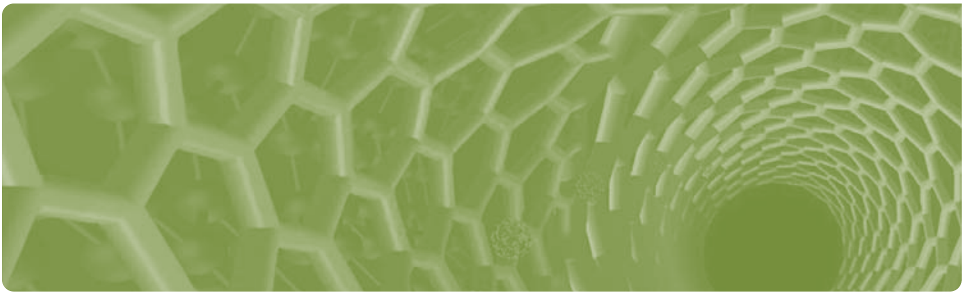
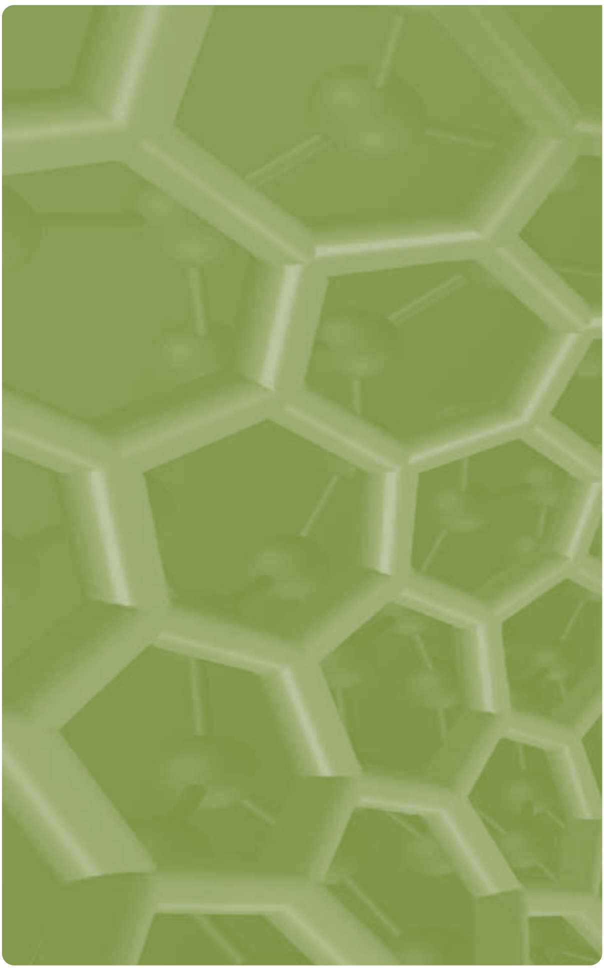
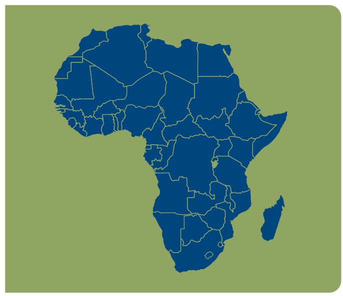


SOCIAL AND ENVIRONMENTAL IMPLICATIONS OF NANOTECHNOLOGY DEVELOPMENT IN AFRICA





Ndeke Musee
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with the collaboration of Noela Invernizzi and Trust Saidi

Pretoria, South Africa
Zacatecas, México
Geneva, Switzerland

CSIR
our future through science

IPEN
a toxics-free future

ReLANS

CSIR (Council for Scientific and Industrial Research) in South Africa is one of the leading scientific and technology research, development, and implementation organizations in Africa. It undertakes directed research and development for socio-economic growth. The CSIR hosts one of two South African Nanotechnology Innovation Centres (NICs) established in partnership with the Department of Science and Technology. Moreover, the organization is a research leader in Africa on risk assessment of nanomaterials in the environmental systems. For more information please contact Ndeke Musee at nmusee@csir.co.za and www.csir.co.za

ReLANS (Latin American Nanotechnology and Society Network) is an academic network composed of researchers from diverse disciplines interested in the development of nanotechnologies in Latin America. The network is a pioneer in the analysis of the impact of nanotechnology on the work force, a theme that has been given little consideration in the global discussion despite its significance. The webpage of ReLANS has a section devoted to documents and organizations that focus on this critical theme: www.relans.org

IPEN is a leading global organization working to establish and implement safe chemicals policies and practices that protect human health and the environment around the world. IPEN's mission is a toxics-free future for all. IPEN brings together leading public interest groups working on environmental and public health issues in developing countries and countries in transition. IPEN's global network is comprised of more than 700 public-interest organizations in 116 countries. In 2009, IPEN established a working group on nanotechnology chaired by David Azoulay, Senior attorney at the Center for International Environmental law (CIEL) and director of CIEL's nano project. For more information please contact David Azoulay at dazoulay@ciel.org, www.ciel.org and www.ipen.org.

Musee, N.; Foladori, G. & Azoulay, D. (2012). *Social and Environmental Implications of Nanotechnology Development in Africa.* CSIR (Nanotechnology Environmental Impacts Research Group, South Africa) / ReLANS (Latin American Nanotechnology and Society Network) / IPEN (International POPs Elimination Network).

CONTENTS

INTRODUCTION

All around the world, nanotechnology is being promoted as a technological revolution that will help solve an array of problems. According to the current hype, nanotechnology promises to provide new ways of solving some of Africa's chronic challenges such as treating tuberculosis and malaria, making water drinkable, conserving food, and diversifying energy sources, among other hosts of applications. However, the potential risks and social implications of this new technology are not often discussed nor addressed. The overall level of awareness and capacity to address these issues remains very low, in both civil society and government, and prevents these actors from playing their social role in ensuring the public good.

Research on nanotechnology, and increased commercialization of products containing engineered nanomaterials (generally called nanoproducts), are currently happening in Africa (e.g., in South Africa, Sudan, Kenya, Zimbabwe, Egypt, Algeria). In several African countries, nanotechnology has been declared a strategic sector of scientific and technological development. To achieve the strategic goals, public funds have been or are being used to encourage nanotechnology development through the establishment of research networks and research centres. South Africa, for example, has spent over half a billion rands to support nanotechnology research and development in the country from 2005 to 2012. In addition, graduate courses on nanotechnology have been initiated in some countries, such as South Africa, Egypt, and Algeria.

Even though potential health and environmental risks of engineered nanomaterials are scientifically documented and numerous uncertainties remain, the public funds dedicated to evaluating these risks are extremely low. As a consequence, the current policy in regards to this technology is far from precautionary as the products enter the market unregulated and unlabeled, neither guaranteeing the safety of the product, nor the information to the consumer.

Conscious of the lack of information, regulations, and supervision of nanotechnology, governmental delegations, experts, and representatives of civil society organizations in Africa called for, among other proposals, a precautionary regulatory framework, in several resolutions adopted unanimously during the regional meeting of the Strategic Approach to International Chemicals Management (SAICM) in January 2010 in Abidjan, Ivory Coast and in April 2011, in Nairobi, Kenya.

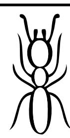
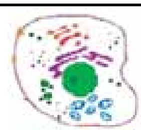
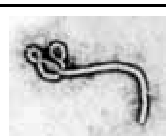
SAICM is a voluntary agreement of the international community envisaged to serve as a global framework in which to discuss methods of cooperation and specific actions that can be taken in relation to achieving safe, responsible, and sustainable management of chemicals. Since the emergence of nanotechnology, engineered nanomaterials have been added as an emerging policy issue. Accordingly, there have been regional reunions and general meetings that have elaborated recommendations and amendments to resolutions that should be adopted by consensus during the Third International Conference on Chemical Management (ICCM3) that will be held in September, 2012, in Nairobi, Kenya.

In this context, this informational brochure has been developed to: (i) provide an overview of nanotechnology development in Africa; (ii) introduce the social, environmental and health implications of nanotechnology for workers and consumers in Africa; and (iii) stimulate and strengthen stakeholders participation in the global and national discussions on the actions to be implemented by governments, industry, and civil society to lay out a precautionary environment for the safe development of this technology.

WHAT IS NANOTECHNOLOGY?

Nanotechnology is the manipulation of matter at a molecular and atomic scale. It means artificially combining atoms and molecules to create particles and structures with functions different from the same material at a larger scale (also called bulk material, or material in the bulk form). For convenience, it is said that nanotechnology works on materials with a dimension of 100 nanometers, although new functions often operate at 300 or more nanometers. A nanometer is a unit of measurement one millionth of a millimetre (10-9 m). As an example, A DNA strand measures roughly 2 nm, a red blood cell approximately 7000 nm, and a human hair is about 80000 nm wide. The last row of the following table illustrates the level at which nanotechnology operates.

THE NANO WORLD

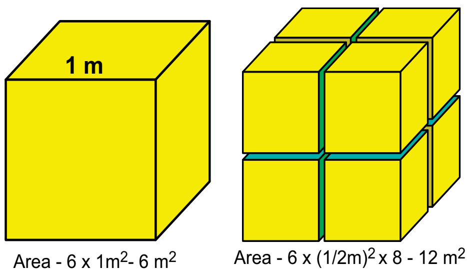
1 meter (m). The macro world		1 person = 1.70 meters
1 milimeter (mm) (1000 milimeters = 1 meter). The small world.		1 ant = 5 milimeters
1 micrometer (μm) (1000 micrometers = 1 milimeter). The celular world.		1 cell = 20 micrometers
1 nanometer (nn) (1000 nanometers = 1 micrometer) The world of nanotechnology.		One virus = 60 nanometers

Source: ReLANS.

Working with matter on such a small scale represents a revolution in technology, because at this scale materials reveal unique novel physical, chemical and biological (including toxicological) properties from their bulk counterpart. It is akin to discovering a world of new materials out of existing materials. The changes of behaviour at the nano scale are due to two different effects: The quantum and surface effects.

