented one of the first conceptual frameworks for nanotechnology governance that may serve as a basis for designing more specific programs tailored to specific applications or countries. However, ongoing involvement of and debate amongst academic researchers, nanotechnology developers, potential users, regulatory or other decision making authorities, and other important actors is essential to ensure the inclusion of an adequate representation of societal forces that ultimately shape the future of nanotechnology.

With the goal of fostering such debate and improvement to the risk governance process for nanotechnology, IRGC organized an important international conference on risk management of nanotechnology which was held on the 6th and 7th of July 2006 at the Swiss Re Centre for Global Dialogue in Rüschlikon, Switzerland.[2] A broad diversity of stakeholders from may societal sectors, international organizations and various countries participated assuring perspectives from a large diversity of representative stakeholders for nanotechnology development worldwide. The section which follows summarizes the key goals of that conference and the responses received regarding the IRGC's Risk Governance Framework for Nanotechnology.

Reception of the IRGC Risk Governance Framework for Nanotechnology: Feedback from an International Conference

The basis for the discussions at the international conference was IRGC's White Paper on Risk Governance for Nanotechnology, with a particular goal of the conference being to identify the strengths and weaknesses of the IRGC approach. To meet this objective, working groups on different aspects of the framework were organized and participants presenting at the conference were asked to give their opinions on the white paper. The feedback from the conference provides a valuable insight into the reception of the framework by different stakeholder perspectives.

Framing the debate on potential risks from nanotechnology: views on Frame 1 and Frame 2

Overall, the introduction of the Frame 1 and Frame 2 distinction and the four generations of nanotechnology development received considerable affirmation. It was felt that the frames provide a good basis for the debate, especially when highlighting the differences in levels of knowledge.

However, it was felt that there were a number of important similarities between Frame 1 and Frame 2 that the white paper did not acknowledge or stress. In particular, it was felt that the two frames shared a number of ethical, legal and social issues. Accordingly, it was felt that the participation methods for both frames should not differ. Often it was also mentioned, that the close relation between Frame 1 and Frame 2 should be emphasized. This could be implemented in the form of a conceptual continuum of complexity of societal and technical questions and governance issues. In addition, a transition period between Frame 1 and Frame 2 technologies was asked for.

Whereas the Frame 1/Frame 2 distinction was generally seen as useful for analytic and academic purposes, it was perceived to be difficult for communication purposes to the public.

Only a few participants rejected the frame altogether. In these cases, the participants felt that the frames failed to cover broad socio-economic questions or were too dominated by the emphasis on knowledge problems.

Risk management recommendations

Frame 1

The issue raised the most regarding the Frame 1 risk management recommendations was that there should be a greater emphasis on ethical, legal and social issues. While the Nanotechnology White Paper properly highlights higher importance of these issues for Frame 2, these types of issues are seen

[2] A conference programme and the presentations can be downloaded from http://www.irgc.org/irgc/events/conferences/ (30.09.2006).

as already critically important today, and especially so when combined with questions of environment, health and safety. Regarding issues of the Frame 1 knowledge level, it was further recommended to monitor possible uncertainties in future which would change the Frame 1 status. In this way the problem of surprise and changing boundaries of knowledge could be emphasised.

The most critical recommendations for Frame 1 issues were perceived to be1) the development of concrete risk (hazard and exposure) assessment methodologies 2) the development of international standards. The participants expressed the hope that an internationally agreed set of standards would arise in the near future that could provide the basis for adaptable systems of regulation. Widely approved risk assessment procedures were perceived to be important inputs for such a set of standards.

Further recommendations were to revisit the transboundary recommendations, to make best practice guidelines available internationally and to pay careful attention to whole supply chain of nanotechnologies. IRGC's recommendations on self-regulation were perceived as unclear and industry commentators suggested that they should be exchanged for voluntary programs.

Frame 2

The forward looking approach of Frame 2 was very much welcomed. For a number of commentators, however, Frame 2's foresight could be strengthened even further by emphasising the importance of detailed scenario development, and by addressing the methodological problems of uncertainty and ambiguity, future hazards and stakeholder problems. These steps could also include stakeholder and public debates on the potential goals of the technologies and the values attached.

As for the definition of Frame 2 technologies, it was suggested that second generation nanotechnologies can be complex and active without being evolving or unstable as mentioned in table 3.

