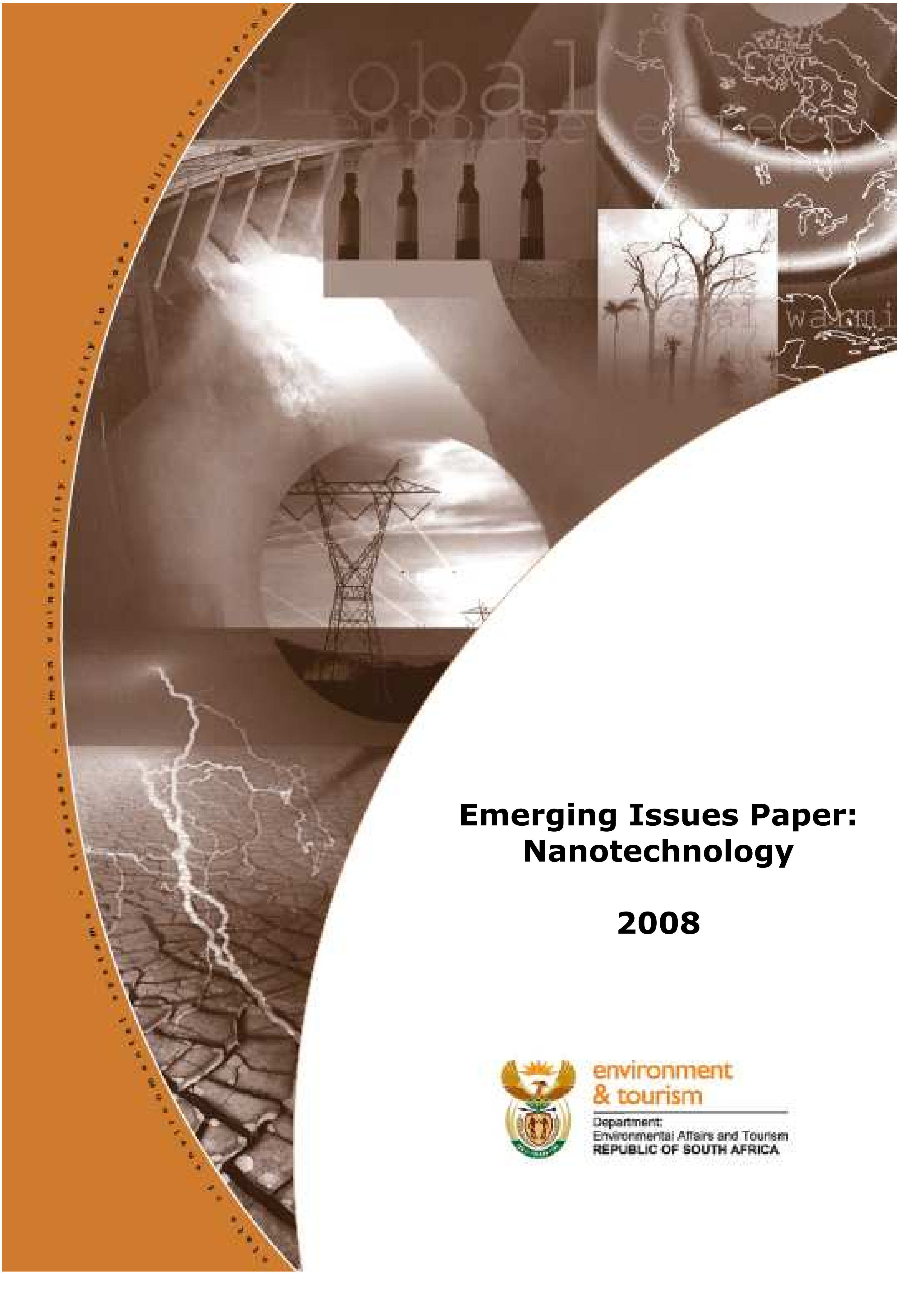

Emerging Issues Paper: Nanotechnology

2008

environment
& tourism

Department:
Environmental Affairs and Tourism
REPUBLIC OF SOUTH AFRICA

NANOTECHNOLOGY AND THE ENVIRONMENT:
A CONSIDERATION OF KEY EMERGING ISSUES THAT MAY IMPACT THE STATE OF THE ENVIRONMENT

This document provides information on emerging issues that may affect the future state of the environment. The purpose of this paper is to draw attention to issues in preparation for the next state of environment reporting cycle.

