Nanotechnologies risk assessment: a perspective from developing countries

Musee, N
Natural Resources and Environment, RSA

7th Congress of Toxicology in Developing Countries, Sun City, South Africa, 6th – 10th September, 2009

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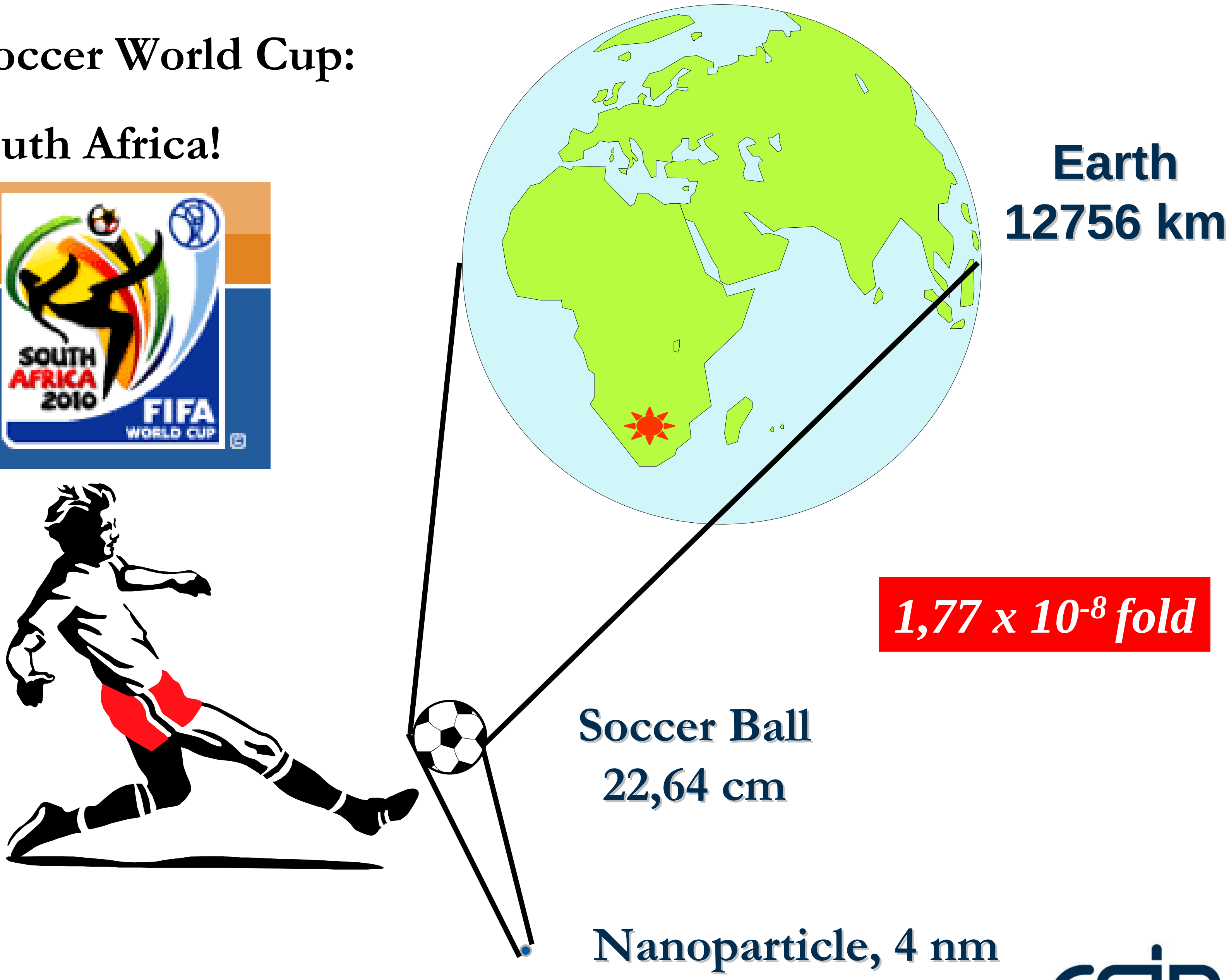
2010 Soccer World Cup:

South Africa!



