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A report on risks from a developing country perspective

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Executive Summary

The objective of this report is to analyse the various dimensions of risk that a socially embedded technology like nanotechnology would entail. This exploratory exercise would in turn give us insights about the factors that need to be considered in any risk governance arrangement. The report is divided into three broad sections corresponding to the key facets of nanotechnology risk: the nature, extent and context of risks associated with the emerging technology.

The first section outlines the complexities inherent in nanotechnology that have given rise to a range of uncertainties and risks affecting natural and human systems. The second segment provides an overview of the range of risks from nanotechnology applications, from environmental, health to occupational risks. Within this, the various exposure routes through which these risks affect the environment and human health are specifically analysed. It also goes on to examine the economic risks of technology displacement that countries are likely to encounter when nanotechnology begins to replace existing technological modes of production. The final section emphasises on the significance of context within which these enlisted risks need to be understood. The context here is the level of development that a particular country has achieved. Thus, the nature of risk from nanotechnology would be the same for all countries engaged in technology development. However, the extent to which populations are exposed to these risks depends on the institutional capacity of a particular state: existing regulatory mechanisms, information policy, stakeholder participation in establishing and reviewing safety standards, to name a few dimensions. Institutional capacity is context-specific, and hence adopting a developing country perspective brings these constraints and enabling factors into sharper focus. This report is an effort to explore and address the risks of nanotechnology by identifying research gaps and making recommendations for evolving an effective framework for risk governance.

CHAPTER 1 A report on risks from a developing country perspective

Introduction

Socially embedded technologies pose several daunting challenges to scientists and policymakers alike. This is particularly so in the case of biotechnology and nanotechnology, which may be termed as strategic technologies due to their complex and transformative nature which induces their wide applicability. Given its organic and inorganic applications, nanotechnology is very amenable to convergence processes and hence becomes an enabling technology, making it an important convergence technology initiative. Nanotechnology risks can be best understood in conjunction with its benefits. Precisely because of which the issue of enhancing capability must be addressed along with the concern for its regulation. In many senses, the imperative to simultaneously respond to both calls presents a dilemma to states interested in tapping nanotechnology. The predicament is more acutely felt in developing countries where limited resources translate into the issue of prioritization between funding research for commercialization and risk research. The complexity of the technology, coupled with the possibility of its wide dissemination in the globalised world renders the technology unpredictable in many senses. A key challenge concerning nanotechnology then is to devise adaptive and responsive governance structures, which can suitably regulate its application in society.

The objective of this report is to analyse the various dimensions of risk that a socially embedded technology like nanotechnology would entail. This exploratory exercise would in turn give us insights about the factors and actors that need to be considered in any risk governance arrangement. The report is divided into three broad sections corresponding to the key facets of nanotechnology risk: the nature, extent and context of risks associated with the emerging technology.

The first section outlines the inherently complex nature of nanotechnology that has given rise to a host of uncertainties and risks affecting natural and human systems. This leads us to the second section which provides an overview of the array of risks we can expect from nanotechnology applications ranging from environmental, health, occupational risks to the economics risk of technology displacement that countries

encounter when nanotechnology begins to replace existing technological modes of production. While it investigates the existing status of research on risks to ensure safe development of nanotechnology, the final section highlights the significance of context within which these enlisted risks need to be understood. The context here is the level of development that a particular country has achieved. This report is an effort to explore the risks of nanotechnology by identifying research gaps and making recommendations for evolving an effective framework for risk governance.

In year 2005, nearly US\$10 billion was globally invested from government and industry for nanotechnology research and development (Lux Research 2006a). Presently, the Indian Government has been playing the key role of nanotechnology developments in India through national Initiative. Department of Science and Technology, Govt. of India has initiated the National Nanotechnology Program, which is funded with \$10 million over 3 years. India has also created a Nanomaterials Science and Technology Initiative and a National Program on Smart Materials; the latter will receive \$15 million over 5 years. Further, companies like Reliance, Tata Steel, Tata Chemicals, Mahindra & Mahindra, Nicholas Piramal and Intel are also looking very closely at nanotechnology and have invested around \$250 million in the domestic market (DMonte 2006). On the other hand, very little investments and research effort is being directed towards assessing the regulatory, social impacts, environment safety and health implications of nanotechnology. There is lot of uncertainty and speculations about the risks of nanomaterials and the safety of products using nanomaterials. Very little information available regarding the environment and health safety of the nanomaterials and the lack of toxicology data makes the adequate risk assessment of these materials difficult.

Government and industry players are investing huge amounts in areas including food processing, food packaging, agricultural production etc. Nanotechnology in the food industry is expected to grow from \$410 million in 2006 to be worth 45.8 billion by 2012¹. The number of companies working in this area is expected to rise to several thousands by 2010². Nanotechnology can be used to develop new products and processes that can improve the quality of life of consumers through improved health, better sensory enjoyment of food, and reduced risk

¹ Cientifica, August 2006

² Study: Nanotechnology in Food and Food Processing Industry Worldwide 2003-2006-2010-2015," Helmut Kaiser Consultancy, Tuebingen, Germany, 2005, accessed on March 20, 2007 <http://www.hkc22.com/nanofood.html>.

associated with food consumption - for example, reduced microbial contamination, or improved traceability of allergenic ingredients. Current nano-food products on the market include canola oil, a chocolate slim shake, nano-bread and several nano-food additives and supplements used in soft drinks, lemonades, fruit juices, margarines and functional foods. The food packaging industries use nano-composites, nano-clays, and nano-coatings to increase shelf life and maintain the flavour of the products. The nanocomposites also offer other benefits like lighter weight and better recyclability, and suggest a significant reduction in transportation and production costs by reducing the amount of material used to package items.

Many of the world's leading food companies (Heinz, Nestle, Hershey, Unilever, and Kraft) are investing heavily in nanotechnology applications in order to exploit the potential of nanotechnology for packaging, food safety and nutritional products. The nanomaterials are new ingredients for food and do not have a history of safe human consumption. Since they are produced from new techniques, all the novel products should be thoroughly assessed for environment and health safety before hitting the market. Learning from the GM experience, there is an indispensable need to figure out the benefits as well as risks of nanotechnology in food. The GM food case illustrates that successful implementation and commercialisation of new technologies technology is contingent on public acceptance of the technology.

What constitutes risk?

Broadly speaking, risk can be defined as 'an uncertain consequence of an event or an activity with respect to something that humans value' (Kates et al. 1985: 21). It refers to both the likelihood of certain consequences from specific activities, and the severity of such effects (Renn 2005: 19). The International Risk Governance Council based in Geneva defines risk as 'the potential for realisation of unwanted, adverse consequences to human life, health, property, or the environment' (Renn 2005: 152). What are the risks we expect from emerging technologies, specifically from nanotechnology? Stated simply, the risks are as heterogeneous as the field of nanotechnology itself. There is a growing pervasiveness of nanomaterials and nanotechnology products in our society. Nanomaterials have already been incorporated in a variety of products ranging from cosmetics and personal care products, textiles and sports goods, pharmaceutical and electronic products, paints and other coatings, catalysts and in some case even in home care and food products. Utilization of nanomaterials to develop applications in the areas of water,

energy, environment, is underway. With 803 products on the market³ in mid 2008, given the large investments in applied research, it is not unreasonable that several new nano-products will be developed in the near future as well as in the long-term as more research bears fruit and companies drive toward commercialisation.

The complexity of the technology, coupled with the possibility of its wide dissemination in the globalised world renders the technology unpredictable in many senses. The Royal Society articulated these apprehensions a few years ago when it observed that ‘manipulation of biological and chemical agents using nanotechnologies could result in entirely new threats that might be hard to detect and counter.’ (Cited in Whitman 2006: 401) Since nanomaterials comprise a diverse group of materials, each with its own set of properties, they present a diverse set of risks that result from their interaction with human and natural systems. The prospect of adding various kinds of coatings on different nanoparticles in order to functionalize them improves some of their characteristics and assigns them additional functions. This dimension not only adds to the diversity that nanomaterials can display but the coatings themselves can also act as a source of toxicological concern (Hardman 2006). As stated by Hoet et al. in their study ‘There is no universal “nanoparticle” to fit all cases, each nanomaterial must be treated individually when health risks are expected’ (Hoet et al. 2004). In addition to this there is a lack of standardised testing protocols for the toxicological evaluation of nanomaterials and it is also undetermined which physio-chemical property (surface reactivity, mass, shape, size) of the nanomaterial can be for the most part correlated with its toxicity and hence measured. Moreover it is also be true that each nanoparticle might differ in this regard. This uncertainty and paucity of information on several counts serves to heighten the risk of nanomaterials and nanotechnologies in the present situation.

Nanotechnology risks can be best understood in conjunction with its benefits. Precisely because of which the issue of enhancing capability must be addressed with the concern for its regulation. In many senses, the imperative to simultaneously respond to both calls presents a dilemma to states interested in tapping an emerging technology. The predicament is more acutely felt in developing countries where limited resources translate into the issue of prioritization between funding research for commercialization and risk research. The nature of risk from nano would be the same for all countries engaged in technology development. However, the extent to which populations are exposed to these risks depends on institutional

³ http://www.nanotechproject.org/inventories/consumer/analysis_draft/

capacity of a particular state: existing regulatory mechanisms, information policy, stakeholder participation in establishing and reviewing safety standards, to name a few dimensions. Institutional capacity in turn is context-specific, and hence adopting a developing country perspective brings these constraints and enabling factors into sharper focus.

The risk debate has diversified into many areas related to nanotechnology applications. The possibility of the abuse of nanoproducts is predicated on their mass production coupled with their economic feasibility. Currently, few nanoapplications have moved beyond the research phase, and thus unless the technical hurdle towards high rate manufacturing isn't overcome the ethical concern with their widespread misuse is unlikely to become a reality.⁴ Significant risks associated with dual-use nanoscale devices such as nanosensors indicate that high potentiality also entails high risks when it comes to emerging technologies. The complexity of the technology is evident in the wide range of risks it spawns, which can be broadly bifurcated into risks to individuals and risks to countries. Risks to individuals, which also include risks certain social groups may face as a whole, include EHS impacts.

Nature: Grasping the potential of Nanotechnology

Nanotechnology is the design, characterization, production and application of structures, devices and systems produced by controlling shape and size at the nanometer scale (Royal Society and Royal Academy of Engineering, 2004). Engineered nanomaterials that form the basis of nanotechnology products and applications, denote a wide variety of substances from carbonaceous materials like carbon nanotubes, fullerenes and graphene to inorganic materials like nano zinc and titanium oxide, nano silver, nano-nickel, quantum dots (lead and cadmium sulphide) and nanowires (silicon, gallium nitride) etc. Nanomaterials differ from their larger analogues due to their extremely small size (less than 100nm at least in 1 dimension) and large surface areas endowing them with unusual physico-chemical properties. The chemical composition (purity, crystallinity, electronic properties), surface structure (surface reactivity, surface groups and coatings), solubility, shape and aggregation also determine the properties of nanomaterials (Nel et al. 2006). Nanomaterials apart from their obvious tiny size could exhibit characteristics and functions that are very different from their larger counterparts in terms of reactivity with other chemicals, binding and absorption, strength,

⁴ The market for nanosensors was worth \$185 million in 2005, from which it was expected to grow to \$2.7 billion in three years.

conductivity, and electronic tribiological properties that are being harnessed to develop applications with socio-economic value. However, these unusual and attractive characteristics that make nanoparticles unique are the very ones that could pose risks or concerns to human beings and the environment. (See Box 1.1)

Box 1.1: Getting the Terms Right

The term “**ultrafine particle**” has traditionally been used by the aerosol researchers and occupational and environmental health communities to describe airborne particles smaller than 100 nm in diameter. It is frequently used in the context of nanometer-diameter particles that have not been intentionally produced but are the incidental products of processes involving combustion, welding, or diesel engines. Similarly, the term “**nanoparticle**” is recurrently used with respect to engineered particles demonstrating size-dependent physicochemical properties. The term “**engineered nanomaterials**” is used to describe inorganic materials of high uniformity, with at least one critical dimension below 100 nm, specifically engineered for commercial applications (Colvin 2003). Ultrafine particles are defined as particles with diameters under 100 nm, are chemically heterogeneous and polydisperse materials that bear little resemblance beyond their physical size to most engineered nanoparticles (Kleeman et al. 2000) although compositions thus making comparisons with engineered nanomaterials problematic (Colvin 2003).

Cutting-edge technologies have always harboured new risks and have a potential to entwined social, economic, environmental, ethical, political and legal issues, which is well illustrated by the GM food issue (Mehta 2004). It is well recognized that without understanding and managing the health and environment risks, the success of the emerging technologies is very improbable. It is therefore essential to understand the complex benefits and risks issues related to the technological innovations. Studies on nanotechnology illustrate a lack of information about the human health and environmental implications of manufactured nanomaterials and safety concerns have been raised (Colvin 2003; Dagani 2003; Masciangioli & Zang 2003 and Michelson 2004). The unique physico-chemical properties (charge, shape, size, hydrophobicity, durability etc), which provide many of the potential benefits, also determine the behavior and toxicity of these nanomaterials in the environment and in biological systems (Holsapple et al. 2005; Oberdorster et al. 2005). Since there is a rapid development, production and use of these materials (drugs, food, agriculture, packaging, environment remediation, cosmetics, paints, clothes etc.), the health (especially in researchers, workers and consumers) and environment risks of these materials during the product life cycle should be thoroughly estimated (CRN 2003, ETC 2002 & 2003).