Especially for NGOs representatives, the most critical points of Frame 2 technologies were the application of nanotechnologies for military and surveillance purposes and their potential role in the economic development - in particular for the global south. These issues were perceived to be important political and security risks but were believed to be underemphasised in the document. It was therefore recommended that the IRGC look into existing work in this area and encourage development of international treaties.

Although participants welcomed the forward looking perspective offered Frame 2, some noted that Frame 2 developments will very much depend on responses to Frame 1 challenges and issues. Others were concerned that the Frame 2 perspective might be too non-specific for nanotechnology and actually could be applied to any technology.

Implementation of the recommendations from the framework

Comments received urged that the roles of the different stakeholders be clearly defined and openly communicated. Regulating institutions are seen as having a leading position in the field and should adhere to principles of transparency for building public trust. All parties involved, however, carry responsibilities and should openly share their perspectives and data. The development of an international data base or information clearing house with a regular update on existing products was seen as useful.

Participants felt that in order to be implementable, IRGC recommendations would need to be further specified and supported by research on technical standards as well as on ethical and societal implications. Commentators from industry expressed willingness to consider voluntary programmes though noted that their implementation could be difficult in practice. Generally, international cooperation and broadly agreed standards were seen as very crucial factors for the implementation of a governance process for nanotechnology.

Risk Communication

Transparent risk communication was perceived as a very important issue for building up public trust in nanotechnologies. A long term strategy to achieve this goal would involve starting before the actual production of specific nanotechnologies and would raise public awareness at the research and development (R&D) stage. Multi-stakeholder dialogues and broad public involvement, as taking place for example in the field brain sciences, were seen as appropriate tools by most participants.
Industry representatives thought it especially important to communicate about nanomaterials that are currently used today. Challenges for risk communication were seen in the need to be responsive to cultural sensitivities and to the communication needs of specific stakeholders. It was also seen as crucial to involve scientists trained for communication purposes in communication efforts.

Non-First-World-Perspective

NGO representatives urged greater focus on the implications of nanotechnology for developing countries and emerging economies. They felt that the IRGC would have to address questions of how nanotechnology could contribute to reducing poverty and how global innovation processes could be linked with local processes in developing countries. These discussions were part of the basic questions of how nanotechnologies could benefit people and how they could be directed towards that goal. In addition to the perspective of developing countries, it was noted that smaller emerging economies especially in the Asian region are struggling with nanotechnology issues. On the one hand, political institutions aim at attracting foreign companies. On the other, they need to develop legal frameworks that provide protection for the people but also ensure legal stability for companies. Major issues here are about environment, health and safety as well as about intellectual property rights. In general, actors in emerging economies are in a different position then those in highly developed countries. Academia, for example, has fewer capabilities for studies on environmental health and safety and/or for communication to the public. Emerging, economies often depend on corporate leadership from abroad and public awareness of developments in nanotechnology is very low.

Benefits of Nanotechnology

Another issue raised frequently by participants from different stakeholder groups was that the IRGC Risk Governance Framework should emphasis more on the benefits and opportunities of nanotechnologies. This view was articulated as a general recommendation for the framework but also as a factor in understanding of public perception; people do perceive new technologies very much as positive and develop hopes and expectations towards them but these expectations are then balanced with concerns. The result is an overall evaluation process. Therefore, commentators thought it would be beneficial to include these positive perceptions in a risk governance approach. However, it was also noted that under these conditions it might be difficult to maintain a focus on risk governance.

Despite points of criticism raised over the two day conference, participants found the IRGC White Paper on Nanotechnology to be a valuable contribution to further development of the debate on risk governance of nanotechnology. The document's advocacy of an integrated approach to risk governance and recommendations that issues be dealt with at an early stage of developments were very much appreciated. The strong focus on communication issues and public participation was also warmly welcomed.

Concluding Remarks

Risk governance for nanotechnologies remains an important issue for all nations. Most countries are experiencing rapid changes and economic transformations that have been welcomed by many but have also increased people's concerns about the potential side-effects of technological change and its impacts on consumers and society at large. Given the prominence of both viewpoints, the danger exists that the public authorities as well as private risk management institutions may not be responsive enough to adequately address the needs those actors who hold them and hence will lose perceived competence and, hence, trust. It is important that all institutions dedicated to nanotechnology risk governance are well prepared to consider all the stages of the risk governance process and develop tools that address the challenges in each step of the process. This implies that resources should be invested in risk governance and that the persons dealing with this issue be adequately trained and prepared.