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Problem Defining Questions

- Why the need for nanotechnologies risk assessment now?
- What are the present global endeavours in this field concerning risk assessment of nanotechnologies?
- How are nanotechnologies likely to impact developing countries? Benefits and Challenges
- What is the present risk assessment status in the developing countries concerning Waste Management ?
- What are probable impact scenarios of introducing nanotechnology into developing countries with respect to risk assessment?
- What are the possible intervention mechanisms to promote environmental stewardship and equitable societal benefits in the developing countries?

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Why Risk Assessment Now for Engineered Nanomaterials Materials (ENMs)?

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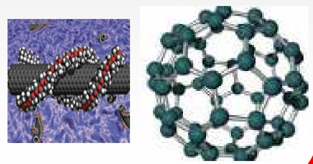
Ecological systems have not evolved in the presence of ENMs: therefore adverse affects by such new materials is highly probable

10,000 BC	1,000 BC	0	1,800	1,900's	2,000	2,010
Stone & wood	Iron	Cement	Steel	Polymers Composites	Nano Materials & Nano Composites	Bottom up Design?



Technological evolution timeline

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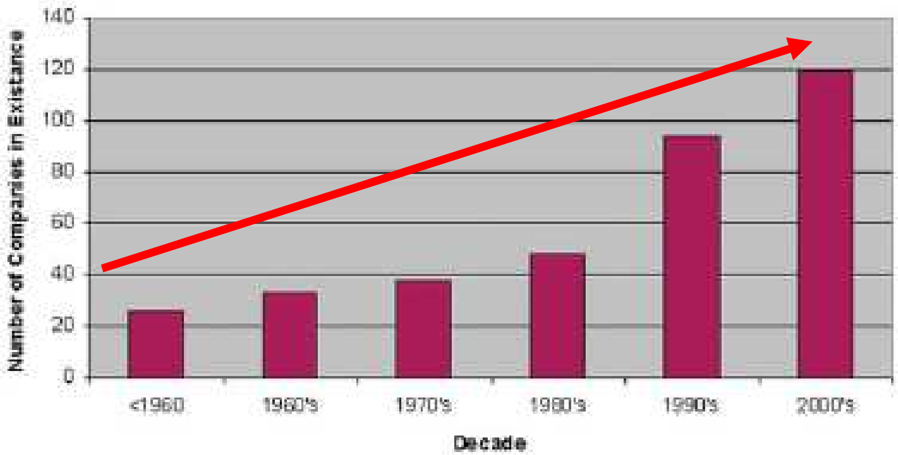
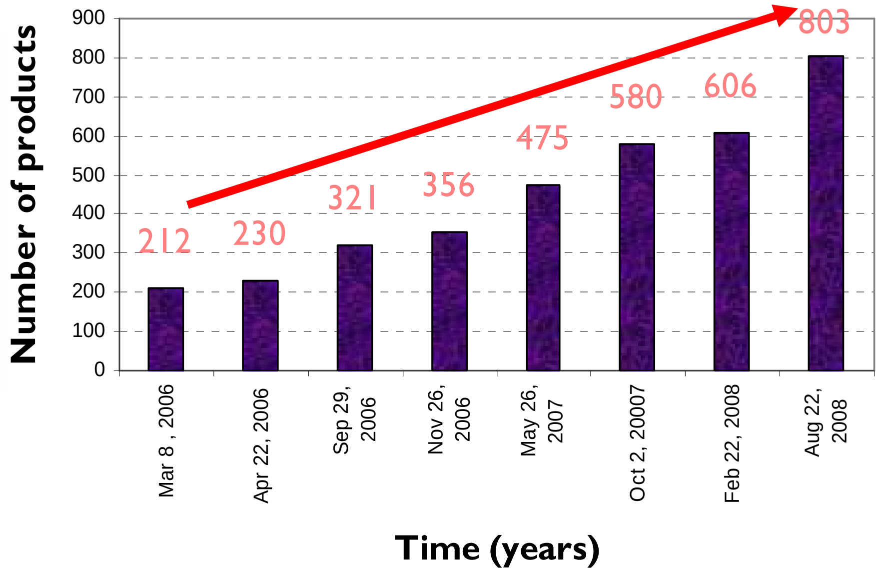
Company and Nanoproducts Growth