Paper prepared for:

Department of Environmental Affairs and Tourism (DEAT)
Directorate: Information Management

Prepared by:

Mrs Rietha Oosthuizen and Mrs Michelle Binedell
CSIR, Natural Resources and the Environment

Peer reviewer:

Dr Lang Tran
Institute for Occupational Medicine (IOM) Scotland, United Kingdom

Date:

March 2008

ISBN NO: 978-0-9814178-6-8

Introduction

Nanotechnology is a new and emerging technology which has radically changed the fields of physical sciences and engineering (CSIR, 2007). Nanotechnology deals with the ability to observe, manufacture and manipulate materials that have novel properties, at a scale generally between 1 and 100 nanometres (nm). At this minute scale, nanoparticles are affected by quantum effects and other physical and chemical properties in ways that are not significant at larger scales (Breggin and Pendergrass, 2007). For example, copper can become transparent at the nano scale and therefore be used in a number of applications – one being as an anti-fungal agent in coatings. Using modern technology, therefore, it is possible to expose matter to extreme conditions (such as extreme cold or a vacuum) which can then change its properties. A metal might become an insulator or a substance might be able to convert light into electricity.

When particles become very small (in the nano range) there are more atoms on the surface than inside the particle, and atoms on the surface may have different properties than those inside the particle (EC, 2004). In other words, due to their size, nanoparticles have much larger surface areas on which chemical reactions can take place, in comparison to macro particles of the same material, when the mass of the two sets of particles is the same (Berger, 2006). A particle with a 10nm diameter has approximately 20% of its atoms forming the surface, whereas a particle of 1nm in diameter has about 90% of its atoms forming the surface (Luther, 2004). The physical, chemical and biological properties of nanomaterials may thus differ fundamentally from those of larger particles. It is for these reasons that nanotechnology applications are numerous and many benefits have been demonstrated. Nanomaterials are currently in use in consumer products such as sun-screens and tennis rackets, stain-free clothing and paints (see Box 1).

Box 1: Nanomaterials in everyday products

Nanomaterials are often stronger, lighter and more durable than conventional materials making them the preferred material in certain products. For example, a baseball bat containing carbon nanotubes is very stiff but light, enabling children to use it. Silver nanoparticles are used in textiles such as socks because of their antibacterial properties and titanium dioxide is used in sunscreens as it absorbs UV light. It is claimed that certain toothpastes contain nanoparticles which are able to adsorb bacteria and plaque during brushing. Nanomaterials are also used in film used to cover glass bake-ware in order to give the glassware "non-stick" properties. Within the medical field, nanomaterials are used in cancer treatment research since certain nanoparticles can cross biological barriers such as the blood-brain barrier and can therefore be used to treat brain tumours (EC, 2004). Drugs can also be adsorbed to nanomaterials and delivered to target (cancer) cells. Nanotechnology has promising applications in the environmental field where more sensitive detection devices and more effective filtration and oxidation processes aid in the remediation of environmental pollutants. For further examples of consumer products that contain nanomaterials, refer to the website: http://www.nanotechproject.org/inventories/consumer/ .