Quantum effect gives nano size materials different optical, electrical, thermal, mechanical (resistance/flexibility) and magnetic properties. Metals, for example, are harder and more resistant at the nano level. Carbon in the form of graphite (like in a pencil), is soft, but when processed at the nano scale and manufactured in the form of tubes, the material created (e.g., carbon nanotubes) is up to 100 times harder than macro scale graphite. The optical properties of materials change, acquiring other colours and reflecting light differently. For example, gold becomes red, when engineered at approximately 30 nm, and green at around 3 nm.

Also, the smaller the particle size, the larger the exterior surface area, consequently its reactivity increases. In the figure below, the surface of the first cube is 6 m2, while the one of the 8 small cubes is 12 m2 for the same mass. The atoms that are on the external surface interact more easily with the atoms of other neighbouring matter. For this reason, gold, chemically stable in the bulk form, becomes highly reactive when engineered at the nano scale.



Surface area

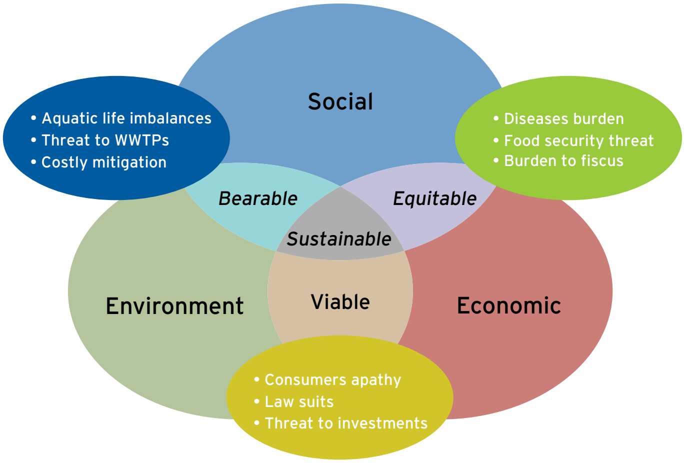
These effects give engineered nanomaterials new properties, including new toxicological and eco-toxicological properties, as for example, in the case of gold, silver, and copper oxide. The increased reactivity and change in chemical and physical properties, increased mobility and capacity for absorption, the tendency to agglomerate or de-agglomerate, thus motivates the need for new scientific and technological development to understand the potential toxic impact engineered nanomaterials may pose to human health and the environment.

Nature also produces nanoparticles from sources such as volcanic emissions, clouds, smoke, fires, etc. Human beings also indirectly produce nanoparticles (e.g., from controlled combustion in engine) and have used some nano properties of materials in the past in making artesian crafts (e.g., when combining glass with metal powders or making dilutions to make stained-glass windows, so common in the Middle Ages, or in producing the Mayans dye known as "indigo blue").

Lycurgus cup

S. IV D.C. British Museum. Glass with nanoparticles of gold and silver. When reflecting light it becomes green when transmitting from inside, red.

The novelty of current engineered nanoparticles comes from the new ability to precisely engineer new particles, structures and derived products at industrial scale. Biological life forms on earth have not adopted mechanisms of coping with potential adverse effects of engineered nanoparticles. Furthermore, increasing data on the toxicity of engineered nanoparticles from scientific community is pointing in the direction of potentially very severe adverse effects. Previous technological revolutions or uses of new materials, such as asbestos or POPs, have shown that it is much easier and much less expensive to prevent such damage than try to adapt or mitigate the damage once it has materialized (when possible at all). This experience with past introduction of new technologies or new materials calls for a precautionary approach to provide a platform for this technology to thrive through societal buy-in. It is therefore critical for the society as a whole to question how nanotechnology achieves sustainability's triple principle of meeting social, environmental, and economic goals but also avoids undesirable impacts.



Prevention of nanotechnology-based adverse effects: Safe-guarding nanotechnology legacy in South Africa for social and economic development interlinked with systematic risk reduction approaches

Source: Ndeke Musee, CSIR, South Africa

In many cases nanoproducts are inspired by nature and try to copy its functions. For example, the leaf of a lotus has a surface of hydrophobic nanoparticles, which could be an inspiration for thin films that repel water. Similarly, lizard's feet have nano-hairs so small that they create forces of molecular attraction that help the animal stick to vertical surfaces and even defy gravity. The following section includes an overview of the types of products and markets.

Lotus leaf (hydrophobic)

THE MARKET FOR NANOTECHNOLOGY PRODUCTS

Technological development history offers insights on how a given technology survives for decades or even centuries in the market place. Nanotechnology is unlikely to be an exception to these rules. It is therefore necessary to understand how the increasing acceptance of nanotechnology by the society creates demand for the products, and to illustrate what the economic, production and research funding data means in terms of potential effects to the society, environment, and human health within the African context.

Presently there are many goods on the market that are produced using nanotechnology capabilities, or that are nanotechnology-based (generally referred to as nanoproducts). The products span in sectors such as foods, cosmetics, household appliances, computers, cellular phones, medicines, textiles, ceramics, construction materials, sports equipment, and military weapons.

In food, nanotechnology is used in products, packaging, nutritional supplements, and agricultural production. There are more than 200 companies that investigate

> The appendix of the book *Out of the Laboratory and into the Food Chain: Nanotechnology in Food and Agriculture,* Miller & Sejen present 106 foods, nutritional supplements and materials that come into contact with food and agrochemicals that contain nanoparticles and are now on the market.

and/or produce goods that utilize nanotechnology in this sector. Nanotechnology is used on the product itself to, for example, to homogenize the texture and enhance the flavour of creams or ice creams, or to reduce the fat content, as Kraft, Unilever, Nestle, and Blue Pacific Flavours have researched. Nanotechnology is also used to add nano-encapsulated nutritional supplements, such as omega 3, fortificants, and weight loss supplements. Research on incorporating cosmetics into food products is also being undertaken, by Loreal in association with Nestle or BASF. Nanotechnology is also used in food packaging to give the product a longer shelf-life, like the nano ceramic bottle by Miller Brewing, or so that the raw material does not spoil, as McDonald's or Mr. Kipling have experimented. Large seed manufacturing companies, such as Syngenta, Monsanto, Bayer, and Dow Chemical, investigate and produce nano-formulation and/or nano-encapsulated formulas for their agrochemicals and for their seeds coatings.

The cosmetics industry has the most nanotechnology products on the market. The majority of transnational cosmetic corporations have anti-wrinkle creams, sunscreens, and shampoos that use nanotechnology, including Chanel, Clinique, L'Oreal, Revlon, Johnson & Johnson, Procter & Gamble, and Lancôme. Using nano-scale materials in sunscreen instead of bulk material allows the cream to be transparent, and hence avoids the dreaded traditional white colour. Nanotechnology is also used among other functions to diffuse light and hide wrinkles. There are toothbrushes and toothpastes with nanoparticles of silver that works as a bactericide. As a result from mounting evidence of potential health and environmental risks, the European Union has now reviewed its cosmetic and biocide regulations to include nano specific provisions, including labelling and specific risk assessment for nanomaterials. No such regulatory tools currently exist in Africa.

Nano in cosmetics

Various electric domestic products include nanoparticles of silver, which operates as a bactericide. Examples include air conditioners, refrigerators, washing machines, and dish washers by Samsung or LG. Thin films engineered with nanotechnology are used to cover floors; nanoparticles are incorporated into paint and in aerosols sprays to apply on furniture and floors. Glass is processed with nanotechnology to prevent dust and dirt from adhering and to facilitate drying. In the textile industry, the application of nanotechnology can make clothing stain and wrinkle resistant. In some cases, nanoparticles of silver are incorporated to make clothing antibacterial; this is applied not only to nurses or doctors uniforms, but also to towels, sheets, and socks.

Nanotechnology is also used in sports equipment such as tennis rackets, golf clubs, bicycle frames, sports shoes, and weather-resistant clothing. The major computer, cell phone, and video game brands use lithium batteries with nano-coated anode, and use nanoelectromechanical devices. Luxury automobiles now come with more than 30 parts that contain nano devices or combine nanoparticles (including anti-scratch paints and antibacterial coatings for interior linings). On another hand, nano medicines holds important promise such as targeted delivery of drugs for enhanced efficiency and limiting side effects.

The defence and weapons manufacturing industry is one that most benefits from and most drives nanotechnology development. From precision missiles to super-explosives, from sensors to bullet-proof vests, the military interest is tied to the advancement of nanotechnology.

Practically all branches of industry have nanotechnology products on the market. According to the ultimate study of the Woodrow Wilson International Center for Scholar's, conducted in March 2011, there were more than 1,317 nanotechnology products on the world market, most of them available on the internet, and therefore available all around the world, including in Africa.

Nano products in the marketplace (The majority of products on the market are luxury goods) Source: David Hawxhurst, PEN

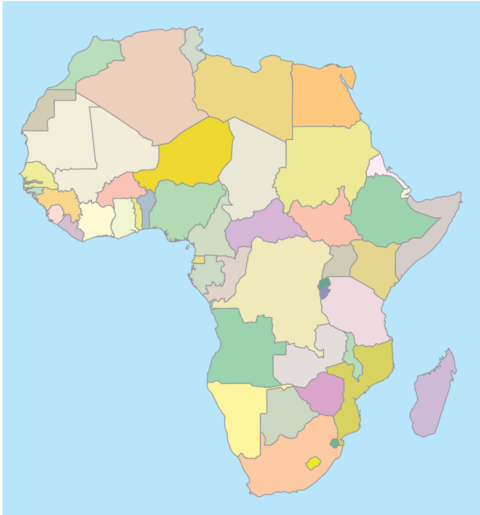
NANOTECHNOLOGIES IN AFRICA

While Africa is a resource-rich continent, many Africans live in poverty as a consequence of several socio-economic factors, including the lack of deliberate technological learning and implementation of technological policies in line with domestic economic problems, intractable challenges of globalization, and acute brain drain of highly skilled personnel.