A



Global growth of companies fabricating NMs (Pitkethly, 2003)

B



Consumer nanoproducts (Woodrow Wilson International Centre for Scholars, 2008)

Comment: Trend for nanowastes generation is obvious

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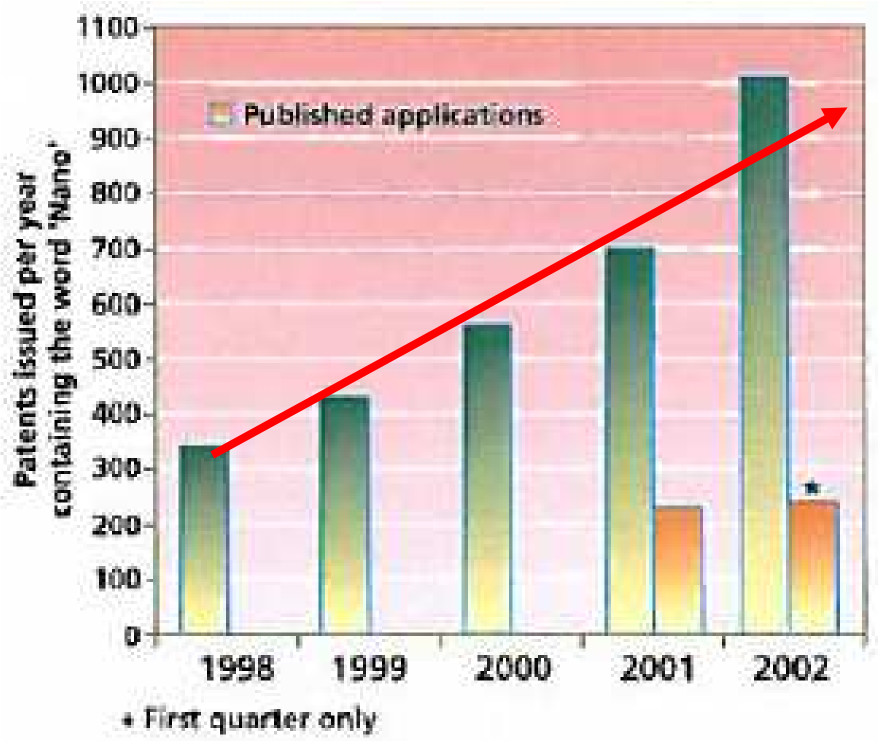
Growth of Nano-related Patents

C



Paull et al., Investing in nanotechnology, Nat Biotechnol 2003;21(10), 1144–1147..