The key environmental issue surrounding nanotechnology is that the very characteristics that make nanomaterials of such interest to material scientists for use in consumer products may also make them potentially harmful to humans and the environment. Globally, there is recognition that the prospective widespread use of engineered nanoparticles in consumer products may increase environmental, occupational and public exposures dramatically (Siegrist, et al, 2007; Maynard et al, 2006; The Royal Society, 2003; DEFRA, 2005). It is therefore imperative that the environmental consequences of this new and emerging technology be better understood through the development of appropriate environmental assessment and management tools. A greater understanding of safety, health and environmental aspects will ultimately lead to the long-term sustainability of the technology.

Discussion

The history of nanoparticles dates back as far as 2400 years ago when the Greek philosopher Democratus stated that material is made up of atoms. In 1912, Democratus' claim was proven, when scientists in Germany found that a copper sulphate crystal was able to split up x-ray light. In the eighties, the scanning tunnel microscope was developed and it became possible to see atoms within a crystal. Within this same decade, a third form of natural carbon (other than graphite and diamonds) was discovered. These were named fullerenes or "buckyballs" since they are spherical carbon-cage molecules about 0.7 – 1.5 nm wide (Figure 1).

In 1991 carbon nanotubes (CNTs) were discovered. CNTs are rolled-up sheets of graphite forming cylindrical fullerenes, but with different properties (Figure 2). CNTs have six to seven times the breaking strain of steel and can now be engineered (Berger, 2006). Fullerenes are not only antioxidants but antibiotics can be bound to them to target specific cells such as cancer cells or bacteria (Berger, 2006). Nanoparticles have thus been present on earth for millions of years, but now man is able to synthesize and manipulate such materials and use them in consumer products.

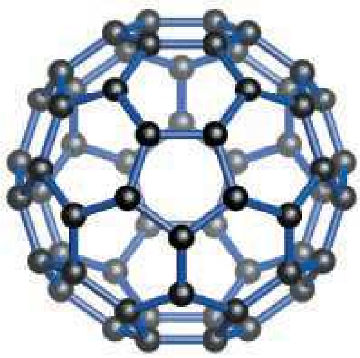

Figure 1: The spherical structure of a carbon fullerene or "buckyball" (EC, 2004).

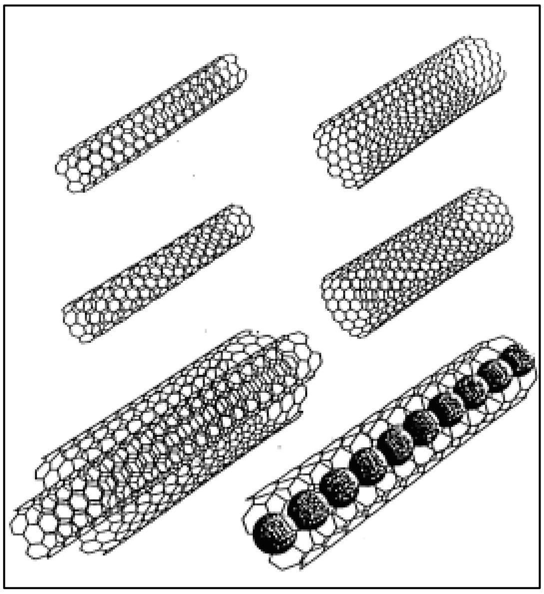

Figure 2: Carbon nanotubes (CNTs) are cylindrical in shape and can be single or multi-walled (Image courtesy of http://www.wtec.org/loyola/nano/f04_06.gif)

Nanotechnology applications cover several scientific disciplines and the industry is growing rapidly. There are already more than 500 consumer products on the market that contain nanomaterials and it is expected that the commercial potential of nanotechnology globally will amount to approximately $2.6 trillion by the year 2014 (Cal-EPA, 2007).

The key issue surrounding nanotechnology is that engineered nanomaterials are finding their way into commercial products and there is not enough evidence surrounding the risks they pose to health and the environment. While it is recognised that nanotechnology holds great promise, there are potentially a number of safety, health and environmental (SHE) imperatives that must be considered within the lifecycle of technology development. It could be possible that real or imagined risks could threaten to slow the development of nanotechnology. This would be an unfortunate scenario since there are many benefits associated with the technology. Thus, there is a need for an evidence-based risk assessment.