Great disparities in the levels of education, science, and technology exist between African nations and the developed world as well as within the African continent itself. Only four African universities are among the world's top 500 universities, and all of them are located in South Africa. Similarly, the top eight African universities are also located in South Africa. It should therefore not come as a surprise that South Africa is the leader in Africa in terms of human capacity as well as research and development in relation to nanotechnologies. In light of these educational disparities, the continent continues to lag behind in terms of technology development. However, this has not always been the case. Before the European colonization, some regions (e.g., Ethiopia, Egypt) had advanced knowledge centers, and students from Europe and Asia traveled to Africa to be trained in certain fields. All this disappeared or was swept off by the colonization process.

Education and R&D capacities in the African continent today are mostly oriented towards European and U.S. models. International organizations, such as the World Bank, and private foundations, such as Fulbright, Rockefeller, Gates, Carnegie, and Ford, as well as many western development agencies, such as the Netherlands Organization for International Cooperation in Higher Education, the Canadian International Development Agency, SIDA/SAREC (Sweden), and the Department of International Development (U.K), contribute to the development of African universities, which in certain ways perpetuates the existing educational paradigms. Nanotechnologies are part of this framework.

Nanotechnology research began, at a world level, in the 1980s and 1990s, before the term nanomaterial was even coined (the preferred term at the time was "ultrafine particle"). When the U.S. launched the National Nanotechnology Initiative (NNI) in 2000, it encouraged the development of the related sciences and technologies in the rest of the world. Today, the vanguard of research and production of nanotechnology-based products and materials are the U.S., Germany, the United Kingdom, Japan, and China. In addition, all developed countries, and many developing countries, including some in Africa, are also investigating and beginning to produce nanotechnology-based products and materials.



Africa

South Africa

South Africa launched the South African Nanotechnology Initiative (SANi) in 2002. In 2006, the National Nanotechnology Strategy (the Strategy) was published with the aim to support and promote nanotechnology R&D, and develop human capacity in this field. The Strategy is structured around two clusters: the social cluster promotes applications in areas of health, water, and energy, while the industrial cluster aims at supporting chemical and bio-processing, mining and minerals, and advanced materials manufacturing. The Strategy outlines key interventions, such as the building of multi-user research facilities, collaboration research networks, development of human capacity, and the establishment of flagship projects. The aim of the flagship projects was to demonstrate the benefits of nanotechnology towards enhancing the quality of life, the promotion of economic development, and the stimulation of innovation and technology transfer.

SANI (South Africa)

As part of implementing the Strategy, two National Innovation Centres (NICs) were developed. These were, the National Centre for Nano-Structured Materials (NCNSM) at the Council for Scientific and Industrial Research (CSIR), and Mintek, and serve as national multi-user research facilities. Both NICs are public research centers developed with the financial support from the Department of Science and Technology (DST). Moreover, both NICs (DST/CSIR and DST/MINTEK) have also established partnerships with private companies, for example, SASOL, ECO-Struct International, Biomass Corp., and De Beers.

The NCNSM hosts a state-of-the art characterization facility, including optical scanning probe, image forming, and x-ray. The centre promotes cutting edge research in advanced materials and there are currently several projects in progress. At the CSIR, research in pursuit of various aspects of nanotechnology has been carried through the establishment of research platforms. For illustrative purposes three examples of these platforms are summarized. The first platform entails projects related to:

- The development of advanced polymer nanocomposites intended for industrial, material and aeronautical applicationsBiodegradable polymers and nanocatalysts for industrial applicationsSynthesis of nanoparticles, carbon nanoparticles, and quantum dots intended for diverse industrial applications including purification of water particularly in remote areas

NCNSM (South Africa)

The second research platform is hosted by the CSIR at the Natural Resources and the Environment Division, in partnership with the DST. Since 2007, its main focus is on nanotechnology health, safety, and the environment (Nano-HSE) research. The Nano-HSE research platform mission is to:

- Develop an inventory database on nanotoxicity, and nanoecotoxicity of nanomaterials
- Support focused research on the effects of nanomaterials on different organisms
- Develop human capacity equipped to address nanotechnology-related risksDevelop infrastructure appropriate to investigate nanotechnology-related risks.

Collaborative partners in this initiative include the Universities of Stellenbosch, Pretoria, Tshwane, and Johannesburg, as well as the Water Research Commission. International collaborators in the current projects include the Universities of

Curtin and Western Sydney, Australia, and the Arizona State University in the U.S. Current projects include:

- Understanding the fate, behavior, and effects of nanomaterials in aquatic systems such as wastewater treatment plants
- Modeling the risks of nanomaterials in different environmental systems (water, sediments, soil, etc.)Studying effects of nanomaterials to biological organisms at sub-lethal concentrations to plants and invertebrates.

A third platform at the DST/CSIR relates to nanomedicine that seeks to address poverty related and infectious diseases, namely tuberculosis, malaria and HIV/Aids. The platform uses tuberculosis as its flagship, and has patented a nanotechnology based targeted drug delivery system presently at pre-clinical phase of development. In 2011, the platform was selected, and became one of the African Network for Drugs and Diagnostics Innovation (ANDI) Centre of Excellence for Health Innovation in Africa, and now is called ANDI Centre of Excellence in Nanomedicine Research. Research projects with national and international collaborators aim at developing a drug-delivery system aiming to address patient non-compliance, toxicity, dose frequency, length of treatment, cost, and bioavailability of drugs in the treatment of these three infectious diseases.

Mintek NIC focuses on R&D in relation to various nanostructured materials for applications in health diagnostics and therapeutics as well as water monitoring and remediation. Research at Mintek NIC involves the development of nano-based targeted drug delivery systems, nanocomposites materials for orthopedic applications, nanomaterials for the rubber industry, and modeling. Mintek NIC has formed partnerships with the Water Research Commission and the Medical Research Council in creating innovative platforms aimed at turning nanoscience into nanotechnology. Other Mintek NIC collaborators in the private sector include Goldfields, 180 degrees, and Real world Diagnostics. The chief aim of the collaboration is to address the innovation chasm through driving nanotechnology research into products and processes. The services rendered by Mintek include nanominerals research and risk assessment of nanomaterials and therapeutic applications. Mintek NIC has established university nodes in the Western Cape, the Eastern Cape, and Gauteng, which address the need to develop the much needed human capital and research capabilities in this field.

DST/MINTEK (South Africa)

The Nelson Mandela Metropolitan University (NMMU) hosts the Centre for High Resolution Transmission Electron Microscope, a national facility housing state of the art instruments needed for innovative nanoscale research. The centre has a full range of characterisation instruments, and it houses a suite of three new high-resolution transmission electron microscopes (HRTEM) with high resolution scanning and transmission as well as analytical and imaging properties. The partners and donors for the development of the centre include: DST, National Research Foundation (NRF), the Department of Education, SASOL, NMMU, NMMU Trust, and Dr Greg Olsen of GHO Ventures in the U.S. The centre offers its industrial partners (e.g., SASOL and NESCA, among others) state-of-the-art facilities to pursue research locally without having to travel to other countries. The Centre for High Resolution Transmission Electron Microscope, offers an opportunity for researchers in South Africa and across the continent to advance their research in the continent.

In 2008, the DST launched the Nanotechnology Public Engagement Program (NPEP). Its aim is to promote credible, fact-based understanding of nanotechnology through awareness, dialogue, and education to enable informed decision making on nanotechnology. It is funded by the Department of Science and Technology, and implemented by the South African Agency for Science and Technology Advancement (SAASTA), a business unit of the NRF. Its target groups include high school students, the scientific community, industry, and the general public. Its mission of promoting nanotechnology is achieved through: the production of resource materials (e.g., books, pamphlets, fact sheets, and featured articles in national and regional newspapers), participation in the media placement; issuing, monitoring, and evaluating grants; Media Round Table (MRT); conducting nanotechnology national facility tours; and participating in both national and international workshops, symposiums, conferences, as well as in science festivals.

South Africa has also signed a number of international agreements related to nanotechnology (e.g., with Russia, Iran, Algeria, Japan, India, Brazil), and is part of a number of international networks. One of the active agreements is a trilateral joint venture consisting of India, Brazil, and South Africa (IBSA), with the primary goal of promoting cooperation and collective learning in nanotechnology in the fields of agriculture, energy, health, and water. Projects in progress include the development of advanced materials for sensors, nanodevice applications, and the development of nanostructured organic-inorganic hybrid solar cells. In addition, a school on health and water was established in South Africa in 2010, and researchers from IBSA countries are collaborating in developing a nano-based drug delivery system for antiretrovirals.

Following the world wave of promoting nanotechnologies as an instrument for development, other African countries have embraced R&D in nanotechnology.

Other African national initiatives

Several African countries have developed research centres in the field of nanosciences and nanotechnology. Since 2006, Nigeria has implemented a project on environmental remediation carried out as a joint collaboration of the African University of Science and Technology and the Sheda Science and Technology Complex. Nigeria also has a project for a national nanotechnology initiative and is currently implementing a pilot project of the United Nation Institute for Research and Training (UNITAR).

Nanotechnology for environmental remediation is also being tested in Tunisia by the Tunisian Society of Nanotechnology for Environment, using nanotechnology-driven capabilities to monitor and purify water from the Medjerda River. The project is implemented in partnership with the National Agency of Environmental Protection, the Aquapole of the University of Liege in Belgium, and the European Commission.

Development of nanotechnology in other parts of the continent have been initiated with strong support from a number of international institutions and organizations, chiefly to promote high tech R&D, and setting up of production facilities in Africa. The UN Department of Economic and Social Affairs (DESA), for example, is engaged in providing support to the construction of high tech R&D and industrial parks in Ghana and Senegal, while Egypt and Kenya already have techno parks and Ethiopia is currently developing a similar project.

In Morocco, after the launch in 2006 of a National Initiative for Nanosciences and Nanotechnologies, an industrial high tech park was built in Rabat (Technopolis), mainly housing foreign corporations' facilities.