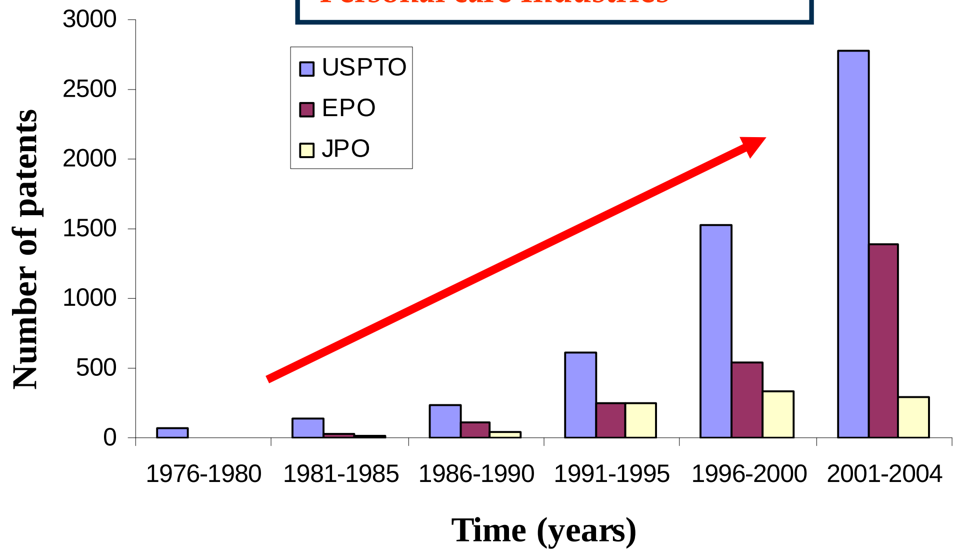
D

USPTO: 55.7%

EPO: 65.2%

JPO: 45.5%

Patents held by Electronics and Personal care Industries



Nano-related IPs (Li et al., 2007; Huang et al.,2004)

Comment: Trend for nanowastes generation is obvious

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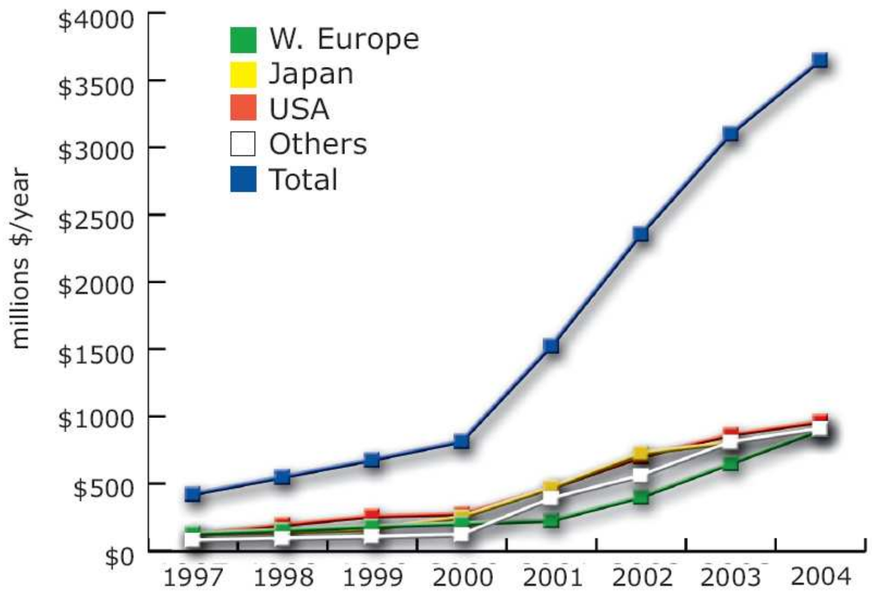
Global Nano R&D and Venture Capital

E



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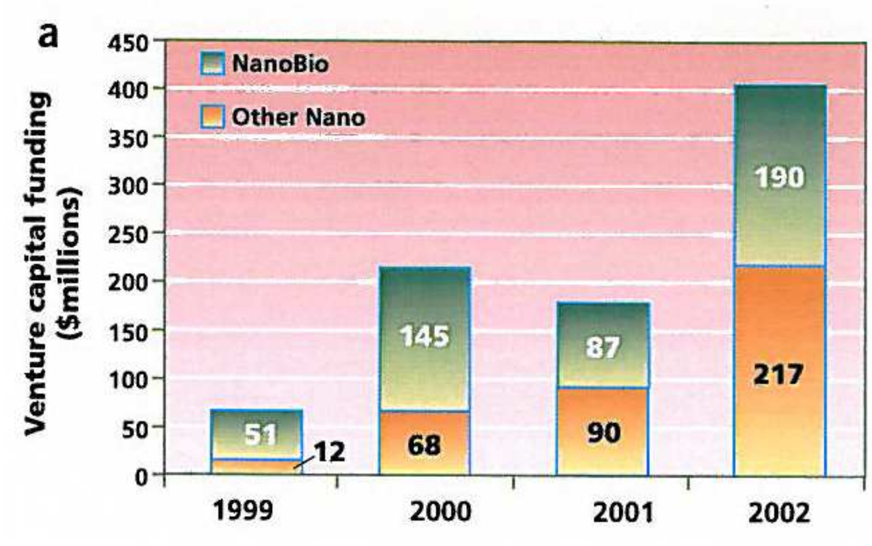