The use of nanoparticles will inevitably lead to these particles being introduced to air, water and soil, and humans being exposed to these particles, occupationally and through contact with contaminated air, water, soil or consumer products. Current knowledge on the ecological and human toxic effects of engineered nanoparticles is very limited, not only in South Africa, but globally. Preliminary scientific research has shown that many types of nanoparticles can be toxic to human tissue and cell cultures (Borm et al., 2006; Chen et al., 2006; Kreyling, 2006; Hoyt and Mason, 2007). The problem which exists is that some nanoparticles have increased mobility and increased reactivity, thereby increasing their potential toxicity. Their toxicity can therefore not be derived from the known toxic effects of the larger particles of the same material, since their properties and characteristics may be different. For example copper may become transparent, platinum can become a catalyst and aluminium combustible. Gold can turn into a liquid at room temperature and silicon, an insulator, can become a conductor (Berger, 2006).

There is also no recognised standard method of determining toxicity of nanoparticles. Although many toxicological studies have been and are still being conducted on nanomaterials, there are still huge uncertainties and even contradictions in research results from different institutions (Schmidt, 2007). Scientists are however learning from the past and analogies have been drawn, for example, on the similarity of the structure of carbon nanotubes to asbestos fibres, of which the detrimental effects on humans are well known.

Due to the fact that the same nanomaterial, produced by different engineering processes can differ in size and shape (physical properties) and therefore in their potential to have environmental and health effects, it is a huge task to conduct all possible toxicological studies before a material is used. In the case of carbon nanotubes about 50 000 different versions can be created (Schmidt, 2007). However, scientists are of the opinion that nanomaterials can at least be classified and impact studies conducted on the different classes, which makes it easier to determine potential risks. It can then be determined what physical and chemical properties distinguish toxic nanomaterials from less toxic or non-toxic nanomaterials.

It can be argued too that nanomaterials might be toxic but that they might never be released to the environment in high enough quantities to be of concern, and that nanoparticles in consumer products are intact and currently the only exposure is occupational, which can easily be addressed. It must however be born in mind that more and more products contain nanomaterials. Apart from the possibility of skin absorption from cosmetics and textiles, consumer products will inevitably end up either in water or on a landfill or in an incinerator, from where air, water and soil pollution and subsequent human and environmental exposure (including microorganisms, larger animals and plants) cannot be ruled out.

Current environmental and health regulations may not be adequate to prevent the dispersion of nanoparticles into the environment or to protect human health. For example, due to their size and weight, threshold limit values for nanoparticles based on mass per volume (currently applicable to "fine" particulate matter of 2.5 μm or less in diameter) might not be protective of human health. The surface area and composition of nanoparticles might also have to be taken into account. It must be noted that there are orders of magnitude more nanoparticles in 10 μg/m3 than micro size particles. Research is thus needed to determine whether existing practices for handling, treating, storing and disposing of bulk forms of solid wastes are appropriate for nanoscale wastes of the same chemicals (Breggin and Pendergrass, 2007).

Risk research however, can also contribute to the benefit of the technology. For example, once the physical and chemical properties of a nanomaterials are known, engineering methods can be adapted to create less toxic or non-toxic nanomaterials. The focus will then be on manufacturing safe nanomaterials, resulting in a possible positive return on investment made by industry and mitigation of environmental losses. A further example is carbon nanotubes which have been used in drug delivery. In this case, toxicity research involving tests in vitro (within a test tube) and in vivo (within the living body), determined the behaviour of nanomaterials and demonstrated their ability to penetrate cells – resulting in new and novel drug delivery.