Extent: Overview of the environmental, health, occupational and economic risks from Nanotechnology

A toxicological update

While the properties of engineered nanoparticles can vary widely, the existing literature on particles and fibers provides a scientific basis from which to evaluate the potential hazards of engineered nanoparticles, which are relevant to understanding the potential toxicity of nanoparticles. The exposure to manufactured nanoparticles is mainly concentrated on workers in nanotechnology research and companies and exposure of the general public originating from dedicated industrial processes is marginal. However, it is inevitable that in the future manufactured nanoparticles will be released gradually and accidentally into the environment. (See Box 1.2)

Box 1.2: What can we learn from previous experiences?

Over the last several years, synthetic chemistry and structural chemistry have progressed, and much of the progress has resulted in harmful materials which industry has lobbied hard for governments to ignore. Learning from past experiences indicates that there is an indispensable need to figure out the benefits as well as risks of nanotechnology in order to setup appropriate regulatory standards. Depending on the techniques used in manufacturing them, nanoparticles could be released in air, water, thereby carrying the risk of soil and food contamination. (Reijnders 2005) It is therefore crucial to understand how the nanotechnology may cause adverse effects to propose and implement safe and sound occupational/environment practices.

Lead: For example lead as a fuel additive is extremely toxic - and patentable and profitable. So, despite studies at its introduction that showed that lead, as a fuel additive would cause major problems for public health, lead became the additive of choice to prevent engine knocking. Today, although it's banned in much of the industrial world, lead for fuel is still synthesized and exported to the developing world.

Arsenic: Over the last 100 years, arsenic has had several major industrial uses as an essential component of animal feed (to promote growth), herbicides and pesticides, lead batteries, metal alloys, semiconductors, wood preservatives, as well as glass manufacturing (Loebenstein 1994). In 1998, 30,300 t (metric tons) of arsenic, contained mostly in compound form, was imported into the United States, mainly from the People's Republic of China (Reese, 1999a). Arsenic, when absorbed through ingestion or inhalation, can exhibit a broad range of symptoms including chronic health effects, including organ damage, cancer, and death (ATSDR, 1989). The EPA has restricted or canceled many of the uses of arsenic in pesticides and is considering further restrictions (ATSDR, 1989). In 1978, the U.S. Occupational Safety and Health Administration concluded that inorganic arsenic is a carcinogen and that worker exposure must be limited (Loebenstein, 1994). In 1980, the EPA listed inorganic arsenic as a hazardous air pollutant based on its findings that inorganic arsenic is carcinogenic (Loebenstein, 1994). For the first half of the 20th century, the greatest use of arsenic was in pesticides, owing to the ability of arsenic and arsenic compounds to kill insects, primarily termites and to lesser extent grasshoppers, and its effectiveness as a fungicide (Loebenstein, 1994).

Although arsenic can be poisonous, and chronic arsenic exposure from industrial or natural sources can cause serious toxicity, arsenic has been used therapeutically for more than 2,400 years (Klaassen CD. Heavy metals and heavy-metal antagonists In: Hardman JG, Gilman AG, Limbird LE, eds. Goodman & Gilman's The Pharmacological Basis of Therapeutics. New York: McGraw-Hill, 1996:1649-1672). Arsenic has a long history of medical applications; before penicillin was developed an arsenic compound was used to treat syphilis and yaws. Pharmacology texts of the 1880s describe the use of arsenical pastes for cancers of the skin and breast, and arsenous acid was used to treat hypertension, bleeding gastric ulcers, heartburn, and chronic rheumatism (Aronson SM. Arsenic and old myths. R I Med 1994;77:233-234).

Determinants of nanomaterial/nanoparticle toxicity

The Royal Society's report on the opportunity and uncertainties of nanotechnology in 2004 concluded based on other studies on air pollutants, mineral dusts and pharmaceuticals that the principal determinants of nanoparticle toxicity were:

- the total surface area presented to the target organ,
- the chemical reactivity of the surface (including any surface components such as transition metals and coatings) and its ability to take part in reactions that release free radicals
- the physical dimensions of the particle that allow it to penetrate the organ or into cells or that prevents its removal
- possibly its solubility, in that soluble particles may disperse before initiating a toxic reaction

Apart from these indicators the dosage and duration of the exposure to the nanomaterial, as well as the route of exposure are also important in determining the toxic effect of nanomaterials. Oberdörster et al. have in their study reported that physicochemical properties such as particle size and size distribution, agglomeration state, shape, crystal structure, chemical composition, surface area, surface chemistry, surface charge, and porosity might be important in understanding the toxic effects of test materials (Oberdörster et al. 2005). Yang et al. in their study identified four types of nanomaterials and explored the interrelationship between particle size, shape, chemical composition and toxicological effects (Yang et al. 2008). They determined that metal nanoparticles were more cytotoxic (inducing cell death) than non-metallic nanoparticles implying that nanomaterial composition was a determining factor in cytotoxicity. On the other hand, carbon nanotubes though less cytotoxic appeared to cause more DNA damage than the former denoting that genotoxicity was determined by particle shape.

In the case of some nanoparticles such as quantum dots environmental conditions (Derfus 2004) and their stability (photolytic, oxidative, and mechanical stability) appear to play a role in determining toxicity. (Hardman et al. 2006) The study concluded that under oxidative and photolytic conditions shell coatings on the quantum dots can become labile leading to several avenues of toxicity from exposure to toxic capping material, intact core metalloids complexes or the core metal components after the dissolution of the metalloid complex. In other cases as with carbon nanotubes, it has been suggested that

ecotoxicity might be determined not just by the nanomaterial but also by the metal and amorphous impurities that are generated during carbon nanotube manufacture and coexist with the carbon nanotubes unless purified (Berger 2008)

Toxicity caused by some specific nanomaterials

Carbon nanotubes (CNTs)

The unique properties of carbon nanotubes had presented an expected market \$700million in 2005 with their utilization in developing composites, electronics, biomedical and even aerospace applications (Lam et al. 2006; Martin et al. 2003; Baughman et al. 2002; Ren et al. 2005). Early studies with carbon nanotubes have indicated that they cause pulmonary toxicity (Lam et al. 2003) and trigger growth of 'granulomas- a combination of dead and live tissue' (Service RF 2003). On the other hand Lam et al in a recent study displayed concern that carbon nanoparticles which are very light can act as suspended particulate matter (PM), leading to inhalation induced occupational hazard (Lam et al. 2006). Results of their tests indicated that carbon nanotubes could cause biochemical/toxicological changes in the lungs. The study pointed out that that single walled carbon nanotubes were more toxic than quartz, which if chronically inhaled is considered a serious occupational health hazard. Inhaling single walled carbon tubes could cause a range of effects such as respiratory function impairments, retard bacterial clearance after bacterial inoculation, damage to the mitochondrial DNA in aorta, increase the percent of aortic plaque, and induction of lesions in the artery of the heart. It was speculated that exposure to combustion-generated multi walled carbon nanotubes in fine PM may play a significant role in air pollution-related cardiopulmonary diseases. Manufactured carbon nanotubes might contain contaminants such as metal catalysts that could also be responsible for adverse health effects. Toxicity studies conducted with nanotubes must take this fact into consideration (Hoet et al. 2004).

Quantum dots (QDs)

Quantum dots made up of a metal complex core, a shielding cap and further biocompatible coatings (if required) are being applied in the electronics industry as well as for biomedical imaging (Hardman, et al, 2006). Their potential for use in drug delivery and site-specific gene delivery is being explored (Rudge et al. 2000; Scherer et al. 2001; Yu and Chow 2005). Quantum dots are of many kinds and their toxicity depends on several physico-chemical and environmental conditions such as size, charge, concentration, outer coating activity (capping material and functional groups), and oxidative, photolytic and

mechanical stability. It was noted that understanding the toxicity of QDs would be complex as toxicity varies widely with the chemical state of the metal and human health hazards could be determined by environmental transformation/degradation and partitioning (Hardman 2006). Once inhaled and depending on their size they might either reach deep lung and alveolar spaces (smaller sized QDs) or deposit in bronchial spaces (larger size QDs). The potential of toxicity due to dermal absorption and accidental ingestion are currently unknown.

Though quantum dots are being recognized for their application for medicinal purposes in humans, their potential toxicity via administrative routes is dependent on several variables and many 'poorly understood factors'. Some studies have determined that quantum dots can be bioaccumulated in organs, tissues and cells for long periods, which might trigger health concerns (Hardman 2006). Several studies have also noted that quantum dots have the potential to cause cytotoxicity as well as damage DNA (Hoshino et al. 2004a and 2004b). Hardman in his study noted that these studies were typically those that were conducted for a longer exposure periods (of 24 hrs) (Hardman 2006; Lovric et al. 2005) in contrast to some studies conducted for shorter and more acute exposures, which did not find evidence of cytotoxicity (Hanaki et al. 2003).

While there are already a host of sectors (medicine, cosmetics, electronics etc) that are beginning to be strongly influenced by the developments in nanomaterials, this is crucial to estimate the risk for regulating the production, use, consumption and disposal of these materials (Oberdorster et al. 2005). The nanoparticles are nonbiodegradable and on disposal, these disposed materials might form a new class of non-biodegradable pollutant and pose a new threat to the environment (air, water, soil) and health (Reijnders, 2005; Maynard, 2006b). If these particles could accidentally enter into the food chain, they can cause damage to the plants, animals and eventually become hazardous to humans due to bioaccumulation. Titanium dioxide, for example, is a generally nonreactive substance used in a number of products (cosmetics, paints etc). Increasingly, nano-sized titanium dioxide particles are used to improve the appearance and performance of the products and experimental data show that these nano TiO₂ particles are highly reactive, generating free radicals that can kill bacteria or can induce skin cancer. Recent studies have shown a significant accumulation of Titanium dioxide (TiO₂) in viscus and gills of fish, while bioaccumulation of TiO₂ nanoparticles in muscle is relative small (Zhang, XZ, Sun, HW, Zhang, ZY 2006). Some scientists express their serious concerns about the impacts of the nanoparticles on soil and water ecology

if they are released in the environment. In contrast, a study shows that there are no unusual risks associated with the production of alumoxane, bulky balls (C60), nano-titanium dioxide, ZnSe quantum dots, or single-walled carbon nanotubes (Robichaud Christine Ogilvie, Tanzil Dickson, Weilenmann Ulrich, Wiesner Mark R 2005). Therefore, careful examination and interpretation of existing data and cautious planning of new research is required if we want to establish the ecotoxicity of nanoparticles as compared to their larger counterparts. It is evident that risks from this technology can be delineated at three levels: individual (health and occupational risks), environment and country (economic risks). The following section examines risks to the environment, human health and occupational safety, as well as looks at the risks countries dependent on commodities, which may be displaced by nanomaterials.

Risks to the Environment

In general ecotoxicological studies have demonstrated that under environmental conditions specific nanoparticles have effects on organisms, although this effect is observed largely at elevated concentrations. The uptake of nanomaterials by aquatic organisms and aquatic toxicity can result from the presence of nanoparticles in water bodies (Nowack and Bucheli 2007). Orberdorster et al. in their study exposed the juvenile largemouth bass, a fish species to fullerenes and observed that the nanomaterial entered through the gills and could penetrate the blood brain barrier, damaging both the gills and the brain at low concentrations (Orberdorster et al. 2004). However these effects disappeared at higher concentrations. CNTs were found to be a respiratory toxicant to rainbow trout (Smith et al. 2007).

Other studies have also noted that nanoparticles can be toxic to unicellular bacteria and protozoa apart from fish species (Nowack and Bucheli 2007). In another study on embryos of aquatic species, zebra fish, carbon nanotubes were found to cause delayed hatching (Cheng and Cheng 2005). In an experiment with another species (copepods) no effects were displayed when the test species were exposed to purified CNTs, however unpurified CNTs resulted in increased mortality (Templeton et al. 2006) indicating that at times contaminants and byproducts co-present with nanomaterials might be the cause of ecotoxicity rather than the nanomaterial itself. On the other hand, growth stimulation of a unicellular protozoan by CNT has also been observed (Zhu et al. 2006). Once again nano TiO₂ was observed to be toxic to aquatic species whereas bulk TiO₂ did not seem to cause adverse health effects (Lovern and Klaper 2006). Some studies have also indicated that

nanomaterials might effect microbial populations and diversity in soil. In experiments it was noted that nanoparticles such as C60, nano CeO₂ were adsorbed on bacterial cells (Lyon et al. 2005; Thill et al. 2005) while others like ZnO have been internalized by bacteria (Brayner et al. 2006). On the contrary fullerenes have demonstrated little impact on soil microbial populations (Tong et al. 2007) unlike nano silver particles that have been used as bactericides (Nowack and Bucheli 2007). The latter along with inorganic nanoparticles like TiO₂, SiO₂ have shown to cause toxic effects on bacteria (Lok et al. 2006; Adams et al. 2006).