Technopolis (Morocco)

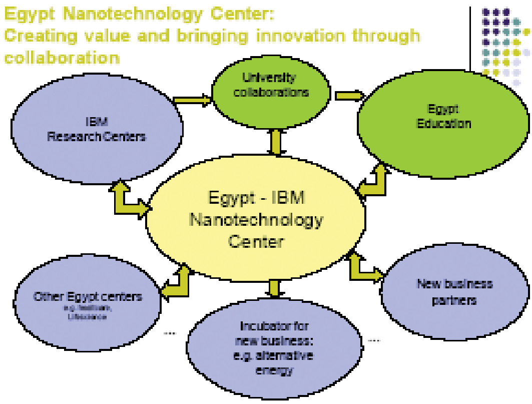
In 2011, Algeria incorporated nano-micro-electronics in the Microelectronics Division of the Advanced Technologies Development Centre, and a National Centre for Research on Nanomaterials and Nanotechnology was established at the University M´Hamed Bougara of Bourmerdes in 2011.

The European Union included in its 7th Framework Programme, a cooperation program with Africa. And since 2007, the INCONTACT (Network of National Contact Points for International Scientific Cooperation Activities) as well as the CAAST-Net (Coordination and Advancement of Sub-Saharan Africa-EU Science & Technology Network) has fostered nanotechnology as one of its focus areas. The European Development Fund also promotes cooperation between higher education institutions in Africa, the Caribbean and the Pacific regions. Other international organizations encouraging nanotechnology in Africa, include the World Bank, the UNESCO (United Nations Educational, Scientific and Cultural Organization), the TWAS (Third World Academy of Sciences), and the Committee on Scientific and Technological Cooperation of the Organization of the Islamic Conference (COMSTECH).

Other countries have developed agreements with corporations to establish nanotechnology centres or research projects. This is the case in Egypt where the Nanotechnology Research Centre was funded by the Information Technology Industry Development Agency and the Science and Technological Development Fund in partnership with IBM, and was launched in 2009. The partnership has R&D on microelectromechanical systems/nanoelectromechanical systems (Mems/Nems) as one of its main targets.

Several U.S and European universities, in partnership with foundations and corporations such as Gates and Siemens, are probing the possibility of developing devices for enhancing health provision, and water purification, mostly targeting the rural areas. These projects are carried out in a number of African countries, for example, Nigeria, Kenya, Cameroon, and Ghana.

Furthermore, several African countries anticipate launching nanotechnology initiatives in the second decade of the 21st century. In January 2011, for example, the National Nanotechnology Strategy was adopted by the Ministry of Science and Technology of Zimbabwe, in partnership with the Zimbabwe Academy of



Nanocentre (Egypt)

Sciences and Zimbabwe Research Council, to guide the local industry in taking advantage of this emerging technology. At the time of writing, the strategy is yet to be considered by the Cabinet Committee on Scientific Research, and in light of the prevailing country's economy, it may take some time before its implementation. Nonetheless, the Ministry of Science and Technology Development is promoting the development of nanotechnology in Zimbabwe, and plans to develop policies to drive nanotechnology as a part of the national scientific agenda.

The Importance of African networks

Some African networks also have had incidence in the development of nanotechnology R&D in Africa. FONAI (Focus Nanotechnology Africa Inc.) for example, is a non-profit organization aiming to foster education and scientific activities not only in Africa, but also in the U.S. and the Caribbean. The projects are financially supported by the U.S., African Union, European Union, Caribbean and Pacific countries, corporations, and international institutions, such as the World Bank. It was launched in 2006 with a 10 billion U.S. dollars budget for a 10 years time scope. It is still unclear whether this network will reflect African interests, and to what extent. The Nanosciences African Network (NanoAfNet), also launched in 2006, is a continental initiative sponsored by several countries from Africa and outside, with headquarters at the Materials Research Group of the iThemba Labs in South Africa.

In 2010, the ANSOLE (African Network for SOLar Energy) was launched with a three-fold objective:

- To foster research activities in the field of solar energy among African scientists working within, and out of Africa
- To encourage the use of solar energy in Africa to boost economic growth, development, and environmental protection
- To foster training and education in solar energy through skills development programs

To achieve its goals, ANSOLE has adopted several initiatives including: encouraging the undertaking of joint research projects, organization of meetings in Africa, promote exchange of scientists and students among different laboratories in the network, create a database on scientific and economic operators of solar energy in Africa, and establish regional research centers on renewable energies in different African regions.

The Inter-Islamic Network of Nanotechnology (generally known as NTNOIC) was created in 2011 by the Committee on Scientific and Technological Cooperation (COMSTECH), which is part of the Organization of the Islamic Conference. Several African countries are members of this network, which aims at linking all individual country networks undertaking research in various branches of nanotechnology. The Materials and Energy Research Center (MERC) in Tehran, Iran, has been appointed as the focal point of NTNOIC. The mission and vision of NTNOIC is to foster closer cooperation among Muslim countries in the development and management of nanotechnology resources. In pursuit of this mission, the organization seeks to generate ideas and policy directions through intensive dialogue, studies and research on a continuing basis. Its key objectives include:

- Promoting cooperation and encouraging of activities in the field of nanotechnology
- Supporting the transfer, development, and management of nanotechnology
- Laying the foundation for joint cooperation of scientific, industrial, and research centers as well as the researchers
- Preserving tangible and intangible resources
- Developing competent human capacity in this field
- All these activities should be carried between the member states.

Concluding remarks

Africa is in the infancy phase of developing nanotechnologies, having followed the recommendations from international organizations that high tech promotes international competitiveness. Research and development of nanotechnologies carried out in several African countries have yielded preliminary results which demonstrated the potential of this technology to address some of the MDGs (e.g., in water, health, and energy). Yet, African countries should also articulate a number of questions as the continent intends to exploit the benefits of nanotechnologies:

- Who will benefit from these technologies in a policy context where external competitiveness underpins the command force?
- How can risk assessment be developed in advance of the market pressures and before nanoproducts are widely spread in the African markets?
- What will be the consequences of training highly qualified personnel in a region where drain brain is epidemic and general education has been severely compromised over the last decades as a consequence of the economic policies imposed by the World Bank and the International Monetary Fund?
- How will disparities with the developed countries, perpetuated by previous technological advancements, be avoided in the context of nanotechnology era?

The South African approach to nanotechnology shows how the country's policy is influenced, albeit timidly, by national interests (e.g., risk assessment, strategic social focus). The South African approach may well deepen this incipient path against the world market forces, and be of significant importance for other sub-Saharan countries with respect to articulating the voices of under-developed and transitional countries in shaping global nanotechnology governance towards promotion of equality and equity. Table 2 gives an overview of what is going on in NT in Africa.

NANOTECH IN AFRICA. GOVERNMENTAL INITIATIVES AND INTERNATIONAL NETWORKS*

Country	Date/National initiatives
South Africa	2002. SANI (South Africa Nanotechnology Initiative)2006. National Nanotechnology Strategy. Department of Science and Technology 2007. Nanotechnology Environment Research Group: Council for Scientific and Industrial Research (CSIR) 2009. Nanotoxicology and risk assessment Unit. National Institute for Occupational Health 2009. NanoSchool 2009. IBSA (India, Brazil, and South Africa) trilateral agreement to foster R&D in nanotech. 2011. Centre for High Resolution Transmission Electron Microscope. Nelson Mandela Metropolitan University 2011 DST/CSIR Nanomedicine Platform was selected as ANDI Centre of Excellence for health innovation in Africa 2012. Nanotechnology and Nanoscience Interdisciplinary Masters Degree. University of Western Cape in Consortia with other three South African Universities
Morocco	2006. Initiative Nationale pour les Nanosciences et Nanotechnologies 2010. Technopolis. Industrial High Tech Park at Rabat - Mainly foreign corporations
Nigeria	2007. African University of Science and Technology (AUST) & Sheda Science and Technology Complex (Federal Ministry of S&T) projects on environmental remediation. 2007. Project for a Nigerian Nanotechnology InitiativeNanotech program at the National Agency for Science & Engineering Infrastructure.

Country	Date/National initiatives
Nigeria *(cont.)*	2007. Foreign Universities probing nanodevices, nanomedicine. 2011. Nigerian American Nanomedicine Org. (NANO). Partnership between National Universities Commission of Nigeria with the State Univ. of New York (SUNY-Buffalo) for health care applications
Egypt	2007. Egypt Nanotechnology Centres (EGNC). Information Technology Industry Development Agency (ITIDA), Science and Technological Development Fund (STDF) & IBM. Partners are Cairo University, Nile University (private), Mansoura University, and the Egypt-Japan University of Science & Technology. 2009. NanoTech Egypt for Photo-Electronics. Fabrication of nanomaterials
Tunisia	2009. Tunisian Society of Nanotechnology for Environment (NanoEcoTec) 2009. Project to monitor and purify the waters of the Medjerda River. Partnership: National Agency of Environmental Protection, NanoEcoTec, Aquapôle University of Liege, European Commission
Kenya	2009. National Committee on Nanotechnology, National Council of Science and Technology2009 Institute of Primate Research Human African Trypanosomiasis (HAT) programme which is collaborative effort between Flanders Institute of Biotechnology (VIB, Belgium), Instituto de Parasitologia Biomedicina (IPB-CSIC, Spain), University Eduardo Mondlane (UEM, Mozambique) and Foundation for Innovative New Diagnostics (FIND, Switzerland), which aims to address research into new diagnostic techniques and chemotherapy of HAT utilising the nanobody technology