- Currently less than 1% on SHE aspects
- Recommended level ca. 10%
- South Africa – no funding yet

Paull et al., Investing in nanotechnology, Nat Biotechnol 2003;21(10), 1144–1147..

Source: M.C. Roco. 2004. *Nanoscale Science and Engineering: Unifying and Transforming Tools.* AIChE Journal, Vol. 50, Issue 5, pp. 890-897.

Comment: Trend for nanowastes generation is obvious

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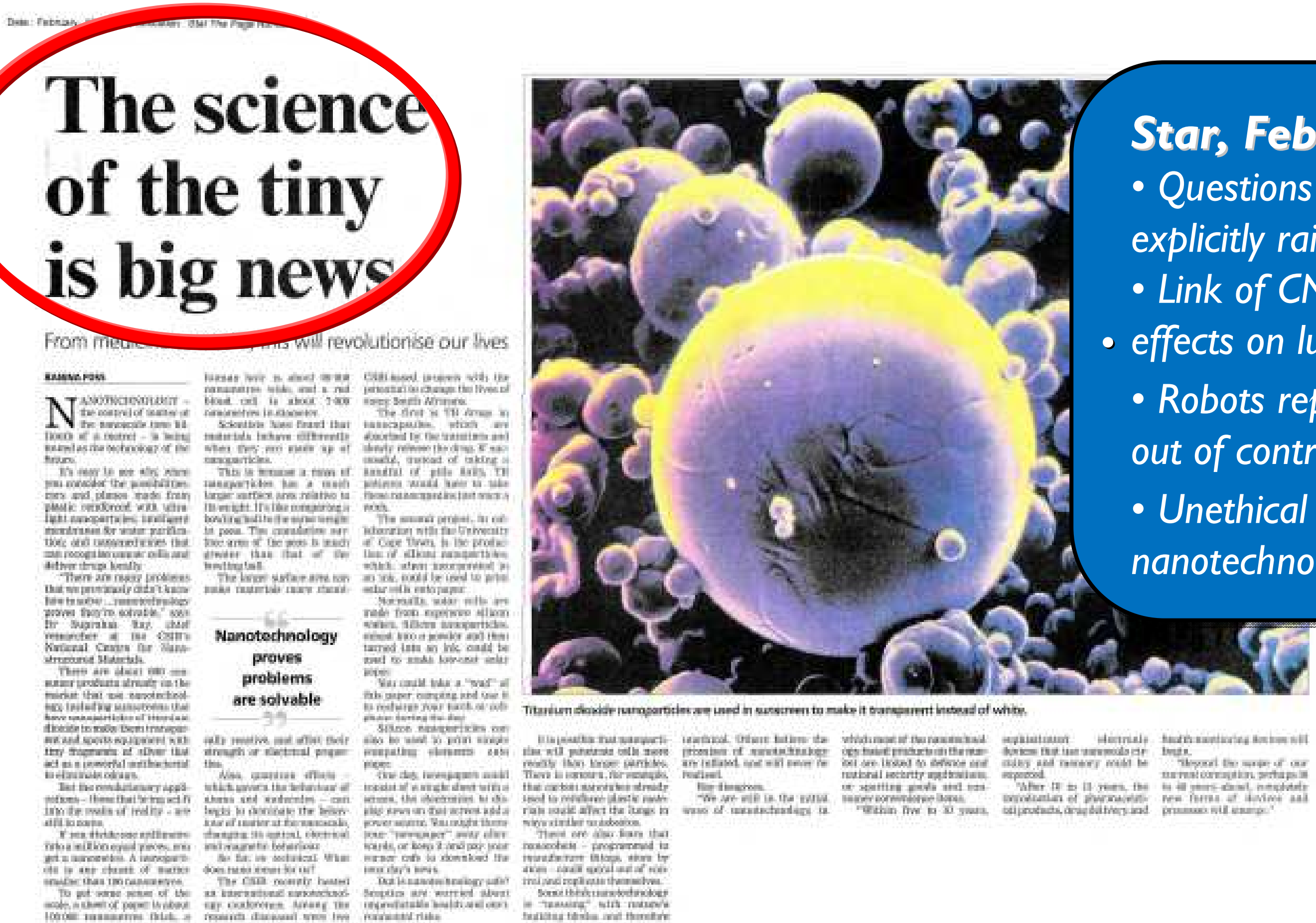
Rapidly growing risk concerns on the applications and safety of ENMs in media