Most studies have concentrated on the toxicological effects of nanomaterials to mammalian cells and fewer studies exist on the ecotoxicity of nanoparticles. Nowack and Bucheli have reviewed how nanoparticles interact in the environment (Nowack and Bucheli 2007). Nanomaterials in the environment could undergo specific processes in the environment such as aggregation, degradation or modification of surface coatings, and removal from embedded matrix resulting in free nanoparticles. Surfaces of nanoparticles might also be modified or functionalised by chemical and biological processes that they encounter in the environment. Depending on their type, size, surface properties and environmental factors they may be transported in porous media. Due to their large surface area and increased reactivity, it has been supposed that nanomaterials could act as adsorbers for a range of other toxic compounds.

This might serve to amplify or alleviate the toxicity of such compounds. In the first case the uptake of the nanoparticle with the adsorbed pollutant might lead to a toxic effect due to either component or a synergistic effect. However if the nanoparticle is not toxic, it might serve to reduce the concentration of the nanoparticle in the environment, diminish its bioavailability and thus its toxicity (Nowack and Bucheli 2007). It has been reasoned that nanomaterials might be nonbiodegradable and on disposal these materials might form a new class of pollutant and pose a new threat to the environment (air, water, soil) and health (Reijnders 2005; Maynrad 2006b). The ability of nanoparticles to biomagnification in food chains has also been speculated (EPA 2007)

Studies indicate that inorganic and oxidic nanoparticles could interact with plant cells, plant root and can be taken up by plant systems (Nowak et al. 2006; Nowak and Bucheli 2007). Research on plant systems indicate that while larger particles did not effect the root growth in crops like maize, cucumber, carrot and soya, aluminium nanomaterials reduced root growth in the same (Yang and Watts 2005). However, Murashov pointed it out that the study did not take into account the

soluble Al^{+3} ion is root toxicant and that the solubility of aluminium oxide is known to increase with decreasing particle size. In a surprising observation, nano sized TiO_2 , when exposed to seeds and leaves of the spinach plant have shown to have a positive effect on the plants growth (Murashov 2006).

The nanomaterials can be or are being released into the environment (air, water, and soil) intentionally or unintentionally during their manufacture, use, and disposal; from accidental spills and leaks during their transport; and from leaks or fires in products containing nanoparticles. One route for these materials to enter the environment is through industrial wastewater and through domestic wastewater due to washing off the consumer products like soaps, sunscreens and other cosmetics containing nanoparticles (Daughton and Ternes 1999). Nanoemulsions and nanoparticles of a lanthanum-based compounds for example are being used in surface disinfectants and to prevent the growth of algae in pools and aquariums which can easily enter the drainage system. Nanomaterials can be released to the environment from hazardous waste sites; illegal or improper disposal of industrial wastes and consumer products; can be released from the products (tyres, packaging materials, electronics, cells, filters, paints etc.) due to leakage, use or from the landfills where they are disposed after using (Oberdorster et al. 2005) and burning of wastes in incinerators.

Since these nanomaterials are produced in bulk quantities, there is a chance for these materials to reach the environment from the manufacturing area as an effluent or from accidental spillage during handling/shipping (Oberdorster et al. 2005). There is not sufficient data on the exposure and effects of nanoparticles on ecotoxicity (Colvin's 2003) and only a few studies have been carried out for ecotoxicological testing. Oberdörster (2004b) showed the 48 hours LC_{50} in *Daphnia magna* for uncoated water-soluble fullerenes nC_{60} is 800 ppb that makes it moderately toxic. Oberdörster (2004a) demonstrated a significant increase of lipid peroxidation in the brain and glutathione depletion in the gill of juvenile largemouth bass (*Micropterus salmoides*) after exposure for 48 hours to 0.5 ppm of fullerenes nC_{60} but the increase was not significant at 1 ppm. The bactericidal properties of fullerenes have been reported by Yamakoshi et al 2003. It is well known that the properties of nanomaterials can be customized through engineering and in the similar manner the toxic effects of these engineered nanomaterials can be customized as well.

For example, a study has shown that the cytotoxicity of water-soluble fullerenes can be reduced by several orders of magnitude by modifying the structure of the fullerene molecules by hydroxylation (Sayes et al. 2004). Increasing the sidewall

functionalization of SWCNT also rendered these nanomaterials less cytotoxic to cells in culture (Sayes et al. 2005). Cytotoxicity studies with quantum dots have shown that the type of surface coating can have a significant effect on cell motility and viability (Hoshino et al. 2004; Shiohara et al. 2004; Lovric et al. 2005). Differences in the phase composition of nanocrystalline structures can influence their cytotoxicity; in a recent study comparing two types of titanium dioxide nanoparticles, anatase was more cytotoxic and produced more reactive species than did rutile with similar specific surface area (Sayes et al. 2006).

Exposure Pathways

Through fertilizers

Fertilizers using nanoparticles have the potential to revolutionize the agriculture but also lead to the contamination of the ground water and soil.⁵ The poorly biodegradable nanomaterials might not readily break down in the soil environment or can strongly bind to the soil and thus may remain there for very long periods of time. They could also enhance the ability of potentially toxic fertilizers to penetrate deep layers of the soil and travel over greater distances. Scientists at The Center for Biological and Environmental Nanotechnology (CBEN) at the Rice University, Houston, are carrying out a project that aims to evaluate the effective dose that a biological organism might encounter to engineered nanomaterials that might be released into the environment.

In order to predict the speed and efficiency of nanoparticles movement through water and soil, it is vital to understand their fundamental transport properties. They have observed that nanomaterials exhibit widely differing transport behaviours in model porous media. Among carbonaceous nanomaterials, hydroxide functionalized C₆₀ (fullerols) and surfactant-dispersed single-walled carbon nanotubes (SWNT) exhibited the greatest mobility, and nano-C₆₀ manifested lower but moderate mobility, with almost 50% of the clusters removed from the flow. Oxide nanoparticles exhibited a size- and material-dependent mobility that varied from highly mobile (57 nm silica) to significantly attenuated (303 nm ferroxane)⁶.

⁵ Nanoparticles could increase the efficiency of fertilizers. In India, Tata chemicals for example is increasing its focus on crop-specific, high-value fertilizers by using nanotechnology.

http://www.tata.com/tata_chemicals/media/20060718.htm accessed on 16.10.2006

⁶ http://cohesion.rice.edu/centersandinst/cben/research.cfm?doc_id=5102

Through remediation

Some nanomaterials have shown to improve the removal of toxic materials from the environment (e.g. removing arsenic from the ground water, removal of organics (Chitose N, Ueta S, Seino S and Yamamoto TA. 2003; Mace, C. 2006), removal of hormones (Nghiem LD, Schafer AI, Elimelech M. 2004; Joo SH, Feitz AJ, Waite TD. 2004). However, there are concerns over the use of the free nanoparticles for remediation since they cannot be tracked. In some reports it is recommended that the use of free nanoparticles should be prohibited in environmental applications until appropriate research has been undertaken (UK Royal Society and Royal Academy of Technology report, 2004⁷). On the other hand the use of free nanoparticles for remediation is in field-testing stages where several sites have been injected with various nanomaterials (Joo et al. 2004; Nagaveni et al. 2004; Mace 2006). Therefore there is a need for risk assessment for these materials before applying it to the remediation sites before they cause irreparable damage to the ecosystem. As a result of these findings, many researchers are calling for more environment and health safety studies on nanoparticles. ETC Group report (2004) called for a moratorium on all food, feed, and beverages that incorporate nanoparticles until the studies prove them to be safe for the use. The report also called for a moratorium on nanoscale formulations of agricultural input products, including pesticides, fertilizers, and soil treatments also until these products are proven safe. However, the call for a moratorium by the ETC Group is rejected but the need is recognised to amend existing regulations to take into account the new and changed properties of synthetic nanoparticles .

There is very little or almost no understanding about the long-term impacts of these materials on environment and health. It is therefore critical to collect environmental, health data before encouraging the widespread use of products based on these nanoparticles as well as perform their Life Cycle Assessment (LCA) to study the environmental impacts throughout a product's life cycle. The fate and transport of these nanomaterials with the LCA (Manufacture, use, disposal and recycling) will help to get an insight into the ecotoxicity of these materials. Studies have shown that nanoparticles may have ecotoxicological effects, which depend on the nature of the particles (Hund-Rinke and Simon 2006).

⁷ Nanoscience and nanotechnologies: opportunities and uncertainties' - published on 29 July 2004

Risks to Human Health

By virtue of their size, nanomaterials like other tiny particles might be able to enter the human body and those of other species imperceptibly through various pathways penetrate organs and pass through cell membranes to reside in cells. The surface characteristics of the nanoparticle largely determine its distribution in the body and its accumulation in organs and cells. Nanoparticles must be individually considered when health risks are being determined. (Hoet et al. 2004) Moreover since their size is similar to the minute components contained in the cellular matrix, it has been suggested that they might be able to evade the natural defenses that species have evolved to combat and remove foreign bodies and might act as “stealth particles” (Moghimi and Hunter 2001; Borm and Kreyling, 2004). Due to this feature of low recognition, nanoparticles can migrate and interact with a various body components, away from the initial deposition site and “cascade” a variety of reactions in diverse tissues and cells (Borm and Kreyling 2004). Studies have documented nanoparticle uptake by different kinds of cells ranging from pulmonary and alveolar (present in the lungs) cells, intestinal cells, and nerve cells, to name a few. It is also expected that nanoparticles will be able to cross the blood brain barrier making it useful for drug delivery but requiring several safety evaluations (Hoet et al. 2004).

Several studies have catalogued the effects of inhalation of nanoparticles over other routes of exposure. Most of these studies have drawn from particle toxicology studies and those that have investigated effects of inhaled fine particles. Based on toxicological studies on particulate matter Borm and Kreyling, who reviewed the toxicological hazards of inhaled nanoparticles, illustrate this point in their research (Borm and Kreyling 2004). Inhalation of nanoparticles can impact the respiratory system by causing inflammation and producing free radicals, producing of tumors, inhibiting the body’s defense mechanism, heightening response to allergens. Based on surface characteristics, nanoparticles can be further translocated from the lungs to circulatory system, the central nervous system and even the liver. The direct presence of nanoparticles in these systems along with mediators released due to pulmonary inflammation could trigger several secondary effects, such as affecting blood flow, cardiac function and coagulation. Inhalation of nanoparticles has also been recently associated with cardiac deaths, more so in cases with cardiovascular disorders. Nanoparticles are also known to impair lung function in asthmatics, further reinforcing the claim that reaction brought about by nanoparticles can

potentially harm susceptible and disease afflicted individuals' more than healthy human beings. (Borm and Kreyling 2004) Researchers have also alleged that the large surface area of nanoparticles enable the “non specific” absorption, binding and carrying of “endogenous” or cellular components. They also claim that the reactive surface that nanoparticles possess due to their small size can also cause them to react with cellular components and important mediators and interfere with important cell functions. Using these two features as a basis, the study also evaluated the health hazards of using nanoparticles in therapeutic applications. Nanoparticles used for drug delivery can interact with other protein molecules in the body after the release of the intended carrier protein molecule. Nanoparticles could form complexes with these other proteins, trigger functional changes and lead to their malfunctioning. Their research also claims that cells and organ receptors have been found to be sensitive to nanoparticles and they can interfere with signaling processes and damage mitochondrial structures and the nucleus (Borm and Kreyling 2004). In this context, carbon black nanoparticles have been implicated in disruption of cell signalling processes (Brown et al. 2004).

Nanoparticles used in drug delivery systems must be biodegradable and soluble or else possess a molecular weight limited to a certain value. Otherwise the nanoparticles could also persist and accumulate in the organs and cells in the body. The study identified the important research gaps in using nanoparticles for drug delivery systems (for the various advantages they present over traditional routes of drug delivery) in terms of the toxicological studies that need to be conducted in order to determine the safety of these nanoparticles. Other studies have also cited that since nanoparticles enter the body via the intestinal tract, and have cautioned that extensive testing must prevail before nanoparticles designed to stabilize food or deliver drugs are marketed (Hoet et al. 2004). While the entry of nanoparticles via the skin appears limited (Hoet et al. 2004) others argue that titanium dioxide nanoparticles used in sunscreens can penetrate the skin and affect the immune system (Kreilgaard 2002). Nanoparticles induce oxidative stress in organs such as the liver and lungs and might lead to the chronic depletion of the anti-oxidant defence causing health problems unless studies prove otherwise.