Country	Date/National initiatives
Kenya *(cont.)*	2010. Some research groups at University of Nairobi & JKUAT (Univ. of Agric & Tech) 2010. Transnational corporations and foreign universities probing devices and technologies (Siemens Found, 2010 Mobile Water Treatment System (Siemens Found & SkyJuice & PureFlow & Global Nature Fund)
Ghana	2009. Technological Parks with support from the United Nations Department of Economic and Social Affairs 2009. Companies awarded funds from World Economic Forum for probing nano devices. 2010. Foreign universities probing devices in rural areas
Sudan	2010. Sudanese Nanotechnology Network
Ethiopia	2010. African School on Nanoscience for Solar Energy
Algeria	2007. Advanced Technologies Development Centre. Division of Microelectronics and nanotechnologies2011. National Centre for Research on Nanomaterials and Nanotechnology, University M'Hamed Bougara of Boumerdes
Zimbabwe	2012. Development of the National Nanotechnology Strategy to be followed by the declaration of 2012 as the year of Nanotechnology by Ministry of Science and Technology Development International African initiatives

Country	Date/National initiatives
FONAI	2006. Focus Nanotechnology Africa Inc. FONAI. A non for profit organisation to foster education and scientific activities in the US, Africa and Caribbean. Funds from the U.S., African Union, European Union, and Caribbean and Pacific countries. Group of 8 Industrialised Nations, Caribbean Community; several foundations: Gates, Rockefeller, Ford, Hewlett, MacArthur, Mellon, Carnegie, etc. Also the World Bank, NATO, France, Russia, Germany, Japan, Italy, Canada, African Union. 10 billion dollars for 10 years. Organisation of USEACANI (US-EU-Africa-Asia-Pacific and Caribbean Nanotechnology Initiative)
NanoAfNet	Nanosciences African Network. Continental initiative sponsored by several countries from Africa and outside, with headquarters at the Materials Research Group of the iThemba LABS in South Africa. It has 318 members and representatives from the different following countries: Algeria, Morocco, Tunisia, Egypt, Senegal, Guinea, Guinea-Bissau, Cote d'Ivoire, Burkina Faso, Congo, Ghana, Nigeria, Afrique Central, Cameroon, Benin, DRC-Congo, Sudan, Ethiopia, Uganda, Kenya, Rwanda, Tanzania, Mozambique, Malawi, Zambia, Namibia, Botswana, Lesotho, Swaziland, and South Africa.
ANSOLE	2010. African Network for Solar Energy
Inter-Islamic Network of NT	2012. Committee on Scientific and Technological Cooperation (COMSTECH). Organisation of the Islamic Conference (1981). More than a dozen African Countries are members.

** Illustrative, not an exhaustive register*

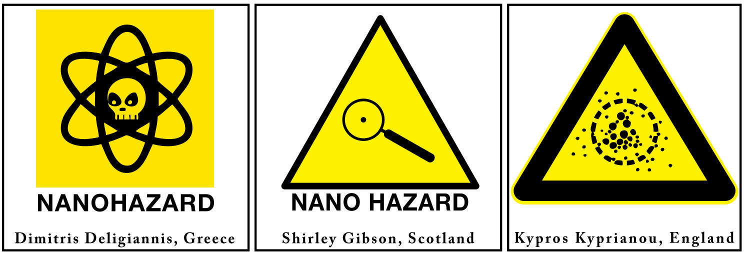
RISKS OF NANOTECHNOLOGY TO HUMAN HEALTH AND THE ENVIRONMENT

Traditional chemical management defines the risk posed by a substance as a function of a) the hazard characteristics of a specific substance, and b) the exposure to this substance (i.e., risk = hazard x exposure or R=HxE).

When information is lacking on either one of these two elements (the hazardous property of a substance or the level of human or environmental exposure to it), it creates uncertainty with regard to the risk posed by the substance, as defined in traditional chemical management. When converging scientific information points in the direction of hazardous properties, but are insufficient to fully characterize the risk, it is often refereed to as potential risks. This section will focus on the hazard characteristics of nanomaterials, while the next chapter will focus on exposure pathways.

Historical evidence supported by scientific findings show that all new technologies come with risks to human health and the environment, and nanotechnology is no exception. The increasing number of engineered nanomaterials and nanoproducts gives rise to increasing breath and extent of the potential risks posed to the human health and the environment. For example, engineered nanomaterials are of similar size range as exhaustion particles from engines combustion, and certain carbon nano tubes are in many ways similar to asbestos fibers, substances that are known to cause adverse effects to human health, namely, cancer and asbestosis. For the last 15 years, diverse stakeholders, such as non-governmental organizations, environmental activists, consumers, trade unions, and other social actors, have raised questions about the risks posed by nanotechnology and manufactured nanomaterials.

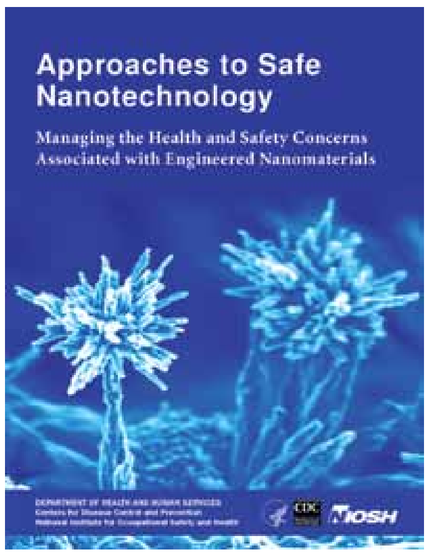
Unfortunately, the response consistently has been that those risks were largely unknown, that it was too early in the technology to evaluate the risks, let alone implement risk management measure, or even that there were no risks to the human health or the environment arising from nanotechnology and manufactured nanomaterials. The uncertainty about nano related risks has not impeded the rapid introduction of nanotechnology products into the market. On the contrary, most nanotechnology policies put in place in the last 10 years have been largely geared towards accelerating nanotechnology introduction into the markets with only very limited consideration of precautionary approaches to address the potential risks of this emerging technology.



Nanohazard symbol

Winners of the symbol for Nanohazard, called by the ETC Group during the Global Social Forum in Nairobi, 2007

As a result of mounting scientific evidence and sustained activism, a number of countries adopted national strategic frameworks in a (mostly failed) effort to balance the management of uncertain risks without compromising innovation and potential benefits. Examples of countries with such frameworks include the U.S., Germany, the Netherlands, and Australia, just to mention a few. There is an increasing number of ongoing research projects under the auspices of these frameworks to characterize, and mitigate these risks. In Africa, South Africa is currently developing a national strategy to address the potential risks of nanotechnology, and thereafter implement it in the same version as the National Nanotechnology Strategy of 2005. It is important to note, however, that despite the multiplication such initiatives for the responsible development of nanotechnology, only 5% of the funds dedicated to nano research are dedicated to identify, characterize, and mitigate the risks, as opposed to 95% of the funds dedicated to the development and marketing of new materials and products. This situation is unfortunate and detrimental to the safe, responsible, and sustainable development of the technology, which, in turn, conditions its wide adoption by downstream users and consumers. This situation requires that potential and demonstrated risks be addressed as a matter of priority.



NIOSH (USA)

More than ten years after the beginning of these initiative, and based on the scientific evidence produced, it can no longer be claimed that there are no risks or that too much uncertainty remains to start addressing them seriously.

An increasing number of databases hosting scientific articles and other forms of data about the health and environmental risks of diverse engineered nanomaterials commonly used in nanoproducts and industrial applications are becoming available. These initiatives aim to: first, collate data on risks of engineered nanomaterials from diverse scientific reports; and, secondly, establish how the accessible data can be applied to understand risks associated with nanotechnology. To this end, several databases on different types of engineered nanomaterials have been developed by various organizations internationally. A few examples are presented to illustrate this point (see Table 3).

The International Council on Nanotechnology (ICON), an institution at Rice University, in Houston, U.S., researches on the risks of engineered nanomaterials and hosts a database on the health, safety, and environmental effects of these materials. From 2000 to 2010, the database registered a sustained increase in published articles in the scientific journals dedicated towards understanding the potential risks of engineered nanomaterials to human health and the environment. By 2010, there were 563 peer reviewed and published scientific articles listed in the ICON EHS database..

Another database was developed by the Nanotechnology Citizen Engagement Organization (NanoCeo). NanoCeo database classified the risks reported in the scientific articles based on the type of the engineered nanomaterial. According to the NanoCeo database, between 2000 and 2010, there were 176 articles on the risks of carbon nanotubes, 190 on silver nanoparticles, and 70 for titanium dioxide, among other engineered nanomaterials. This accumulation of scientific knowledge no longer permits ignoring the reasonable suspicion that various engineered nanomaterials will pose a variety of toxic effects to human health and the environment. Although the overall picture is highly complex owing to the large diversity of engineered nanomaterials and their distinctive forms, the section below presents a few examples to illustrate the potential risks of engineered nanomaterials.

Among others, potential benefits of carbon nano tubes are often hyperbolically presented in scientific and media reports, such as reports presenting the possibility of attaching carbon nanotubes or buckyballs to carcinogenic cells in order to kill them off without side effects, thus transforming cancer into a treatable illness. Consideration of their potential risks is however, often overlooked. In 2008, Polland and collaborators reported that in the abdominal cavity of mice, carbon nanotubes have similar effects as asbestos fibres, and are hence carcinogenic.

Similarly, in 2008, Takagi and collaborators demonstrated that carbon nanotubes produce mesothelioma in mice. Even single-walled carbon nanotubes, which are much more perfect, homogenous, and of higher purity than multi-wall carbon nanotubes have been shown to cause toxic effects to mouse. Chou and co-workers showed that single-walled carbon nanotubes produced granulomas in the lungs of mice. Even protozoa that ingested carbon nanotubes showed higher mortality rates, became paralyzed, or at least had limited mobility according to published findings of Ghanfari and collaborators. Other studies have also demonstrated that as the size of carbon nanotubes, nanoparticles of black carbon and other materials decreases, the allergic responses also increase.