With respect to institutional responses to the nanotechnology debate, the IRGC is promoting the following actions:

- Development of systematic liaisons between governmental agencies, academic, industrial, NGOs and other actors to share risk information and to promote socially responsible outcomes beyond the present cooperation. It is crucial that relevant information be shared and necessary actions coordinated. Public visibility and potential for stakeholder input into the present assessment processes must also be assured.
- Provision of sufficient resources and capability for conducting concern assessments along with the risk assessments in order to identify concerns early in the risk governance process for nanotechnology. As far as we know, there has not been a systematic survey comparing risk perceptions, social concerns, and public attitudes on nanotechnology in a variety of countries. Such a study would be very helpful to design appropriate management and communication strategies on a global scale.
- Organisation of systematic feedback from the various actor groups and stakeholders, including the general public. Such rounds of feedback could provide valuable information about the concerns, hopes, worries, visions and preferences of the various actor groups and the public at large. Among the many instruments to perform such feedback rounds are stakeholder dialogues, round tables, citizen fora and citizen juries (OECD 2002). The present international activities, especially within OECD, in this direction are already a valuable attempt to collect feedback. It would be advisable, however, to ensure that other relevant actors such as consumer groups, NGOs and other civil society groups have the opportunity to raise their concerns and to provide input to global governance.
- Provision of information to consumers so they are better able to make informed choices regarding the products that they purchase. This task could be delegated to internationally operating consumer groups. Package inserts or leaflets that are handed out to consumers together with their purchased goods, special articles in Consumer Reports and other popular journals are just some of the information strategies that could be used.

- Making decision making processes on nanotechnology R&D and investment transparent so that stakeholders and the public are aware of how decisions are made and what evidence they are based on. Stakeholders can contribute to framing the issues related to the risks of nanotechnology by adopting a proactive approach. For example, collaboration should take place among various specialised organisations to create and maintain databases for knowledge on toxicity for nanomaterials, regulations, R&D needs and investment needs.
- Increasing transparency of decision making by publishing all non-proprietary information on test results, impact assessments and their interpretations on the internet or in other forms.
- Establishing appropriate communication forums that help address the purposes for different actors in society want future technologies to be developed. Such discourse activities should be conducted prior to development of the new technologies or their applications. A targeted and effective communication programme is necessary and should include suggestions for a special educational initiative in the context of the worldwide activities to enhance public understanding of scientici, technological and humanitic implications of nanotechnology development at confluence with other emrging technologies
- Involvement of different actors in the joint development of scenarios for future applications of nanotechnology, particularly referring to third and fourth generation products and processes. National or international exercises for constructing scenarios that appear relevant to the context of the diffusion of nanotechnology and the likely social reactions to it should be encouraged. The scenarios suggested in the White Paper may serve as starting points for designing more specific scenarios that relate to the specific situation and the contextual conditions of the countries selected for the analysis. These scenarios could act as catalysts for public debate and consensus-seeking exercises.
- Promotion of international cooperation for establishing common rules and standards for potentially high-impact, long-term projects in nanotechnology. Incentives should be provided for promoting and sustaining international cooperation.

The IRGC’s White Paper on Nanotechnology Governance presents for the first time a conceptual framework for nanotechnology risk governance at an international level for short and long term issues which are upstream of specific implementation policies. By considering the particularities of nanotechnology as an emerging technology, the proposed conceptual framework and guidelines on risk governance provide a step forward in assisting risk management agencies as well as private companies to integrate scientific assessments and concern assessments into one appraisal process and to select the appropriate risk management and stakeholder involvement strategies.

To further contribute to the discussion on nanotechnology governance, the IRGC has published a report on the nanotechnology conference at Rüschlikon in July 2006 (SwissRe, 2007) and a policy briefing based on its White Paper on Nanotechnology Risk Governance (reference needed). In 2007, IRGC is also undertaking an in depth analysis of risk governance of the use of nanotechnology in food, food packaging and cosmetics. The application of IRGC’s proposed framework to concrete nanotechnology applications will constitute a further effort of the IRGC to contribute to the beneficial governance of nanotechnology.

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