In contrast to some of the above studies, Stern et al report that data exists to support the fact that lung, gastrointestinal tract, and skin to act as a significant barrier to the systemic exposure of many nanomaterials (Stern et al. 2008). The incidence of acute systemic toxicity of several nanomaterials appears to be low while the potential pulmonary toxicity of certain nanomaterials, such as carbon nanotubes, seemed to be

considerable. Risks emerging from nanomaterials appear to be nanomaterial specific and hence data limited to certain studies need not be generalized. Others argue that it is still unclear if all nanomaterials are intrinsically toxic as testing methods are not adapted to nanomaterials and can produce false positive results e.g. (Krug 2008). Worle-Knirsch et al concluded in their study that for nanomaterials cytotoxicity tests must be correlated with at least two others when data needs to be verified (Worle-Knirsch et al. 2006). Moreover, they suggested that there was a need to standardize nanotoxicological assays and develop reference materials. Contaminants within the nanomaterials and the solvents used during the application have shown higher toxicity than the nanomaterials themselves. However, considerable research needs to be undertaken to decipher risks emerging from nanomaterials and there is a need to address several toxicological parameters such as accumulation, deposition and kinetics, apart from emphasizing on ecotoxicological issues.

Further, some studies have also indicated that only a limited number of nanomaterials have demonstrated toxic effects in tissue culture and animal experiments and that too at high doses. The study summarizes nanomaterials might create toxic effects and entail immediate safety evaluations and safe manufacture and implementation of nanomaterials. However, at present there exists 'no conclusive data or scenarios to indicate that these effects might become a major problem or that they cannot be addressed by a rational scientific approach' (Nel et al. 2006 : 627)

Engineered nanoparticles ranges from the multi-ton production of carbon black and fumed silica for applications in plastic fillers and car tyres to microgram quantities of fluorescent quantum dots used as markers in biological imaging (Hoet et al. 2004). Their widespread use allows for potential exposure to manufactured nanoparticles during the whole lifecycle of a variety of products. While looking at possible exposure pathways for manufactured nanoparticles, inhalation, dermal and oral exposure (Hoet et al. 2004) are the most obvious, depending on the type of product in which nanoparticles are used. It is indispensable to monitor the various consumer products incorporating the nanomaterials to estimate the dose and the route of exposure to these materials. Therefore it is extremely important to identify the sources of exposure and to identify methods to monitor the exposures (biomonitoring⁸, outdoor/indoor air etc), and monitoring work practices,

⁸ Biomonitoring involves taking samples of blood, tissue, urine or hair to detect the presence of certain substances in the human body.

Personal protective clothing, respirators, disposal of nanomaterials at the workplace etc.

Exposure Pathways

Inhalation

Accidental or involuntary contact during production or use is most likely to happen via the lungs from where a rapid translocation through the blood stream is possible to other vital organs (Nemmar A, Vanbilloen H, Hoylaerts MF, Hoet PH, Verbruggen A, Nemery B. 2001). Due to their small size the nanoparticles can easily enter the lungs and reach the alveoli. These particles can be cleared from the lungs, as long as the clearance mechanisms are not affected by the particles themselves or any other cause. Nanoparticles are more likely to hamper the clearance resulting in a higher burden, possibly amplifying any possible chronic effects caused by these particles. It is also important to note that specific particle surface area is probably a better indication for maximum tolerated exposure level than total mass. Inhaled nano-fibres (diameter smaller than 100 nm) also can enter the alveoli and their clearing would, in addition, depend on the length of the specific fibre. Recent publications on the pulmonary effects of carbon nanotubes confirm the fear that nano-sized fibre can induce a general non-specific pulmonary response. Recent studies in rodents suggest that significant amounts of carbon particles travel from the nose via the olfactory nerve to the central nervous system (Oberdorster et al. 2004; Elder et al. 2006).

Dermal

The external layer of the skin, the stratum corneum, is considered a mechanically strong and resilient structure that can withstand physical strain and stress. It is considered an effective barrier essential to the protection of the internal milieu from the external environment. Numerous products (including more than 100 sunscreens, cosmetics and personal care products by cosmetic companies) contain potentially hazardous nanoparticles but lack adequate warning labels of their possible health effects. The U.S. Food and Drug Administration regulate sunscreens as nonprescription drugs and do not require extra safety tests for products containing nanoparticles. Silver nanoparticles are used as an antibacterial agent for bandages in medical uses. Products made with silver nanoparticles have been approved by a range of accredited bodies, including the U.S. FDA, U.S. EPA, SIAA of Japan, Korea's Testing and Research Institute for Chemical Industry and FITI Testing & Research Institute. Friends of the Earth is calling for a moratorium on further commercial release of such products, a withdrawal of those currently on the market until further

studies have been completed, and regulations put into place for the general public, workers manufacturing such products, and environment.

Recent studies show that quantum dots are capable of penetrating through the dermis of the skin samples (Ryman-Rasmussen, 2006). Studies show that the healthy skin is a barrier to nanoparticles (Lademann et al. 1999; Tsuji et al. 2006) and there is experimental evidence where the micrometer particles (0.5- and 1.0- μm) penetrate the stratum corneum of mechanically flexed human skin samples and reach the epidermis and, occasionally, the dermis (Tinkle et al. 2003). Several reports provide evidence for fine and ultrafine particle translocation through the stratum corneum or into hair follicles.

Titanium has been reported in the epidermis and dermis following topical application of titanium dioxide-containing sunscreens (Lademann et al. 1999; Tan et al. 1996), although this remains controversial. (Ryman-Rasmussen et al. 2006) Multi-walled carbon nanotubes were *in vitro* examined for dermal exposure in occupational settings and in the consumers. In this study, on MWCNT exposure the human epidermal keratinocytes showed cytokine-mediated inflammatory response (Monteiro-Riviere et al. 2005).

Ingestion

Nanoparticles can be consumed as food additives and drugs. Accidental consumption of these particles is also strong possibility, given that adequate measures providing adequate protection are not often taken. Drug delivery (Hoet et al. 2004) is an area that is already showing significant impact from nanotechnology, with some approaches using nanoparticles or nanocapsules to deliver drugs through the skin, lungs, stomach and eyes already in clinical trials and many more in pre-clinical trials. The potential advantages of these approaches are many and include increased solubility and resistance to gastric enzymes (offering oral delivery of drugs that previously needed intravenous delivery), controlled release and the ability to direct the drug, by various means, to where it is needed.

Food companies are doing research to incorporate nanoparticles to detect spoilage and pathogens in the food. Gastrointestinal absorption can also occur through intentional ingestion or accidental cross contamination of food or drink with nanoparticles. Oral occupational poisonings might occur by contamination of food or cigarettes from unwashed hands, and by accidental swallowing. It is good practice to prohibit eating or drinking at workplace, making ingestion unlikely. Ingestion may also accompany inhalation because the particles that are cleared from the respiratory tract via the mucocilliary

escalator may be swallowed (ICRP 1994). Little data is available on the possible adverse effects caused by the ingested nanoparticles. Crohn's disease is a chronic relapsing inflammatory bowel disease that is characterised by transmural inflammation anywhere in the gastrointestinal tract. The dietary sources of nanoparticles (e.g. natural dietary contaminants, man-made food additives or pharmaceuticals) are associated with the Crohn's disease (Lomer MC, Thompson RP, Powell JJ. 2002; GATTI Antonietta M. 2005). The patient's immune system is triggered to attack the gut lining, causing it to ulcerate and break up. It is possibly a result of faulty responses to microbes living in the gut. Altered lifestyles and changes in the environmental may largely explain the increased incidence in the last 50 years.

Occupational safety: working with engineered nanomaterials

It is estimated that the global value of nanotechnology products will exceed US\$ 2.5 trillion (Lux Research, 2004) but the immediate concern is the presence of nanomaterials in the workplace environment now, which raises occupational health and safety issues. Many nanomaterials are synthesized in enclosed reactors and the enclosures are under vacuum or exhaust ventilation, which prevent exposure during the actual synthesis. The most common route of exposure to airborne particles in the workplace is by inhalation. The greatest current risk is to the occupational health of the workers involved in the production, packaging or transport of the nanomaterials. With the increase in the application of the nanomaterials in various products, the risk of the exposure of the consumers and the general public will also increase. Studies suggest that if the workers are exposed to respirable CNTs, they may be at risk of developing serious lung diseases (Muller et al. 2005). Many researchers and industry workers are handling and producing nanomaterials without having enough information and the health risks (Maynard AD & Kuempel ED 2005).

Nanomaterials can have a wide range of effects on human health, and studies indicate the need for more data on potential exposures of workers to the engineered nanoparticles. Maynard et al. 2004 reported relatively low airborne mass concentrations of raw SWCNT material (single walled carbon nanotube) in one facility, although concentrations increased considerably when the material was agitated. Given the unusual toxicity of SWCNT observed in rodent lungs at relatively low mass doses and the uncertainty about potential adverse effects in workers if exposed, it is prudent to minimize worker exposure to airborne CNTs (carbon nanotube) through the use of effective

engineering controls, work practices, and personal protective equipments. Depending on how the nanomaterial will be used, many kinds of toxicity tests may be required. Now the question arises if the available test methods and the tools are adequate to estimate and characterize the exposures.

The use of protective clothing such as chemical suits and gloves should be considered seriously, especially at the particle recovery and bagging stages of the process and during maintenance and cleaning. There is currently no information on the penetration of nanoparticles through glove or protective suit materials. Workplace safety capability for industrial scale operations involving nano technology can be divided into five major areas:

- Hazard identification.
- Measurement of aerosol concentrations and particle size distribution in air and aqueous media. Thus being able to confirm extent of exposure.
- Safe practices to control exposure to safe levels (The term “safe practices” is intended to include the full gamut of locating exposure sources and controlling them via the appropriate combination of engineering, administrative and personal protective equipment. Within this context we also need to be able to establish safe levels).
- Identification, quantification and mitigation of potential Process Safety risks (over pressure, under pressure, fire and explosion).
- Control of environmental waste streams (air, water and solid) and verification that environmental fate of wastes is not harmful to the environment. The sum of items 1-5 can be considered an approach to Risk Assessment and Control.

It is important to know about our current regulatory system and if there is any nanomaterials been officially assessed or is under assessment. Therefore there is a need to focus on whether the current protective measures are sufficient to minimize occupational exposures. Mass concentration of nanoparticles is generally very low and therefore they cannot be easily determined in current standard exposure measurements. Exposure assessments can be done by room/area measurements since personal samples for nanoparticles measurements do not exist (Borm et al. 2006)⁹.

Working safely with nanomaterials involves following standard procedures that would be followed for any particulate material with known or uncertain toxicity: preventing inhalation,

⁹ Borm et al., Particle and Fibre Toxicology 2006, 3:11

dermal, and ingestion exposure. For example, if the dermal toxicity of a material is too high then it is important to protect the skin with clothing, gloves etc. A glove having good chemical resistance to any solution the particles are suspended in should be used. If working with dry particulate, a sturdy glove with good integrity should be used. Disposable nitrile gloves commonly used in many labs would provide good protection from nanoparticles for most procedures that don't involve extensive skin contact. Two pairs of gloves can be worn if extensive skin contact is anticipated (Problem with the charge). Alternatively, if a material is harmful on inhalation then respiratory protective equipment is necessary while handling the material. Inhalation exposure can occur during additional processing of materials removed from reactors, and this processing should be done in fume hoods. In addition, maintenance on reactor parts that may release residual particles in the air should be done in fume hoods. Another process, the synthesis of particles using sol-gel chemistry, should be carried out in ventilated fume hoods. This reduces the amount health risks in occupational settings due to the exposure to hazardous nanomaterials during the manufacture, packaging, transportation and disposal.

Fire and Explosion¹⁰

Although insufficient information exists to predict the fire and explosion risk associated with nanoscale powders, nanoscale combustible material could present a higher risk than coarser material of similar quantity (HSE 2004). Decreasing the particle size of combustible materials can reduce minimum ignition energy and increase combustion potential and combustion rate, leading to the possibility of relatively inert materials becoming highly combustible. Dispersions of combustible nanomaterial in air may present a greater safety risk than dispersions of non-nanomaterials with similar compositions. Some nanomaterials are designed to generate heat through the progression of reactions at the nanoscale. Such materials may present a fire hazard that is unique to engineered nanomaterials. In the case of some metals, explosion risk can increase significantly as particle size decreases. The greater activity of nanoscale materials forms a basis for research into nanoenergetics. For instance, nanoscale Al/MoO₃ thermites ignite more than 300 times faster than corresponding micrometer-scale material (Granier and Pantoya 2004).

Electrostatic charges can build-up on powders during transport, handling and processing. The charging tendency of highly insulated powders observed in industrial operations does not

¹⁰ NIOSH, Approaches to safe nanotechnology

depend much on the composition of the powder, but more on the operations performed and the specific surface area of the powder (Glor M. 1998). The charging tendency has been found to drastically increase with increasing specific surface area. For example log-log plots of charge to mass ratio *vs.* specific surface area for various organic powders show a near linear relationship. Nanopowders, because of their large specific surface areas, may well become highly charged in use and thus be their own ignition source if the powder is dispersed to form an explosible cloud (Health and Safety Laboratory, 2004).