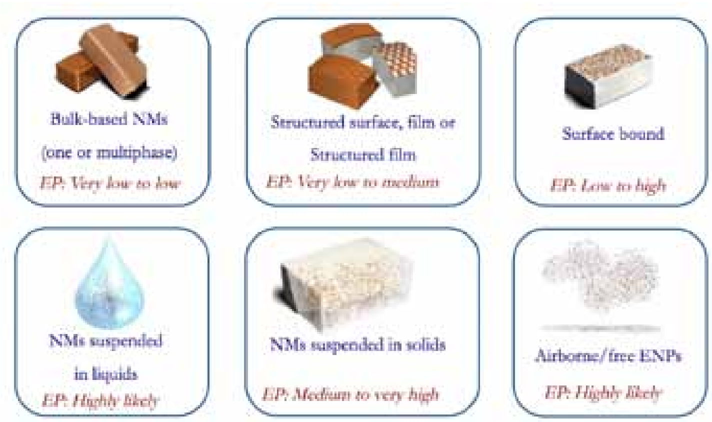
Producers of these materials and some scientists argue that nanotubes are firmly (fixed) embedded in product matrixes and are not, therefore, available for direct exposure, such as the isolated particles tested in the toxicological studies, and are thus less likely to interact with humans or the environment during the application phase of the products. They conclude that these materials pose no risks to the consumers. This, however, is correct only to a certain extent. Carbon nanotubes (and other manufactured nanomaterials) are widely used in many different industries, from cosmetics, automobiles, and cellular batteries, to sport clothing, and equipment. Each of these products has a distinct life cycle which can lead to exposure. The production of carbon nanotubes at industrial settings and their incorporation into the products for example, holds a serious possibility for workers to inhale those particles, before they are integrated into a matrix.

Similarly, trash burning of textiles, batteries, and other nanotechnology products can separate carbon nanotubes from the product matrixes, and because they do not break down at temperatures below 850oC, they can survive burning and can then be inhaled or introduced into the food chain. In addition, manufactured nanomaterials can also wear off from products such as clothing when the garment in which they are embedded wears down, and this can imply direct contact with human skin and hence penetration. These possibilities were considered, analyzed, and reported by Kohler and collaborators in 2008.

In 2009, Takeda and collaborators demonstrated that titanium dioxide can cause hereditary damage. They also clearly demonstrated the possibility for nanoparticles to cross the placental barrier and cause a reduction in sperm production in the male embryos. Moreover, in terms of genetic effects, Yang and collaborators asserted, in 2009, that silver nanoparticles can interact with genetic material, modifying it and affecting its replication.

As a result of increasing concerns on the potential penetration of engineered nanomaterials from cosmetics to the human skin, in 2010, Wischers and Musee examined the available scientific data on the subject. Their findings were that engineered nanomaterials do penetrate the upper part of healthy skin where they can be visualized but do not penetrate deeper into the viable layers of the epidermis. At the same time, the opening around the hair follicle where sebum is located often acts as a reservoir and engineered nanomaterials accumulate there till they are removed with the sebum flow.

Classification of potential exposure of engineered nanomaterials



Source: Wischers and Musee, 2010

In 2009, Sharma and collaborators reported that nanoparticles of zinc oxide, commonly used for sun blocking in cosmetics, caused damage to the DNA of human epidemic cells that were tested at lower concentrations than is typically used in cosmetics. It also generated oxidative stress responsible for the production of free radicals responsible for causing skin cancer. Furthermore, in another study, Deng and collaborators affirmed that nanoparticles of zinc oxide have the potential to damage and kill brain stem cells of lab mice. It is known that nanoparticles can cross the cell barriers, travelling via the blood or lymphatic system, and even enter into the brain by olfactory nerves, crossing the blood brain barrier, as demonstrated by Oberdorster and colleagues in 2005.

These few examples (selected and presented from a much larger body of evidence), and increasing body of published scientific evidence, points to likelihood of toxic effects to the humans from a number of manufactured nanoparticles. In this context, these risks merit to be addressed further in order support long-term responsible exploitation of nanotechnology without leaving a legacy of adverse effects to the society.

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PLT is the exclusive agent for the exciting NutraLease™ nano-encapsulation technology for the functional food marketplace, NutraLease™ is a delivery system for food and beverage applications.

Source: www.pithomas.com/PLTbrando/NutraLease2.htm visited January 2007

The toxicity of nanoparticles is not limited to human health, but also affects other forms of biological organisms in the environment. A body of evidence shows the increasing accumulation of nanoparticles in ecosystems with potential for transfer to higher organisms through the food chain which may result in exposure of humans through foods such as fish and vegetables, among others. For instance, numerous scientific reports have illustrated the possible toxic effects of engineered nanomaterials to the organisms found in the environment such as: fish, bacteria, earthworms, and snails, among others.

In 2007, for example, Roberts and co-workers reported that water fleas (Daphnia magna) that consumed carbon nanotubes encompassed in lipid had blocked digestive tracts and mortality was observed. In 2008, Leroueil and collaborators demonstrated that various organic and inorganic nanoparticles produced imbalances to plants and animals. For example, titanium dioxide, a key ingredient for the cosmetics industry has been reported to have damaged algae and also caused fish to become completely disoriented, according to a research report from Federici and collaborators in 2007.

Within the scientific community, some have advanced the argument that the toxicity demonstrated in vitro does not occur after the same engineered nanomaterials are incorporated into final products. Again, this form of generalization is problematic in light of the diversity in the manner and form in which these materials are incorporated in numerous and diverse products. It is therefore important to distinguish between engineered nanomaterials that are suspended in liquids, solids and those that are firmly integrated into the solid matrix.

Following this classification protocol, the National Institute for Occupational Safety and Health of the United States (NIOSH) has recognized that the engineered nanomaterials that present the most risks are in powders of solid states, dispersed or condensed into powders as they are used in cosmetics for example. The second level of risk is presented by manufactured nanoparticles suspended in liquids, like nanotubes in water. The third level of risks arises from nanoparticles integrated into networks and matrixes, such as thin films. Finally, those posing the least risk are those incorporated into nanostructures, like in metal alloys. This analysis, however, does not fully consider the possibility of transformation and release of the particles at different stages of their life cycle.

The degree of risk is also related to the different possible ways in which nanoparticles interacts and enter into the organisms or organs. In general, humans are exposed to engineered nanomaterials either through, ingestion, inhalation, or penetration through the skin. Manufactured nanoparticles can be injected or can dissolve for example in the case of implants and medical products. It is also important to consider the possibility of accidents, like fires or explosions, which can also expose unprotected individuals to the risk of engineered nanomaterials, which to date is yet to be studied in great depth to allow any form of generalization of what can cause risk or not.

Finally, although nanotechnology risks are being explored fairly early in their development compared to other technologies, commercialization of product and thus human and environmental exposure is still happening without due consideration for their potential risks.

EXAMPLES OF INSTITUTIONS HOSTING DATABASES USEFUL FOR SUPPORTING RISK ASSESSMENT OF ENGINEERED NANOMATERIALS.

Center for the Environmental Implications of NanoTechnology (CEINT)

Duke University

Direct and conduct collaborative research studies in behaviour of nano-scale materials in complex systems including fate, transport, exposure, and toxicity. The center is involved in developing inventories of key properties of ENMs that influence their fate and transport, and development of predictive toxicity models.

http://www.ceint.duke.edu/

PEN of Charities

Woodrow Wilson International Centre for Scholars

The Project on Emerging Nanotechnologies – nanotechnology inventories on the global trend of the type and quantity of manufactured nanomaterials. Most of the information is provided voluntarily by global industries.

Silver Nanotechnology Commercial Inventory – database of silver nanotechnology in commercial products

http://www.nanotechproject.org/

Nanomaterial Stewardship Program (NMSP)

United States Environment Protection Agency (US EPA)

Voluntary testing and inventory development of engineered nanoscale substances manufactured, imported, processed or used, in collaboration with volunteer companies.

http://www.epa.gov/oppt/nano/stewardship.htm

International Council on Nanotechnology (ICON)

Non-commercial organization affiliated to the United States National Science Foundation Center for Biological and Environmental Nanotechnology (CBEN), Rice University

Develops and communicates information on potential environmental and health risks of nanoscience and nanotechnology that would foster risk reduction and maximize socio-economic benefits

http://www.icon.rice.edu/

Center for Environmental Implications of Nanotechnology (UC-CEIN)

University of California

Direct and conduct collaborative research studies in environmental, health and safety impacts of ENMs, and generate data to develop risk-ranking models based fate, transport and toxicity. An inventory of data generated that is accessible through journal articles provides information to researchers and scholars on the ENMs toxicology.

http://www.cein.ucla.edu/

The available data indicate the diversity of engineered nanomaterials risk profiles to humans and the environment (e.g., while some manufactured nanomaterials show elevated risks, others show low toxicity or no specific risks), but taken together, they point to the critical need to develop a precautionary approach to the development of this technology, as part of the regulatory-driven measures..

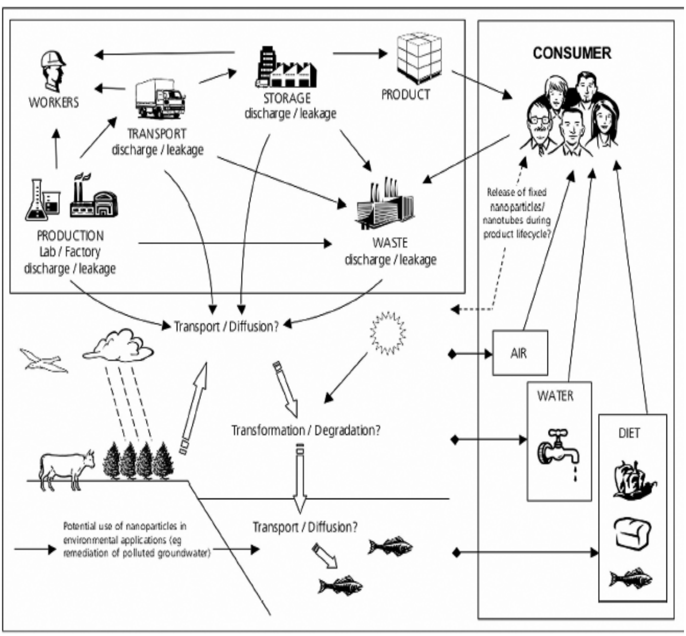
> The precautionary approach was first formalized in principle 15 of the Rio Declaration on Environment and Development from the 1992 Earth Summit which read: *"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."* This approach gave rise a precautionary principle. This principle does not have a globally agreed formulation, but was summarized in 1998, by a meeting of scientists, lawyer, policy makers, and environmentalists as the following: *"When an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically."*

A precautionary approach would ensure that this technology does not leave a legacy of human death, health impairment and environmental damages. Rather, nanotechnology could provide a unique test platform of how risks of a rapidly emerging technology should be handled proactively to harness its greater good for the society.