The European Commission's Framework Programme has been funding nanotechnology research and development over the past 10 years. Total funding of projects addressing the environmental, health and safety aspects of nanotechnology has experienced an upward trend with 2.5 million Euros allocated between 1998 and 2002, and 25 million Euros between 2002 and 2006 (Aguar, 2007). While this investment is certainly not as significant as the funding going to material research, it does indicate that globally strategic environmental research is gaining support and science is being recognised as a support for sustainable nanotechnologies – where risks are minimised and benefits maximised. This situation however has not yet been experienced locally.

In South Africa, nanotechnology is being encouraged and nanoparticles are being manufactured on a small scale for research and development purposes. The national perspective for nanotechnology in South Africa, articulated in DST's National Nanotechnology Strategy, is that nanotechnology is a tool that will address global development challenges and will provide solutions to some of the country's key development challenges (such as provision of safe water or innovative delivery of health services). The result is that nanotechnology research and development in South Africa is being encouraged to the order of R450 million over the next three years. The strategic objectives of the strategy relate directly to supporting the design, manufacture, synthesis and characterisation of nanomaterials through understanding these processes and developing human capital and supporting infrastructure (DST, 2004).

South Africa has yet to develop a national research strategy and provide the necessary funding for the purpose of investigating the safety, health and environmental aspects of nanotechnology. This research gap needs urgent redress as South Africa is an active global player in researching and fabricating nanomaterials. This perceived limitation in a country's strategy is not unique to South Africa, as the exact words "insufficient emphasis on health and environmental effects" were used in the conclusion of the Council for Science and Technology in the UK in their revision on the UK's policy on nanotechnology published in March 2007 (Schmidt, 2007). It therefore remains a global challenge.

Conclusions

In the not too distant future, South Africa is expected to experience a substantial growth in nanotechnology. While manufacturing of nanomaterials is still not on a large scale and in large quantities it is envisaged that this, and associated use by consumers, will grow exponentially. Along with this growth many environmental concerns and challenges will arise. Global research irrevocably states that people and ecosystems will be exposed to engineered nanomaterials – the magnitude and significance of this exposure is the key question. This will be determined by the type of material, the process used to produce it and its handling through its lifecycle (Maynard, 2007).

Nanotechnology (and the environmental, health and safety aspects associated with it) is not exclusively an environmental issue. The future sustainability of the technology and the return on financial investments, are dependant on an understanding of the real and perceived risk of the technology and the materials and products that are produced. It is currently perceived that the public in general is ignorant regarding nanotechnology. However, as it became clear with genetically modified (GM) crops and food worldwide, the public's perception and attitude can be crucial in the realisation of the technology. Without strategic risk research, public confidence in nanotechnologies could be reduced through real or perceived dangers (Maynard et al, 2006).

The challenges and issues surrounding nanotechnology are not only a global concern but a local one since it is a new and emerging technology in South Africa. The development and commercialisation of nanomaterials will affect a wide range of regulatory frameworks. Important strides are needed to advance knowledge on environmental risks of nanotechnology in the early stages of its development as an emerging technology (Dunphy Guzmán, 2006). South Africa is yet to develop an economically effective strategy required to harness the health and safety research that is being conducted in Europe and the USA. Strong ties and alliances are required to integrate and apply this research into testing and regulations in South Africa. An outcome of such a strategy would be the manufacture and production of nanomaterials in line with "western standards" creating a competitive niche for South African exporters of nanomaterials. Furthermore, by staying abreast with European and US research developments, South Africa will be in a position to develop our own nano-risk research strategy, building on the advances of the rest of the world.

A South African research strategy that addresses the safety, health and environmental aspects of nanotechnology, and increase public awareness related to the issue, will provide an opportunity to ensure the long-term sustainability of the technology while at the same time avoid negative impacts to humans and biological systems. This will require a multi-stakeholder and multi-disciplinary approach within science, society and policy as well as an increase in funding towards nano-environmental research. It is imperative that knowledge of the health and environmental impacts of nanoparticles should not lag behind the technological advances.