Key Findings

The detailed analysis of the environmental, health and occupational risks has led us to arrive at certain conclusions about the need to effectively map and address risks from nanotechnology:

- The possible benign nature of their larger counterpart does not preclude the safety of nanomaterials. Toxicity of nanoparticles can arise from any of the various properties that they seem to possess apart from the minute size itself. Impurities along with the manufactured nanoparticles and the environmental conditions the nanoparticles are exposed to could play important roles as well.
- Especially in developing countries risk related research and investment lags far behind in comparison to research on nanoscience and technology development.
- The emergence of toxicity related studies with nanoparticles has indicated that several nanoparticles with significant industrial potential (for example, nanoparticles used in drug delivery, carbon nanotubes and quantum dots) have the potential of being toxic to human health and the environment.
- The potential for application of nanoparticles in diverse sectors indicates ubiquitous pathways for human exposure and entry into the environment.
- An issue of immediate concern is the exposure, occupational health and safety of those who are in direct contact with larger quantities of nanomaterials through processes such as the manufacturing, packaging or transportation of these materials. Guidelines and precautionary methods are central to this area especially in developing countries.

Economic risks: country risks from nanotechnology applications

Development potential of commodity dependent countries is strongly linked to the earnings of these countries from the export of commodities. Literature on trade, technology and development indicates that many commodity dependent developing countries faced adverse impacts through introduction of new technologies leading to reduction in the demand for certain commodities exported by these countries. (See Box 1.3)

Box 1.3: Country Group-wise Risk Overview

Based on the nature of commodity dependence, countries of the world could be classified into the following categories – viz. a) “Perennial Non – Diversified Commodity Exporters”, b) “Transitory Non Diversified Commodity Exporters”, c) “Successful Non – Diversified Commodity Exporters”, d) “Diversified Commodity Exporters” (UNCTAD 2002).

“**Perennial Non – Diversified Commodity Exporters**” includes LDCs, small island states with large share of total export earnings coming from one or two commodities. These countries because of small geographical area and population are not able to move out of their dependence on these commodities. So the country risks due to nanotechnology applications impacting commodity exports are larger for these countries.

“**Transitory Non Diversified Commodity Exporters**” includes mainly African LDCs and non – LDCs. Countries in this category are also dependent on couple of commodities. But these countries could diversify into alternative areas of commodity production and exports with a larger focus on high valued agricultural commodities. The country risks due to nanotechnology applications affecting export demand for certain commodities is lesser in this category as they can diversify into alternative opportunities and options of commodity production and exports.

“**Successful Non – Diversified Commodity Exporters**” includes countries that are solely dependent on one or two commodities for their export earning. These countries are highly exposed to shocks in export market of commodities that could arise from nanotechnology applications. Such shocks could largely impact the employment generation in this group of countries and could impact the development.

“**Diversified Commodity Exporters**” includes countries of Asia and Latin America whose economies and development are less exposed to the shocks of the commodity markets arising from nanotechnology applications. This is because the earnings for economic growth are dependent on various sectors apart from the commodities. But sections of rural population in this category of countries rely on commodity production and exports for their livelihoods. Any shocks in the commodity market would impact these sections to a larger extent within the economy of these countries. However the country risks due to shocks in commodity exports owing to nanotechnology applications are the least for “Diversified Commodity Exporters” amongst all the above - mentioned categories of commodity exporters.

Thus the nature of the commodity exporting countries would determine to what extent they would bear the risk of any shocks in commodity exports arising from nanotechnology applications.

The extent of the socio – economic country risks for the commodity dependent countries would depend on the category of the commodity dependent countries (explained in the box above) The nature and extent of such risks would also depend on whether nanotechnology application substitutes the use of the commodities or whether it complements the existing use of the commodities. Policies have to be implemented to mitigate the possible shocks that could be experienced by commodity

dependent developing countries in case of nanotechnology applications. An integrated policy making through a coordinated trade, labour, industrial and employment policy with the presence of compensation mechanisms could be useful in reducing the vulnerability of commodity dependent developing countries in the context of emergence of socio-economic risks from nanotechnology applications.

UNCTAD analysis in 2002 showed that three commodities (cotton, copper and coffee) accounted for half of the gross export earnings for 46 developing countries (UNCTAD 2002). This fact clearly indicates the dependence of such developing countries on export earnings from commodities for their livelihoods. Statistical research by UNCTAD (The Trade and Development Index 2005) shows that there is a positive correlation between commodity dependence and human development index. Volatility of commodity prices could largely impact the income of the commodity dependent countries by affecting the livelihoods of the people engaged in the production of commodities that are exported. Impact on the livelihoods could contribute in enhancing the poverty levels of the people engaged in the production of commodities and thereby could impact the development of the country. One of the ways by which volatility in commodity prices could take place is through introduction and development of new technology like nanotechnology. Nanotechnology applications could reduce the demand for commodities like cotton, copper, coffee and might contribute to the decline in the long-term prices of these commodities. Thus there is a linkage between the extent of commodity dependence and development in the backdrop of nanotechnology applications that could affect the demand for commodities. However the degree of risks borne by the commodity exporting countries in such a context would depend on the nature of commodity dependence of the country. The following section illustrates this rationale.

Nanomaterials are already being incorporated in a variety of commercial products such as textiles, sports goods materials etc which are produced from primary commodities. It has been predicted that through 2009, commercial breakthroughs will unlock markets for nanotechnology innovations, with revenues rising to \$292 billion and from 2010 onwards, nano technology will become commonplace in manufactured goods, with revenues rising to \$2.6 trillion in 2014¹¹. Thus the future could see a meteoric rise in corporate investments as well as research, development and commercialization of various nanoproducts due to the commercial value of nanomaterials, industrial and

¹¹ Background Paper presented at conference on 'Nanotechnology and the Poor', organised by IDRC-Meridian Institute, Rio de Janeiro, May 26-29, 2007

consumer demand. The pressure from market could raise the volume of production of nanoproducts, which could thereby hurt the commodity exporting countries to a larger extent. Due to this fact, it is extremely likely that nanotechnology would also have major impacts on the existing social, economic and trade milieu as well as on global markets and commodity driven industries. History shows that past introductions of major technological interventions in the global community have resulted in socio-economic impacts in vulnerable communities.

In the same vein, despite the anticipated benefits, nanotechnology could lead to global disruptions in commodity supply and demand and trade with serious implications for commodity dependent countries. This is because the alleged “cure all” nanomaterials and nanoproducts could replace existing commodities, and eliminate commodity associated manufactured goods, processes and labor requirements. Many developing countries are dependent on commodity trade and exports for their earnings and employment. It is reported that around 67% developing countries derive 50% of their export earnings from commodities (T.R.A.D.E 2005). In these countries, the large work force that relies on commodity driven industries and trade for employment may not be able to quickly adapt to the influx of nanotechnologies that would replace their commodity dependent livelihoods. This would have serious implications for the economy and development of these countries as well. This issue was mentioned at the first North-South dialogue on nanotechnology sponsored by the United Nations Industrial Development Organization in February 2005, where South Africa’s Minister of Science and Technology stated that with increased investment research and innovation in nanotechnology, most traditional materials could be threatened as they would be replaced by cheaper, functionally rich and stronger materials. Some of the possible nature and extent of risk from nanotechnology could be contemplated based on the knowledge on what kinds of commodities are being impacted by this technology. The extent of the risks for the commodity exporting countries would be determined by the extent of the total export earning, GDP and employment generated from the commodity exports and production. Other than this, impact on commodity exports from new technologies like nanotechnology could also adversely affect the trade of dynamic products. This could pose risk for countries trading dynamic products.

Nanotechnology applications might substitute or replace the use of primary commodities like coffee, cotton, copper and could impact the demand for these commodities. This could thereby hurt the exports of commodity dependent countries and would entail a subsequent loss in employment in the above-mentioned

commodity producing sectors. So the degree of country risks from nanotechnology applications depends on the nature and extent of commodity dependence of the respective countries.

Export Commodity-Wise Impact of Nanotechnology on Countries

A study done by “The South Centre” on “The Potential Impact of Nano Technologies on Commodity Markets: Implications for commodity dependent developing countries” (T.R.A.D.E 2005) highlights the potential impacts of nanotechnologies on commodity dependent countries which are given below -

Coffee

Current R&D on nanotechnology through a project of Kraft’s nanotech (Elizabeth Gardner 2002) consortium aims to develop nanocapsules for beverages, incorporating greater bioavailability, fresher tastes and strong aromas. The long term impact of this could be a drop in the demand for tropical beverages like coffee which comprises 75% of Burundi’s total export earnings, 62% of Ethiopia’s and 54% of Uganda’s export earnings. The probable long-term impact on the export values of this African Countries could impact the growth and development of these small African countries whose economic growth (in terms of GNP growth) depends to a large extent on the export realization from these commodities in the global commodity markets.

Textile Fibre

Nanoengineered fabrics are being produced, commercialised and used by many large-scale clothing manufacturers. This could create a negative impact on the countries exporting natural fibers like cotton. The global market value of cotton is US\$24,000 million and 1000 million people in countries such as in Africa, India, China and Pakistan are engaged in cotton production. Thus the substitution of cotton fibers by nanomaterial fibres could have a large-scale impact on the global market and employment and earnings in the cotton sector of developing countries. This includes countries like Burkina Faso, Chad, and Benin for who export earnings from cotton account for 39%, 37%, and 33% of their total exports (Gerald Estur 2004).

Rubber

Countries like Thailand, Malaysia, Indonesia and Sri Lanka are some of the world’s largest producers and exporters of natural rubber. Apart from exports, countries such as Sri Lanka use rubber as input in the merged tyre companies (through the merger of local firms and international firms like CEAT) formed through foreign direct investments. The natural rubber and skilled labour used by international firms is locally situated such as in Sri Lanka, whereas the technology for production of tyres

is being channelled through FDI. With the advent of novel nanomaterials, the demand for natural rubber could increase if they are used to enhance the properties of rubber (Toru Noguchi et al. 2005)¹². But in the future there is a possibility that materials such as aerogels (a matrix of nano-sized particles of silica and plastic that have air bubbles trapped in them) could replace rubber and will be used to build lighter and long lasting tyres. Thus in case novel nanomaterials succeed in replacing rubber in the industry it would cause a reduction in the global demand for natural rubber. This would result in the loss in employment for the workforce engaged in natural rubber sector and subsequent loss in national income, which would create negative impacts on the development of natural rubber producing and exporting countries like Thailand, Sri Lanka and Malaysia¹³ due to application of nanomaterials.

Mineral Commodities

Nanomaterials have been implicated as replacements for mineral commodities such as copper and platinum in the future. This is due to the professed ability of the nanomaterials to deliver enhanced performances as compared to their existing counterparts. Future developments in the bulk manufacture of nanomaterials could in turn enable cheaper technological processes and might result in higher profit margins. Platinum has great demand in the automotive, battery and fuel cell industry as a catalyst (Kendall Tom 2005)¹⁴. The high price of platinum coupled with its limited reserves impacts the economic viability of related products. For instance, production of fuel cell incorporates platinum, for which, substitutes are being considered (Baker Monya 2005)¹⁵. In this regard, work at academic and private research institutions and industry has begun to replace platinum catalysts with novel nanomaterials such as QuantumSphere Inc.'s nano-nickel/cobalt alloy for hydrogen fuel cells. (QuantumSphere 2005) and NanoStellar Inc.'s nanoparticles that combine precious metal with other less costly metals.¹⁶ While the former has applied for three broad patents for its nanoscale nickel, NanoStellar Inc. is preparing patents for its low cost nanocatalysts¹⁷. If nanomaterials are able to replace platinum in the near future, it will drastically reduce

¹² NanoProducts press release, "Nanotechnology creates safer, more durable tires," accessed on http://www.nanoproducts.com/site/content_page.php?p=new_developments

¹³ In 2004, Malaysia produced 1.2 million tones of natural rubber which was 14 % of global production, accessed on 3rd November 2008

www.statistics.gov.my/eng/images/stories/files/journalDOSM/reviewing_rubber.pdf

¹⁴ QuantumSphere, Inc., Company News Release, "QuantumSphere Achieves Milestone: Nano-Nickel/Cobalt Alloy, Replaces Platinum," August 29, 2005. accessed on: www.nanoinvestornews.com

¹⁵ *Fuel Cell Industry Report*, Vol. 6, No. 9, September 2005, p. 1.

¹⁶ PCAST, "National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel, May, 2005, p. 13. <http://www.ostp.gov/pcast/PCASTreportFINALlores.pdf>

¹⁷ *Ibid*

the demand for platinum and negatively impact the mining and quarrying sectors of developing countries such as South Africa and Zimbabwe that are amongst the largest producers and exporters of platinum. This would also impact the national economy and disrupt the livelihoods of the large workforce dependent on this industry in these countries.