EXPOSURE OF HUMANS TO ENGINEERED NANOMATERIALS AND RISK MANAGEMENT APPROACHES

As indicated above, risk is characterized by the product of hazard and exposure. The aim of chemical risk management is to protect humans from the adverse effects of a given substance. In order to adequately manage the risks of engineered nanomaterials (when they can be) to humans and the environment, it is important to understand how humans and the environment can be exposed to these materials at various stages of their life cycle. It is therefore important to identify the exposure scenarios that may occur during the entire lifecycle of engineered nanomaterials, (i.e., during the production, transportation, storage, use, and disposal phases) so as to support appropriate risk assessment and risk management.

In 2004, a report by the UK Royal Society on Nanosciences and Nanotechnologies voiced concerns about the potential health and environmental risks of engineered nanomaterials. The figure below illustrates the potential exposure pathways of engineered nanomaterials to the human and environments that were identified in this report.



Exposure pathways of nanomaterials

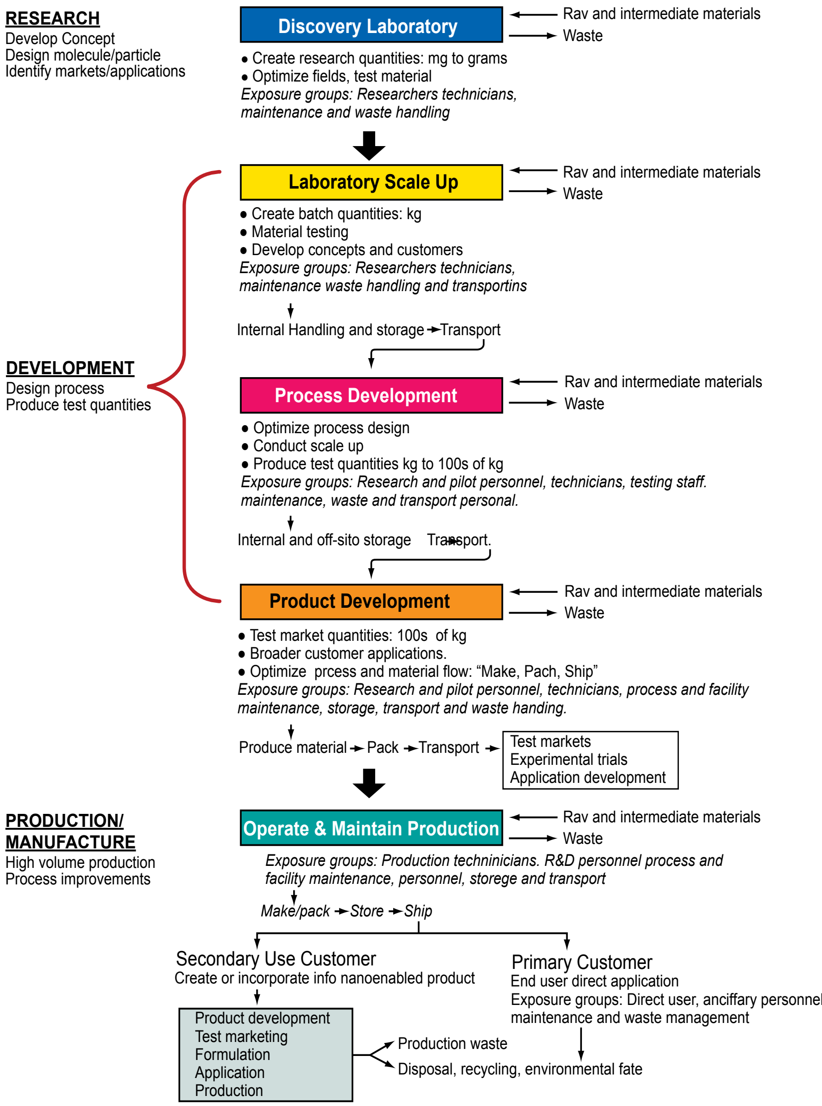
Workers currently present the highest degree of exposure to engineered nanomaterials. Workers can be exposed through various operations such as release of engineered nanomaterials as aerosol in non-closed systems, during the handling of different types of engineered nanomaterials suspended in powders and liquids with no or poor protective equipment, in cleanup operations, during maintenance of equipment and processes used for the production, and finally, when handling waste streams containing engineered nanomaterials (generally called nanowastes).

A number of reports highlighted that most engineered nanomaterials are and will continue to be produced mainly by small business. Such small businesses in Africa and around the world have a relatively poor record on workers safety and protection from exposure to harmful chemicals in occupational settings. There is no compelling evidence to date suggesting that the production of engineered nanomaterials will be different, nor that the protection of the workers will be handled differently.

Furthermore, in light of increasing trends on the re-location of industries owing to increasingly stringent occupational and environmental legislations in most developed countries through foreign direct investment (FDI) platform, it is clear that nanotechnology industry will not be an exception. Therefore, as the number of African countries using and or producing nanotechnology increases, the issues on occupational exposure, use, and disposal of engineered nanomaterials merit careful consideration to ensure that no adverse effects result from the development of nanotechnology.

Schulte and collaborators from NIOSH presented the diagram below to outline the risks of occupational exposure to nanomaterials. Although the associated risks to the environment and consumer do not appear in the diagram, they can logically be deduced at each stage. For example, all the stages demonstrate the presence of waste, as shown on the far right of the diagram. Such waste eventually end-up into the environment as the final sink. Mechanisms to prevent the release of engineered nanomaterials to the environment are inadequate at the moment as has recently highlighted by Musee in 2011.

Workplaces with potential for occupational exposure to engineered nanoparticles



Note: The diagram illustrates the life cycle of nanomaterial from laboratory research development through product development, use, and disposal. Each step of the life cycle represents opportunities for potential worker exposure to nanoparticles.

Source: Schulte, et al. (2008).

The diagram also shows that within every stage humans are subjected to various degrees of exposure, and ultimately risk depending on the nature of their occupation. At the research stage, for example, researchers and technicians are exposed to engineered nanomaterials risks, including during the maintenance, waste handling, and storage. Nanowaste transporters from the laboratories are likely to be exposed to engineered nanowastes in the waste streams as well.

In the second stage, the diagram illustrates large-scale development or production of raw nanomaterials. Workers directly involved and exposed include: researchers, technicians, pilot personnel, testing staff, facility maintenance crew, and personnel responsible for storing and transporting nanomaterials to industries for incorporation into products, as well as workers handling waste.

The next phase of exposure is during the production stage, manufacturing of intermediates, and final products. Nanomaterials are incorporated into various industrial processes, with the final objective of endowing the product either for commercial or utilitarian advantage.

Consumer direct exposure then occurs with the use of nanoproducts. It leads to different degrees of risk depending on the product type and the form as well as route of exposure (e.g. inhalation, ingestion, dermal contact, etc.). Relationship between exposure to nanomaterials and health risks is controlled by multiple factors. These include inherent nanomaterials properties, degree of exposure, environmental conditions, and the use of protective systems such as clothing and other preventive methods.

The body of evidence pointing to risks associated with exposure to engineered nanomaterials call for the development and implementation of prudent approaches to control the exposure, in particular in occupational settings. In order to deal with engineered nanomaterials proactively, the approaches below should be implemented as part of a precautionary approach to limit exposures and to increase our collective understanding of the potential risks of engineered nanomaterials.

Systematic health surveillance of the workers in occupational settings: These should comprise of hazard surveillance, medical surveillance as well as transversal health monitoring of workers. In the African context, because of the limited resources, the governments should institute as a minimum, a mandatory requirement for industries manufacturing engineered nanomaterials to undertake a health monitoring of their workers. This requires independent bodies to validate the data generated as part of the health surveillance.

Labelling requirement for all nanoproducts: The absence of information relating to the presence of nanomaterials for most nanoproducts in the market today, including in particular in Africa, is detrimental to the health and right to know of workers and consumers. To guarantee the respect of this right to know, all products containing nanomaterials, whether they are manufactured in Africa or imported should be legally required to be adequately labelled. Further information including premarket testing data (in certain jurisdiction is regarded as “pre-manufacturing data”) demonstrating that the product is not hazardous, should be provided along the supply chain. This would allow the development of control measures.

Exposure control measures and personal protective equipment: Specific measures should be made mandatory to ensure that workers are not exposed to hazardous materials. Examples of such mechanisms include the use of engineering controls (e.g., exhaust ventilations, process design, design of benign engineered nanomaterials, use of wet chemistry during production, closed system) and administrative controls in form of policies that would reduce the exposure of workers to the engineered nanomaterials (e.g., good housekeeping practices, systematic scheduling of workers performing tasks in areas of high exposure to limit/minimize the exposures to workers, and also the numbers expose). Moreover, the provision of adequate personal protection equipment (PPE) to workers, such as respirators, gloves, and protective clothing, may also be warranted. It is critical that the provision of PPE is not seen as a substitute for the engineering controls but rather as an essential measure in the face of remaining uncertainty relating to the risks of engineered nanomaterials.

IMPLICATIONS OF NANOTECHNOLOGIES FOR EMPLOYMENT

The question of impacts on employment has not yet entered into the research agendas on the social implications of nanotechnology. Even though there are currently relatively few products, industries, and workers involved in nanotechnology compared to other industries, it appears clear that this technology is high tech and sophisticated, which deepens the trend to reducing workforces and automate the processes of production and services, a trend which began with the microelectronic revolution and resulted in a dramatic reduction of employment in many sectors of the economy.