References

Aguar, P. 2007. Research topics related to impact assessment of nanoparticles: Current opportunities and future activities. Nanotoxicology 2007, Venice, April 2007.

Berger, M. 2006. Nanotechnology Risks – The Real Issues. *nanoRisk* **1**(1): 1-8.

Borm PJ, Robbins D, Haubold S, Kuhlbusch T, Fissan H, Donaldson K, Schins R, Stone V, Kreyling W, Lademann J, Krutmann J, Warheit D, Oberdorster E. 2006. The potential risks of nanomaterials: a review carried out for ECETOC. *Part Fibre Toxicol.* **14**(3),11.

Breggin, L and Pendergrass, J. 2007. Where does the nano go? End of life regulation of nanotechnologies. Woodrow Wilson International Center for Scholars. Project on Emerging Nanotechnologies, PEN 10, July 2007.

Californian Environmental Protection Agency (Cal-EPA). 2007. Experts to Explore Environmental and Health Risks of Nanotechnology Products. [Online] Available:
www.dtsc.ca.gov/TechnologyDevelopment/Nanotechnology.

Chen, HW, Su, SF, Chien, CT, Lin, WH, Yu, SL, Chou, CC, Chen, JJ and Yang, PC. 2006. Titanium dioxide nanoparticles induce emphysema-like lung injury in mice. *FASEB journal: official publication of the Federation of American Societies for Experimental Biology*. **20**(13), 2393-5.

CSIR, 2007. ScienceScope: Emerging Research Areas, Understanding and controlling the basis building blocks, CSIR publication, June 2007.

DEFRA, 2005. Characterising the potential risks posed by engineered nanoparticles: A first UK government research report. Department for Environment, Food and Rural Affairs, United Kingdom.

DST, 2004. The National Nanotechnology Strategy for South Africa. Department of Science and Technology, Government of South Africa, 2004. ISBN 0-621-36395-2

Dunphy Guzmán, K.A., Taylor, M.R., and Banfield, J.F. 2006. Environmental risks of nanotechnology: National Nanotechnology Initiative Funding, 2000-2004. *Environ. Sci. Technol.* **40**(5), 1401-1407.

European Commission (EC). 2004. *Nanotechnology: Innovation for tomorrow's world* EUR 21151EN [Online] Available: *www.cordis.lu/nanotechnology*

Luther W, 2004. Ed: Industrial application of nanomaterial: chances and risks. *Future Technologies*, 54: 1-112.

Hoyt, V W and Mason, E. 2007. Nanotechnology: Emerging health issues. *Journal of Chemical Health and Safety.* Article in press.

Kreyling, W. G. 2006. Translocation and accumulation of nanoparticles in secondary target organs after uptake by various routes of intake, *Toxicology Letters* **164S,** S34

Maynard, A. D. 2007. Is engineered nanomaterial exposure a myth? [Online] Available: *Url: www.safenano.org*.

Maynard, A.D., Aitken, R.J., Butz, T., Colvin, V., Donaldson, K., Oberdörster, G., Philbert, M.A., Ryan, J., Seaton, A., Stone, V., Tinkle, S.S., Tran, L., Walker, N.J., and Warheit, D.B. 2006. Safe handling of nanotechnology, Nature, **444**, pp 267-269

Schmidt, K. 2007. The Great Nanotech Gamble. *New Scientist* 195 (2612): 38-41

Siegrist, M., Keller, C, Kastenholz, H., Frey, S. and Wiek, A. 2007. Laypeople's and experts' perception of nanotechnology hazards. *Risk Analysis*, **27**(1), 59-69.

The Royal Society, 2003. Nanoscience and nanotechnologies: Opportunities and uncertainties. The Royal Academy of Engineering and the Royal Society. United Kingdom. [Online] Available: *Url: www.nanotec.org.uk/finalReport.htm*.