On a similar note, the replacement of copper and copper wires by novel nanomaterials such as carbon nanotubes displaying superior properties could have serious implications for developing countries that mine and produce copper and copper goods. For example in 2004, copper mining accounted for 7.9% of Chile's and 12% of Indonesia's GDP, and 45% of Chile's exports. Chile and Indonesia employ 74,000 and 500,000 workers in the mining and quarrying sector respectively^{18, 19}. Copper is also Zambia's largest export earner contributing to 55-70 % of the country's foreign exchange earnings and the country's copper trade is also expected to contribute to the small trade surplus²⁰. The livelihood of people living in poor countries such as Zambia and in developing countries like Chile and Indonesia largely depends on the mining and export of primary commodities such as copper. Nanomaterials replacing copper and copper goods in various industry sectors internationally could result in a decline in demand for copper and related goods resulting in a fall in copper trade. This could lead to a reduction in the copper exports and the closing down of the copper mining and refining industry in the above mentioned countries that could negatively impact their GDP, socio-economic development and could also leave thousands of the workforce in that sector unemployed.

The table below shows how different groups of countries across the world are engaged in trading of dynamic products.

¹⁸ Chile Country Profile, *Economist Intelligence Unit*

¹⁹ Indonesia Country Profile, data from Country Studies Program, Federal Research Division, Library of Congress, United States of America.
<http://lcweb2.loc.gov/frd/cs/profiles.html>

²⁰ The potential impact of nanotechnologies on commodity markets: implications for commodity dependent developing countries. Trade-Related Agenda, Development and Equity (T.R.A.D.E) Research Paper 4; 2005, The South Center

Table 1.1: Country group-wise ranking of dynamic products, and products using copper

Rank	Developed	Developing	First Tier Newly Industrialized Countries	ASEAN – 4	South Asia	South America
1	Transistor and Semiconductors	Computers	Computers	Computers	Television Receivers	Fuel Wood and Charcoal
2	Textile Undergarments	Optical Instruments	Natural Abrasives	Parts of Computer and Office Machines	Computers	Copper
3	Perfumery and Cosmetics	Parts of Computer and Office Machines	Road Motor Vehicles	Optical Instruments	Condensation Products	Crude Vegetable Materials
4	Optical Instruments	Condensation Products	War Fire Arms and Ammunitions	Sound Recorders	Iron and Steel Universals, Plates and Sheets	Edible Product Preparation
5	Computers	Heating and Cooling Equipments	Optical Instruments	Iron or Steel Ingots and Forms	Organo – Inorganic Compound	Prepared Meat or Preserved

Source: UNCTAD REPORT 2002

Nanotechnology applications could impact countries that are not exporting primary commodities. This could happen by affecting the flow of trade in dynamic products across different groups of countries as shown in the table above. So implicitly, nanotechnology applications could pose socio economic risk for both developing and other types of countries through different channels. For the commodity exporting countries, the channel could be through its impact on the commodity exports. For other groups of countries, it could potentially impact on the trade of dynamic commodities, which uses various primary mineral commodities as intermediary inputs for production of dynamic products.

Specifically, to illustrate the importance of the above fact, nanotechnology applications like carbon nanotubes could also impact the per capita consumption of copper in countries like India, which stands at 0.3 kg per annum. This could impact the demand for copper that is expected to increase at an annual rate of 7-8% per annum over the short term. Copper imports as a percentage of total imports has increased from 0.52% in 2001 to 0.59% in 2006 (Source - ICRA, The Indian Copper Industry, October 2006) whereas the exports of copper as a percentage of total exports has increased from 0.37% to 1.48% during the same time frame. Application of carbon nanotubes on the trade balance of copper for a country like India would depend on the extent to which the exports and imports are affected by such applications. Any impact on the copper industry from nanotechnology applications could mean an impact on 0.3% of

the Indian GDP, which is the contribution of the copper sector to the Indian GDP. This could also impact on 40% of copper production, which is exported now. Reduction in exports, production of copper in India would entail an impact on employment to an approximate maximum range of 0.04 million²¹.

Thus nanotechnology applications could pose different extents of country risks depending on the type and nature of the exported commodities it impacts. It also depends on the nature of the countries whose commodity exports are being affected. The extent of country risk would also depend on the nature of the use of nanotechnology. This would mean whether nanotechnology applications replace the use of a commodity or whether it complements the use of a commodity. For instance, for copper the extent of risk for countries exporting copper would depend whether – a) Nanotechnology would replace the use of copper or b) Nanotechnology would complement the use of copper. Nanotechnology could be used to replace copper for developing power cables, super conductors or quantum conductors to rewire the electricity grid and enable long-distance, continental, and even international electrical energy transport, and reduce thermal sag failures, eddy current losses, and resistive losses by replacing copper wires. Any growth in demand for these applications would mean a larger extent of country risk for copper producing and exporting countries.

However, in cases where nanotechnology applications complements the use of copper such as usages of copper nanoparticles for polymers and plastics, lubricants, inks and metallic coatings²², the reduction in demand and exports of copper would be less. In such cases, the extent of risks of loss of employment earnings, export earnings for copper-exporting countries would be low. Thus the extent of country risk in the case of a commodity like copper would depend also the nature of the nanotechnology application. So the differential extents of country risks would determine how far the countries are vulnerable to the commodity export shocks from nanotechnology applications. The vulnerability of the countries would also depend on certain other factors that are illustrated below -

Context: The degree of vulnerability to risk

Vulnerability of the commodity dependent countries would depend on whether these countries have domestic policies to

²¹ ICRA COPPER REPORT, 2006

²² Canano Technologies, 230 Metcalf Street, P.O. Box 911, Tweed, Ontario, K0K 3J0.

provide – a) compensation for livelihood losses due to shocks in commodity exports from nanotechnology applications, b) flexible employment framework to provide alternative employment opportunities to mitigate job losses, c) diversification options to switch to other sectors, d) flexible trade policy to cushion the risks of loss in export earnings, e) institutional structure to guarantee income transfers for the commodity dependent people. The policies within the commodity dependent countries have to address and mitigate the impacts on commodities and derived products of commodities, which could be crucial in the presence of constrained capacity of domestic production of commodities and derived products. Industrial and trade policies have to be aligned in these countries to reduce the vulnerability from the existence of such constrained capacities. For instance, impact on trade of copper ores, scraps and value added copper products from import and export duties could impact both the consumers of these copper category types. The designing of the duty structure on the importable copper items would have a substantial effect on the net welfare gains of each player involved in the entire value chain of copper production which includes the copper producers, employees, end consumers. The extent of the effect could go up when there is a constrained capacity production in the entire industry. So there is a need for integrating trade, industrial and labour policies to reduce the vulnerability of commodity dependent countries.

Another important factor that could add to the vulnerability of the commodity dependent countries could be the level of IPR protection for new technologies like nanotechnology. One of the possible adverse impacts could be the creation of monopoly rents from the patents and licenses for new technology like nanotechnology, which could impact developing countries to get access to new technologies controlled by developed country players. The transfer of such technologies from developed to developing countries would depend on the nature and type of the IPR protection regime²³. The time and tenure of the patent license would also be a critical determining factor in assessing the impact of commercial application of nanotechnology on the socio – economic risks and vulnerability of the commodity dependent, exporting countries. In this regard it also important to assess how an IPR regime could be created which provides equal access to technology for all the nano- products (which could replace the use of commodities). Patent regimes could have implications on the vulnerability and socioeconomic risks of commodity dependent countries. This would depend on -

²³ The type of the patents viz. product or process could effect the nature of the market (monopoly or perfectly competitive)

- Ownership and control of nanotechnology applications processes and products
- Nature and Overlapping Patent Claims
- Negotiations regarding acquisition of licenses from multiple patent owners of developed countries by researchers of developing countries aiming to develop nanotechnologies

All the above-mentioned issues have implications for the copper industry in India. This becomes clearer once the industry structure of the copper industry in India is explored. The copper industry comprises of Hindustan Copper Limited, Hindalco and Sterlite Industries. Amongst these Hindustan Copper Limited is linked with mining, smelting and refining segment of the copper industry. So it is a vertically integrated entity. But Hindalco controls the major share (45% market share²⁴) of the copper industry and is a private entity being owned by the Aditya Birla group. The Sterlite Industries is not a major player. Hindalco is largely engaged in production of copper cathodes, continuous cast copper rods²⁵. So it is not engaged in mining of copper ore that is largely being done by Hindustan Copper Limited.

Hindalco imports copper concentrates for processing it to produce copper cathodes, continuous cast copper rods²⁶. It also imports copper ores from two of its own mines in Australia. Hindalco also buys copper ores, concentrates from Hindustan Copper for processing. Annual turnover of Hindalco's smelting and refining units of copper in 2006 had been Rs. 53800 million²⁷. Sterlite industries is another player in the refining and smelting of copper which produces products like - Continuous Cast Copper Rods, Copper Wire Bars, Bus bars, Billets, Ingots, Moulds, Copper based alloys and downstream products, Copper tubes, strips and foils. It uses copper ore, concentrates mined by Hindustan Copper Limited as well as imports copper concentrates. Amongst these firms Hindustan Copper Limited is a government of India enterprise whereas the other two firms are private enterprises. Any impact on demand and supply of copper concentrates, ores owing to nanotechnology applications, technology patent regimes would also influence these firms differentially as the nature of the entities are quite different. Thus livelihoods associated with these industries would also be impacted differentially. Any shocks in the demand for copper products could impact the financial condition of the two private firms, which could result in firing of employees in the two private firms. Policy measures should be particularly designed for such possible scenarios in order to reduce the vulnerability of the employees in the two

²⁴ <http://www.hindalco.com/products/copper.htm>

²⁵ <http://www.hindalco.com/products/copper.htm>

²⁶ <http://www.birlacopper.com/major.htm>

²⁷ <http://www.birlacopper.com/about.htm>

firms. Moreover it is also questionable what happens to a public sector entity like Hindustan Copper in such a scenario. A glance in the financial report²⁸ of Hindustan Copper Limited shows that the manpower in Hindustan Copper Limited has gone down to 5451 in 2006 – 07²⁹ from 5583 in 2005 – 06. This has happened although the turnover and profits have increased from INR 10537.6 million to INR 17996.4 million in 2006-07, and INR 1642.5 million to INR 3666.8 million in 2005-06. So in case of a shock from nanotechnology there could be a further reduction in manpower as any such shock would impact the turnover and profits. The role of market structure and government policies would be very important during those shocks. As of now the copper market is largely under the control of three firms with one of them being a public entity. So it is close to a duopoly with Hindalco having a major share of the market. Dominance of market by single player could raise the vulnerability from loss of livelihoods in situations of shocks to copper demand, supply from nanotechnology applications. Thus a policy has to be designed to check the vulnerabilities from loss of livelihoods, which could arise from nanotechnology applications. Such a policy has to reflect the vulnerabilities arising from domestic market structure and nature. It also has to align the domestic policy with the international policy framework covering the IPR and Trade regimes. This would contribute in making the policy holistic, industry relevant and responsive towards the social and economic costs, which could arise due to reduction of copper demand owing to nanotechnology applications.

The nature and extent of economic welfare losses would depend on the extent of risks that could arise in these countries. The risks could have different impacts on the countries differentially based on their vulnerability to such socio-economic risks. Those vulnerabilities would depend on how well the domestic and international policies are interlinked and integrated. This thereby entails the need of policy co-ordination and linkage between areas of policy making such as science policy, industrial policy, labour policy, trade policy, IPR regimes when assessing and addressing the impact of new technologies like nanotechnology across different countries of the world.

²⁸ Accessed at:

<http://www.hindustancopper.com/Glance.asp?FirstLink=Financials&Seco ndLink=Financial%20Report&LastLink=10%20Years%20at%20a%20Gla nce>

²⁹ Accessed at:

<http://www.hindustancopper.com/Glance.asp?FirstLink=Financials&Seco ndLink=Financial%20Report&LastLink=10%20Years%20at%20a%20Gla nce>

Key Issues for Nanotechnology Risk Governance

The detailed analysis of the various types of risks from nanotechnology has yielded several findings on the gaps in research and policymaking that need to be urgently addressed. The risk mapping exercise on environmental, health and occupational risks stress the need for undertaking risk assessment early in nanotechnology research. Exposure pathways to nanotechnology products are multiple, and effectively monitoring them becomes a daunting challenge since these exist along the manufacturing and consumption chain. Comprehensive LCA (life cycle analysis) for nanoproducts entering the market is imperative, particularly since their safe waste disposal (of nano drug delivery systems, for instance) is critical to environmental and human well-being. Nanoparticles when released intentionally or unintentionally into the environment and the food chain might prove to non-biodegradable and toxic. Detailed risk research have to be undertaken of not only the nature and extent of toxicity from nanomaterials, but also of the levels of accumulation and deposition caused by them. This brings us to the need to standardise toxicity tests of nanomaterials. The benefits accruing from standardisation are dual: it would avoid unnecessary duplication of results in laboratories; and more importantly, it would help avoid expert controversies. Although the scientific community is divided on the dangers from nanotechnology, rival research studies arriving at radically different conclusions on the threats it poses leave the public wary of its health and safety implications. Given that nanotechnology is socially embedded, inconclusive risk research can lead to adverse public perceptions on its possible use.