Telephone Central in 1930 and telephone central today

Nanotechnology products that are already on the market allow us to identify three common characteristics: the products have multiple functions that previously required more than one product (multifunctional), the products remain useful longer, and the products use fewer raw materials. Some products combine two or three of these characteristics. Taken together, this means that manufacturing these products will lead to decreased demand for workers. In addition, these innovations reduce the demand for traditional products that compete with them.

The food industry illustrates the multifunctional aspect of nanotechnology well. Food corporations add vitamins, collagen, photo extracts and other nano-encapsulated substances to food and drinks. George Weston Foods adds the fatty acid omega-3 to one of the most popular brands of white bread in Australia. The Qinhuangdao Ialji Ring Nano-Product Co. Ltd. enriches its nano-tea with selenium. These are examples of nutraceutical products that simultaneously have aesthetic, nutritional, and medicinal functions, which were previously delivered with different products.

CHT Brazil Chemical (Brazil Quimica) produces Nouwell E, a textile fibre that has cosmetic functions, transferring vitamin E to the skin and releasing perfume. The Life Shirt, for example, monitors the respiratory, cardiac activity, and changes in posture and transfers this information to a portable computer.

These multifunctional products demonstrate a trend of merging of productive branches, and signify a reconfiguration of current industrial sectors and workforce distribution. It is likely that there will be fewer jobs available and a demand for less specialized employees. The aggregating of functions also brings the centralization of transportation, distribution, marketing and commercialization, which possibly results in fewer employees in these fields as well.

Many nanotechnology products are used to make goods more durable on the market. EMBRAPA developed digestible films with nanoparticles to cover macadamia nuts to block the entrance of oxygen and water vapour, making the nut last longer. Miller Brewing uses bottles from a plastic that incorporates nanoparticles of ceramics to establish a barrier blocking molecules of carbon dioxide from escaping and molecules of oxygen from entering the bottle, keeping the beer fresh and giving it a shelf-life of up to six months. Scientists from companies like Kraft, Bayer, and Kodak are developing a variety of packaging materials that absorb oxygen, detect pathogens in foods, and alerts the consumer when the food is spoiled.

By using nanotechnology, companies can produce products that have a longer storage life in supermarkets. This will help companies because it will reduce the amount of products wasted. In addition, the economic activities revolving around transportation, storage, quality assurance, shelf maintenance and other functions will be reduced. With this increase efficiency, fewer workers will be required. What sort of public policy are governments considering to remedy this loss in employment? None thus far.

Other products exploit the advantages of new materials produced by nanotechnology to substitute for other raw materials. Adidas uses carbon nanotubes to produce running shoes with lighter weight traction systems. Easton Sport uses carbon nanotubes to produce bicycle frames. Elko's Invisicion uses the conductive properties of carbon nanotubes in the manufacturing of transparent covers for flat screen (TVs) with OLED light and for solar cellular phones. Nanotubes also could replace the copper wires that transmit electricity, modifying all global commerce. Braskem produces a resin of polypropylene with added nanoparticles of ceramic that replaces metals and other plastics in the automobile and domestic appliances industries.

These changes in the materials used alter the distribution of the workforce between different sectors. Given that the exploitation of raw materials is tied to geographic characteristics, on a national and international level, the changes in demand will bring about a new regional and international distribution of employment opportunities.

SAICM AND THE RECOMMENDATION FOR COUNTRIES OF AFRICA

SAICM is a voluntary agreement, approved in Dubai, in the United Arab Emirates in February 2006 at the International Conference on Chemicals Management. This strategic approach is composed of a High Political Declaration, a Global Political Strategy and a World Plan of Action, which all together constitute a regulatory framework that pursues the following global objective: that chemical substances are produced and used in a way that significantly reduces the impact on the environment and health. SAICM is administered by the United Nations Environmental Program and with the World Health Organization, run the Secretary of this agreement.

SAICM is the only multilateral international space where the development of chemical products over their entire life cycle, including the impact on occupational, and environmental health is discussed. SAICM's participants includes industrialized countries, countries with economies in transition, and developing countries, as well as intergovernmental organizations from the Inter-Organization Program for the Sound Management of Chemicals), and civil society groups with public and industrial interests. SAICM decisions are adopted by consensus. Although it is not legally binding, each member country has the responsibility to develop a national plan to reach SAICM objectives, including via the implementation of specific activities in the Global Plan of Action.

At the Second International Conference on Chemical Management (ICCM) held in Geneva in 2009, governments and NGOs recognized and decided that nanotechnology and engineered nanomaterial are a new emerging policy issue that should be addressed by SAICM (Resolution 11-4-E). The resolution includes a specific focus on assisting developing countries and countries with economies in transition so that they maximize the benefits of nanotechnologies while minimizing its risks. In addition, it calls on government and industry to maintain a dialogue with the workers and their representatives during the creation and implementation of regulations, to protect human health and the environment, and to maintain a more general public dialogue with all interested sectors.

Within this framework, regional awareness raising and capacity building workshops on nanotechnology and nanomaterial were organized in Africa, Latin America, and Asia by the United Nations Institute for Training and Research (UNITAR) and the Organization for Economic Co-operation and Development (OECD). In Africa, such workshops were held in Abidjan, Côte d'Ivoire, from January 25-29, 2010, and in Nairobi, Kenya, from April 5-8, 2011. In these regional meetings series of recommendations regarding nanotechnologies and engineered nanomaterial policies were unanimously adopted. Furthermore the Nairobi workshop discussed the inclusion of specific nano related activities in SAICM's Global Plan of Action. This discussion was based on the proposal from the Swiss government.

Below is a general summary of the overarching themes and key proposals that were included in the African resolutions along with some additional commentaries. In these resolutions, African stakeholders to SAICM called for:

The application of the precautionary approach to the complete life cycle of engineered nanomaterial. The resolution, adopted in Abidjan, recommended to include the "critical role of the precautionary approach in addressing the issue of nanotechnology and manufactured nanomaterials throughout their life cycle" (resolution 1-a). One must remember that applying a precautionary approach forms a part of Article 15 of the Declaration of the United Nations Conference on Environment and Development in Rio de Janeiro 1992 signed by all countries. The application of the precautionary principle as the general principal in risk management was also a recommendation unanimously approved by governments, industry and other non-governmental groups in the declaration on nanomaterial and nanotechnology from the International Forum on Chemical Safety (IFCS) held in Dakar, Senegal in September 2008; unfortunately, at ICCM2, in 2009, the pressure of developed countries and industry succeeded in preventing this principle from being invoked. Regardless, this principle should be included in the design of national policies on nanotechnology. The Abidjan resolution goes even further, calling for the implementation of the "no data no market" principle, meaning that adequate risk assessment data should be made available prior to the introduction into the market and commercialization of nanotechnology products (Abidjan resolution "1) c).

Transparency and the recognition of the right of consumers and workers to information. The resolutions demanded that producers provide adequate information on the contents of engineered nanomaterial, so that authorities and consumers know the potential risks through the registration and labeling of products (Abidjan resolution "1) d, l, and o,"; Nairobi, resolution "1) a-i, a-iii; 2) b). Resolutions further called for the mandatory labeling of products containing nanomaterials (Abidjan resolution "1-o"; Nairobi resolution 2) b) to allow consumers free and informed choice on what to consume or not. This language is reminiscent of Covenant 154 on the Collective Bargaining by the International Labor Organization which recognizes the right of unions to access information from producers.

The strengthening of capacity to effectively evaluate the potential risks of engineered nanomaterials, especially for vulnerable groups, such as children, pregnant women, and elderly individuals (Abidjan resolution "1) f); Nairobi, 2) a). It must be added that these evaluations must be done within the establishment of national and regional institutions so that they are evaluated independently from industry.

The incorporation of multisectoral participation, particularly from workers and health sector, in the elaboration of policies, programs and training materials relating to occupational health and environmental safety of nanotechnologies and engineered nanomaterials (Côte d'Ivoire resolution "1) q). Participation of workers, consumers and other groups of public interest is essential to elaborate policies of science and technology to ensure that nanotechnology policy is oriented towards satisfying social needs, training the workforce, and providing remedial measures for resulting technological unemployment. Workers must know when they are handling nanoparticles and should also be consulted regarding safe labor programs. Workers, as well as patients, who are exposed to nanoparticles or nanodevices should be informed (Côte d'Ivoire resolution "1) l, m, n).

The establishment of trade regulations such as the development of customs codes specific to engineered nanomaterial. Resolutions also included a call for residual waste that contains engineered nanomaterial not be transferred to counties who do not have the capacity to appropriately dispose of them, and propose the recognition of countries' right to accept or reject the importation and use of engineered nanomaterial and products that contain them, with the purpose of minimizing risk. The resolution finally suggests the necessity to regulate transportation of engineered nanomaterials on the basis of safety criteria (Abidjan resolution "1) g; 2; Nairobi, 2) f).

This emerging issue was further discussed at the Open Ended Working Group of SAICM held in Belgrade, Serbia, on November 15-18, 2011. Discussions looked in particular at the proposal to add specific nano activities to the SAICM GPA and at future nano-related work after the third conference of the ICCM (due to take place in Nairobi in September 2012). During the discussion, calls from the African region were not seriously considered and most propositions for new specific nano activities to be included in the GPA were opposed by the chemical industry and a number of industrialized countries, including the U.S., Canada, Japan, and Australia. For this reason, it is critical that civil society organizations demand that governments in Africa consult with public interest organizations and represent general interests above commercial interests in the future discussions on nanotechnology at the third conference of the ICCM. African countries must defend their positions, as expressed in both resolutions adopted in 2010 and 2011 and support their recommendations for the inclusion of nano activities in the GPA. Africa, as a region, should coordinate with other affiliated regional groups, such as the Latin American region, to accomplish the general strategic objective of SAICM to significantly reduce the risks in the production and use of engineered nanomaterials and increase the response to the real social necessities of African countries.

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