Given the potential, versatility and reach of nanotechnology, what is immediately evident is that it is amenable to being a convergence technology initiative. As the overview of economic risks indicated, it is imperative to forge linkages between the arenas of trade policy, industrial policy, labour policy and social policy. The prospect of technological displacement due to nanotechnology applications would have to be met with a host of well-coordinated measures such as compensation for livelihood losses, flexible trade and employment policies, as well as exploring trade diversification options. However, much as an integrated policy making framework is in order, the extent to which nanotechnology would pose an economic risk would be context-specific. The context in this case would be two-fold: the nature of commodity dependency of a particular country, and the nature of the nanoapplication-commodity interface (i.e.

whether nanotechnology substitutes or complements the use of a select commodity).

Inclusive Risk Governance

One of the chief reasons behind the categorisation of nanotechnology as an interdisciplinary technology can be found in technological systems convergence. Given its organic and inorganic applications, nanotechnology is very amenable to convergence processes and hence becomes an enabling technology, making it an important CT initiative.³⁰ As Nordmann notes, 'From the point of view of nanotechnology, what used to be separate domains of biomedicine, information technology, chemistry, photonics, electronics, robotics, and materials science come together in a single engineering paradigm.' (Nordmann 2004: 12) Former President of India A.P.J. Abdul Kalam's optimism was evident in his assertion that 'Nanotechnology is knocking at our doors and is the field of the future'. Kalam saw technology convergence of nanotechnology, ICT and biotechnology as a means of further enhancing nanotechnology's potential. (*The Hindu* 2007) Technology convergence also draws together state and non-state actors (here, pharma MNCs and specialised international associations) who are increasingly engaged in governing and regulating transnational issues, which include technology transfer.

In this regard, it is necessary to locate these actors within the broad rubric of institutional capacity, which would constrain and enable the development of an emerging technology to a significant extent. Institutional capacity includes the assets, skills and capabilities that constitute the knowledge structure within a given society. The extent to which this knowledge base can grow depends on certain other factors that are extraneous to the immediate interests of the scientific community itself. For instance, denial of access to technology due to a restrictive patent regime can limit a country's capacity to benefit from it. Furthermore, every risk governance framework should seek to include stakeholders who are affected by the regulation, production and consumption of nanoapplications. Risk governance would include the laws, processes and institutions by which decisions regarding risk analysis, communication and management are taken and executed. It takes into cognizance both the structures (i.e. the actors who are the participants involved in the decision making process) and the process (i.e.

³⁰ Technology systems convergence is defined as 'a combination of enabling scientific discoveries (genetics, nanoscience), techniques (informatics, gene splicing), and advances in allied tools (computing power, scanning tunnelling microscopes, robotics) that greatly accelerate the basic sciences involved and their practical applications, across a breathtaking range of subjects, from human health to materials science.' (Whitman 2006:400)

the procedures that make decision making legitimate and participatory within the overall governance framework). An inclusive risk governance framework then would entail democratizing science by strengthening the involvement of four key actors- political, business, scientific and civil society communities.

Given that nanotechnology is comprehensive in its reach and hence is interdisciplinary in nature, ensuring the accountability of actors involved in its application and regulation is essential. It's a socially embedded nature entails that its credibility depends on fostering partnerships among the various stakeholders. This would ensure that scientific research does not overwhelm public perception and the social analysis of technology, an approach that would be particularly relevant in the case of nanotechnology governance. Thirdly, the political culture plays a key role in ensuring the effectiveness of any risk governance mechanism. An open and vigilant political system with its multiple feedback channels makes for a responsive risk governance structure that addresses the challenges posed by nanotechnology.

Addressing Uncertainty

In the case of nanotechnology with which significant degree of uncertainty is attached given its evolving nature, the staple set of concerns for regulating authorities are further amplified. There exists the concern that in a field where debates on nanotechnology (let alone the regulation) are struggling to keep pace with technological advancements, the possibility of abuse by malicious and unstable political elements is ever present. This danger is more acutely felt in the case of nanoapplications in defence research where the current arms control regimes with its categorisation of chemical, biological and nuclear weapon systems might prove ill suited to regulate nano-based defence systems. (Whitmann 2006: 401) Capitalising on the technology's potential faces challenges from several fronts. Firstly, nanotechnology development is a capital-intensive process requiring heavy investment in R&D activities. Secondly, the gestation period from fundamental research to commercialisation is a long and uncertain one. There is poor lab-firm integration, which is compounded by the paucity of skilled manpower, which could provide linkages between the technology and commercial domains. Venture capitalists are also cautious about investing in a technology the benefits of which are not fully known at present. This reluctance is explained by the extremely low success rate (at 3 percent) that nano projects have globally in terms of turning out as lucrative ventures for investors. (Varadarajan 2008)

One among the many challenges that can potentially influence the ambit and effectiveness of governance institutions in the future is the polarization of the debate on nanotechnology's benefits and dangers. There is a danger of the debate going the biotechnology way in which the supporters and the critics were arrayed at extreme positions on the issue. The course that the biotechnology debate took had considerable influence on public perception of the technology's potential benefits and hazards. Expert dissent and controversies within the scientific community raise suspicion among members of the public as to the risks and vulnerabilities that a new technology would entail. Dissent in itself is a good phenomenon, especially if it brings into focus the health and safety risks associated with an emergent or emerging technology. However, polarized expert positions that have no commonalities whatsoever make the public wary of a technology's potential, both good and bad. Extreme positions pre-empt an understanding of nuances and contingencies from developing. If such a scenario is to be avoided in the case of nanotechnology, it is essential for scientists not to prematurely assume positions that remain unsubstantiated at present. Nanotechnology holds tremendous potential that is hailed as revolutionary in its reach, but for technology to take its course a balanced perspective is due: a balance between enhanced public awareness and scientific expectations.

Promoting risk research

Another challenge that nanotechnologists should address early in their research is according due priority to risk research. Currently, funding allocated for analyzing risks from nanotechnology is abysmally low compared to the vast amounts invested for its commercial applications. Given that nanotechnology is going to be increasingly embedded in society as new products and enhanced performance of existing ones, it is essential to pursue risk research in tandem with the technology's commercialization. The health hazards from nanoparticles are yet not fully known; for instance, the safe disposal of nano drug delivery vehicles is still a concern for scientists. Several pathways of exposure exist along the chain of the manufacture, consumer usage and waste disposal of either the materials or products that can cause the contact of nanomaterials with humans and other species along with their incorporation into the environment. Already at the level of research labs several nanomaterial related studies are being undertaken that expose workers and researchers to nanomaterials. While waste disposal and the environmental introduction of nanoparticles are issues in this case as well,

occupational health hazards for people working at such labs along with nanomaterial manufacturing units constitute a crucial issue. These factors have made adequate research into nanomaterial related EHS issues vital, obligatory and urgent. As far as safety standards are concerned, there have been no concerted efforts to conduct independent assessments on consumer goods using nanotechnology. The possibility of 'uncontrollable or unwanted interactions' between different actors involved in developing and processing the technology makes the potency of nanotechnology ambivalent in nature. It is therefore important to develop strategies for risk management and to engage all stakeholders to maximize the understanding of technology and the endorse stakeholder participation in the technology development and implementation process. To ensure the environment and health safety, adequate financial support and investments should be made available for relevant risk research in India.

What must be remembered is that policy makers and scientists should refrain from approaching EHS risks as solely an issue requiring a scientific solution. Be it environment or health, these are largely social arenas, which require more of human resource management than technological interventions: lifestyle changes, awareness generation, individual and moral responsibility towards the environment and the community, for instance. Technology intervenes to enable better management of issues and offer only partial solutions in themselves. That is why managing risk is not a matter of scientific management but becomes a critical matter of governance.

Furthermore, the pressures of globalisation present a considerable challenge for technology development. International trends in R&D lead to the development of certain products that can be classified as either high-end luxury goods or quality enhancement of products that benefit a small segment of society. The challenge for developing countries would be to resist the tendency to uncritically follow international trends in research that do not address their developmental needs. Within the context of the health sector, for nano applications to be effective, they should seek to prioritise core public health concerns for India such as communicable diseases, which significantly contribute to the mortality rate in India, over furtherance of research into lifestyle diseases.

Currently, there exists a trust deficit between the optimism of the scientific community and the apprehensions expressed by public interest groups regarding nanotechnology's potential. Bridging this gap would be critical in determining the extent to which India can avail of international opportunities to enhance

its capabilities on the development front. Far from seeking to co-opt the public to pre-empt a hostile response (which a number of information sharing exercises often become), a nuanced strategy should seek to ensure nanotechnology's safe and sustainable application, environmentally, socially and economically. Such a strategy should steer clear of stark polarization in the debate on nanotechnology, especially when it projects opposition as a non-progressive and irrational stance.

Appendix

Export related statistics on select commodities

Product	Top Exporter	Export Earning (M\$) (2006)	Value added in GDP (2005)	Employment generated ('000)
Coffee	Brazil	2953	4.8 B\$	4000
	India	316	288000 MT	600
Rubber	Germany	11501	21760 M Euro	398
Iron and Steel	Germany	28465	20559 M Euro	264
<u>Source:</u>				
Value added for Coffee in Brazil: http://www.brazzil.com/component/content/article/175-january-2007/9787.html				
Value added and employment in Germany: http://www.euklems.net/				
For Value added and Employment, Rubber is grouped as Rubber and Plastic, while Iron and Steel is grouped in Basic metals				
Export earning: http://www.intracen.org/appli1/TradeCom/TP_TP_IC.aspx?IN=09&YR=2006				
Employment in Brazil Coffee: www.springerlink.com/index/J3DMXLC4MX76WTQV.pdf				
Employment in Indian Coffee: http://www.business-standard.com/india/storypage.php?autono=333179				
Value added in India Coffee is production data from Coffee Board of India				
In India Agriculture contributes 17.8 % to GDP in 2007				

References

Adams LK, Lyon DY and Alvarez PJJ. 2006

Comparative eco-toxicity of nanoscale TiO₂, SiO₂, and ZnO water suspensions
Water Research Volume 40: 3527-3532

American Chemical Society. 2002

New Lightweight Materials May Yield Safer Buildings, Longer-Lasting Tires
Science Daily

Agency for Toxic Substances and Disease Registry (ATSDR). 1989

Arsenic

Public health statement

Baker Monya. 2005

Sheer Energy: Thinner, cheaper fuel cell catalysts
Technology Review

Berger Michael. 2008

Comparing apples with oranges: the problem of nanotube risk assessment
<http://www.nanowerk.com/spotlight/spotid=5248.php> (10.05.2008)

Brayner R, Ferrari-Illiou R, Brivois N, Djediat S, Benedetti MF, and Fievet F. 2006

Toxicological impact studies based on Escherichia coli bacteria in ultrafine ZnO nanoparticles colloidal medium
Nano Letter Volume 6: 866-870

Borm P J A and Kreyling W. 2004

Toxicological hazards of inhaled nanoparticles – potential implications for drug delivery
Journal of Nanoscience and Nanotechnology Volume 4(5): 521-531

Brown DM, Donaldson K, Borm PJ, Schins RP, Dehnhardt M, Gilmour P, Jimenez LA, Stone V. 2004

Calcium and ROS- mediated activation of transcription factors and TNF-alpha cytokine gene expression in macrophages exposed to ultrafine particles
American Journal of Physiology, 286: L344-353

Baughman RH, Zakhidov AA and de Heer WA. 2002

Carbon nanotubes- the route toward applications
Science Volume 297: 787-792

Chitose N, Ueta S, Seino S, Yamamoto TA. 2003

Radiolysis of aqueous phenol solutions with nanoparticles. 1. Phenol degradation and TOC removal in solutions containing TiO₂ induced by UV, gamma ray and electron beams

Chemosphere Volume 50 (8): 1007-13

Cheng and Cheng. 2005

Carbon Nanotubes Delay Slightly the Hatching Time of Zebrafish Embryos.

229th American Chemical Society Meeting, San Diego

Cientifica. 2006

Nanotechnologies and Food

accessed on 10.11.2008 <http://www.campden.co.uk/whatsnew/nano4.pdf>

Daughton C, Ternes T. 1999

Pharmaceuticals and personal care products in the environment: agents of subtle change?

Environmental Health Perspectives Volume 107: 907-938

DMonte Leslie. 2006

India thinks big about nano

Business-Standard, 17 March 2006

Derfus A. 2004

Probing the cytotoxicity of semiconductor quantum dots

Nano Letter 4: 11-18

Environmental Protection Agency Report (EPA). 2007

Nanotechnology White Paper

Washington DC: U.S. Environmental Protection Agency Report EPA [100/B-07/001]

Gatti Antonietta M. 2004

Biocompatibility of micro- and nano-particles in the colon. Part II

Biomaterials Volume 25 (3): 385-392

Glor M. 1988

Electrostatic hazards in powder handling

New York: Research Studies press Ltd, John Wiley and Sons Inc

Gardner Elizabeth. 2002

Brainy Food: academia, industry sink their teeth into edible nano

Small Times

Gerald Estur. 2004

Cotton: Commodity Profile

Washington, D.C: International Cotton Advisory Committee, pp 1- 2

Hoet P H M, Bruske-Hohlfeld I and Salata O V. 2004
Nanoparticles- known and unknown health risks
Journal of Nanobiotechnology Volume 2: 12

Hund-Rinke Kerstin and Simon Markus. 2006
Ecotoxic Effect of Photocatalytic Active Nanoparticles (TiO₂) on Algae and Daphnids
Environmental Science and Pollution Research Volume 13 (4): 225-232

Hoet, Peter HM, Brüske-Hohlfeld, Irene and V Salata, Oleg. 2004
Nanoparticles – known and unknown health risks
Journal of Nanobiotechnology Volume 2: 12

Hardman Ron. 2006
A toxicological Review of Quantum dot: Toxicity depends on Physiochemical and environmental factors
Environmental Health perspectives Volume114: pp 165-172

Hanaki K-I, Momo A, Oku T, Komoto A, Maenosono S, Yamaguchi Y, et al. 2003
Semiconductor quantum dot/albumin complex is a long-life and highly photostable endosome marker
Biochemical Biophysical Research Communication Volume 302(3): 496–501

ICRP (International Commission on Radiological Protection). 1994
Human respiratory tract model for radiological protection
England: Elsevier Science Ltd., International Commission on Radiological Protection
Publication No. 66

Joo SH, Feitz AJ, Waite TD. 2004
Oxidative degradation of the carbothioate herbicide, molinate, using nanoscale zero-valent iron
Environmental Science and Technology Volume 38: 2242-2247

Kendall Tom. 2005
Platinum 2005: 20th Anniversary
UK: Johnson Matthey plc.

Kreilgaard M. 2002

Influence of microemulsions on cutaneous drug delivery

Advanced Drug Delivery Reviews **Volume 54:** S777-S98

Krug, Harald, Pulsakang Karin, Worle-Knirsch Jorg

Invitro assessment of nanomaterial toxicity: Need for better characterization of materials and methods

NanoEco Nanoparticles in the environment: Implications and Applications, 2-7 March 2008, Monte Verita, Switzerland

Kates, R W et al. 1985

Perilous Progress: Managing the Hazards of Technology

London: Westview Press

Lomer MC, Thompson RP, Powell JJ. 2002

Fine and ultrafine particles of the diet: influence on the mucosal immune response and association with Crohn's disease

Proceedings of the Nutrition Society **Volume 61(1):**123-30

Lux Research. 2004

Sizing Nanotechnology's Value Chain

Paper presented at conference on *Nanotechnology and the Poor*, organised by IDRC-Meridian Institute, Rio de Janeiro, May 26-29, 2007

Lam CW, James JT, McCluskey R and Hunter RL. 2003

Pulmonary toxicity of single walled carbon nanotubes in mice 7 and 90 days after Intratracheal Instillation

Toxicological Sciences **Volume 77:** 126-134

Lux Research. 2006a

The nanotech report

New York, NY: Lux Research Inc., 4th edn.

Lovern SB, Klaper R. 2006

Daphnia magna mortality when exposed to titanium dioxide and fullerene (C60) nanoparticles

Setac Journals **Volume 25:** 1132-1137

Lyon DY, Fortner JD, Sayes CM, Colvin VL and Hughes JB. 2005

Bacterial cell association and antimicrobial activity of a C60 water suspension.

Setac Journals **Volume 24:** 2757-2762

- Lovric J, Bazzi HS, Cuie Y, Fortin, GRA, Winnik FM and Maysinger D. 2005
Differences in subcellular distribution and toxicity of green and red emitting CdTe quantum dots
Journal of Molecular Medicine Volume 83 (5): 377–385
- Lok CN, Ho CM, Chen R, He QY, Yu WY, Sun HZ, Tam PKH, Chiu JF, Che CM. 2006
Proteomic analysis of the mode of antibacterial, action of silver nanoparticles
J. Proteome Res. Volume 5: 916-924
- Lam CW, James JT, Mc Cluskey R, Arepalli S and Hunter RL. 2006
A review of carbon nanotube toxicity and assessment of potential occupational and environmental health risks
Critical Reviews in Toxicology, Volume 36 (3): pp 189-217
- Loebenstein R.J. 1994
The materials flow of arsenic in the United States
U.S. Bureau of Mines Information Circular 9382
- Mehta, M.D. 2004
From biotechnology to nanotechnology: What can we learn from earlier technologies?
Bulletin of Science, Technology & Society Volume 24 (1): 34-39
- Michelson Evan. 2004
Analyzing the European Approach to Nanotechnology
Washington, DC: Woodrow Wilson International Center for Scholars
- Mace C. 2006
Nanotechnology and Groundwater Remediation: A Step Forward in Technology Understanding
Remediation Journal Volume 16 (2): 23-33
- Maynard A.D. and Keumpel E.D. 2005
Airborne nanostructured particles and occupational health
Journal Of Nanoparticle Research Volume 7 (6): 587-614
- Murashov V. 2006
Comments on “**Particle surface characteristics may play an important role in phytotoxicity of alumina nanoparticles**”, by Yang L, Watts D J. 2005
Toxicology Letters Volume 158: 122-132
- Monteiro-Riviere N. et al. 2005
Multi-walled carbon nanotube interactions with human epidermal keratinocytes
Toxicology Letters Volume 155: 377-384

Martin CR and Kholi P. 2003

The emerging field of nanotube biotechnology

Nature Reviews Drug Discovery **Volume 2**: 29-337

Mynrad AD. 2006b

Nanotechnology: managing the risks

Nano Today **Volume 1**: 22-23

Nghiem LD, Schafer AI, Elimelech M. 2004

Removal of natural hormones by nanofiltration membranes: measurement, modeling, and mechanisms

Environmental Science and Technology **Volume 38**: 1888-1896

Nemmar A, Vanbilloen H, Hoylaerts MF, Hoet PH, Verbruggen A, Nemery B. 2001

Passage of intratracheally instilled ultrafine particles from the lung into the systemic circulation in hamster

American Journal of Respiratory and Critical Care Medicine **Volume 164** (9): 1665-1668

Nowack B, Schulin R, Robinson BH. 2006

A critical assessment of chelant-enhanced metal phytoextraction

Environmental Science and Technology **Volume 40**: pp 5225-5232

Nowack Bernd, Bucheli Thomas D. 2007

Occurrence, behavior and effects of nanoparticles in the environment

Environmental Pollution **Volume 150**: pp 5-22

Nel Andre, Xia Tian, Madler Lutz, Li Ning. 2006

Toxic potential of materials at the nano level

Science **Volume 311**: pp 622-627

Nordmann, A. 2004

Converging Technologies for Improving Human Performance: Shaping the Future of European Societies

accessed at: http://www.ntnu.no.no/2020/pdf/final_report_en.pdf

Oberdorster E. 2004

Manufactured nanomaterials (fullerenes, C60) induce oxidative stress in the brain of juvenile largemouth bass

Environmental Health Perspectives **Volume 112**: 1058-1062

Oberdörster E. 2004

Manufactured nanomaterials (fullerenes, C60) induce oxidative stress in the brain of juvenile largemouth bass

Environment Health Perspectives **Volume 112**: 1058-1062

Oberdörster, G. et al. 2005

Principles for characterizing the potential human health effects from exposure to nanomaterials: elements of a screening strategy,

Particle and Fibre Toxicology Volume 2: 8

Robichaud Christine, Ogilvie, Tanzil, Dickson, Weilenmann, Ulrich and Wiesner, Mark R. 2005

Relative risk analysis of several manufactured nanomaterials: An insurance industry context

Environmental science & technology Volume 39 (22): 8985-8994

Rayman-Rasmussen JP, Riviere JE, Monteiro-Riviere NA. 2006

Penetration of intact skin by quantum dots with diverse physiochemical properties

Toxicological Sciences Volume 91 (1): 159-165

Rudge SR, Kurtz TL, Vessely CR, Catterall LG and Williamson DL. 2000

Preparation, characterization, and performance of magnetic iron-carbon composite microparticles for chemotherapy

Biomaterials Volume 21 (14): 1411-1420

Ren SF, Zhang L, Cheng ZH, Guo YL. 2005

Immobilised carbon nanotubes matrix for MALDI-TOF-MS analysis: applications to neutral small carbohydrates

Journal of the American Society for Mass Spectrometry Volume 16: 333-339

Reijnders L. 2005

Cleaner Nanotechnology and Hazard Reduction of Manufactured Nanoparticles

Journal of Cleaner Production Volume 14 (2): 124-133

Renn, Ortwin. 2005

Risk Governance: Towards an Integrative Approach

Geneva: International Risk Governance Council.

Reese R.G. Jr. 1999a

Arsenic

U.S. Geological Survey Mineral Commodity Summaries p. 26-27

Stern S T and McNeil S E. 2008

Nanotechnology Safety Concerns Revisited

Toxicological Sciences Volume 101(1): pp 4-21

Salata OV. 2004

Application of nanoparticles in biology and medicine

Journal of Nanobiotechnology Volume 2

Service R. 2003

Nanomaterials show signs of toxicity

Science : 300:243

Scherer F, Anton M, Schillinger U, Henke J, Bergemann C, Krüger A. et al. 2001.

Magnetofection: enhancing and targeting gene delivery by magnetic force in vitro and in vivo

Gene Therapy **Volume 9** (2) :102–109

Smith CJ, Shaw BJ and Handy RD. 2007

Toxicity of single walled carbon nanotubes to rainbow trout, (*Oncorhynchus mykiss*): respiratory toxicity organ pathologies, and other physiological effects

Aquatic Toxicology **Volume 82** : 94-109

South Centre. 2005

The potential impact of nanotechnologies on commodity markets: implications for commodity dependent developing countries

Geneva: Trade-Related Agenda, Development and Equity (T.R.A.D.E) Research paper 4

Toru Noguchi et al. 2005

English Abstract of “Carbon Nanotubes as Fillers

The Journal of the Society of Rubber Industry **Volume 78**(6): 205-210

The Royal Society and the Royal Academy of Engineering. 2004

Nanoscience and nanotechnologies

UK: The Royal Society

Web: <http://www.raeng.org.uk/policy/reports/nanoscience.htm>

Templeton RC, Ferguson PL, Washburn KM, Scrivens WA, Chandler GT. 2006

Life-cycle effects of single-walled carbon nanotubes (SWNTs) on an estuarine meiobenthic copepod

Environmental Science and Technology **Volume 40**: 7387-7393

Thill A, Zeyons O, Spalla O, Chauvat F, Rose J, Auffan M, Flank AM. 2006

Cytotoxicity of CeO₂ nanoparticles for Escherichia coli. Physico-chemical insight of the cytotoxicity mechanism

Environmental Science and Technology **Volume 40**: 6151-6156

Tong Z, Bischoff M, Nies L, Applegate B, Turco RF. 2007

Impact of fullerene (C₆₀) on a soil microbial community

Environmental Science and Technology **Volume 41**: 2985-2991.

The Hindu 2007

Convergence of Technologies, Hope for the Future: Kalam

Accessed at:

<http://www.hindu.com/2007/09/03/stories/2007090353860400.htm>

UNCTAD (United Nations Conference on Trade and Development). 2005

The Trade and Development Index: country ranking

www.unctad.org/Templates/Page.asp?intItemID=3582&lang=1

UNCTAD. 2005

Diversification of production and exports in commodity dependent countries, including single commodity exporters, for industrialization and development, taking into account the special needs of LDCs

Geneva: UNCTAD secretariat, 26-28 June 2002

Varadarajan, Nitya. 2008

Taking Baby Steps into the Nano World

Business Today

Accessed

at

http://businesstoday.digitaltoday.in/index.php?option=com_content&task=view&issideid=28&id=5150&Itemid=1&page=in&latn=2

Worle-Knirsch Jorg, Pulsakang Karin and Krug Harald F. 2006

Oops they did it again- Carbon nanotubes hoax scientists in viability assays

NanoLetters, Volume 6: pp 1261-1268

Whitman, Jim. 2006

Governance Challenges of Technological Systems Convergence

Bulletin of Science Technology Society Volume 26 (5): 398-409.

Yang H, et al. 2008

Comparative study of cytotoxicity, oxidative stress and genotoxicity induced by four typical nanomaterials: the role of particle size, shape and composition

Journal of Applied Toxicology, accepted for publication.

Yu S and Chow G. 2005

Carboxyl group (-CO₂H) functionalized ferrimagnetic iron oxide nanoparticles for potential bioapplications

Journal of Material Chemistry Volume 14: 2781-2786

Yang L, Watts DJ. 2005

Particle surface characteristics may play an important role in phytotoxicity of alumina nanoparticles

Toxicology Letters Volume 158: 122-132

Zhu Y, Ran T, Li Y, Guo J, Li W. 2006

Dependence of the cytotoxicity of multi-walled carbon nanotubes on the culture medium

Nanotechnology Volume 17: 4668-4674

Zhang XZ, Sun HW, Zhang ZY. 2006

Bioaccumulation of titanium dioxide nanoparticles in carp

Huan Jing Ke Xue **Volume 27** (8): 1631-5