Nanotechnology Risk Concerns in South Africa


The science of the tiny is big news

Nanotechnology proves problems are solvable

Titanium dioxide nanoparticles are used in sunscreen to make it transparent instead of white.

Star, February 16, 2009

- *Questions on potential risks were explicitly raised by the media*
- *Link of CNTs and asbestos health effects on lungs were inferred*
- *Robots replacing humans and getting out of control*
- *Unethical aspects related to nanotechnology were raised*

Example 1

Web link: http://intraweb.csir.co.za/news/inthenews/2009/TheStar_Nanotech.pdf

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Nanotechnology Risk Concerns in South Africa…

Example 2

Nanotubes may carry asbestos-like health risk

NANOTUBES, one of the wonder materials of the new age of nanotechnology, may carry a health risk similar to that of asbestos, a wonder material of an earlier age that turned into a scourge after decades of use when its fibres were found to cause lung disease, researchers said this week.

This time, the warning comes long before anyone has fallen ill, and experts say the findings call for caution, not alarm, in handling nanotubes, which are tiny, superstrong carbon fibres.

Although nanotubes are already found in some products like tennis racquets, researchers say the fibres appear to pose little risk to consumers.

Nanotubes, discovered in 1991, are essentially rolled-up sheets of carbon that can be used to produce materials that are far lighter and stronger than steel, for example.

But scientists have also long wondered whether the needle-shaped nanotubes might cause the same types of disease as needle-shaped asbestos fibres.

An article published on Tuesday on the website of the journal Nature suggests that the answer may be yes. Researchers said that injecting nanotubes into the abdomens of mice induced lesions similar to those that appear on the outer lining of the lungs after inhalation of asbestos.

In the case of asbestos, th
lesions eventually be
mesothelioma, a deadly ca
Consumers would pro
not be able to inhale nano
embedded in a golf club
cycle frame, for instance.

But there could be a co
that nanotubes in pro
could be released later, mu
asbestos in concrete or
mobile brake pads was in
by construction workers o
chanics.

The greatest risk would
people working in laborat
or at nanotube manufactu
— © (2008) The New York Tim

Sunday Times, May 25, 2008

- *CNTs link to health risks similar to asbestos suggested*
- *Current researchers' findings reported in Journal of Nature supports this view*
- *Not yet single case of disease has been reported associated with CNTs*
- *Cautionary approach was proposed*
- *Risk health effects postulated after the products lifespan*
- *Greatest risk for workers in research labs and manufacturing sector were raised*

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Global Initiatives in Nanotechnology Risk Assessment

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Nanotechnology Risk Assessment: International Scene

- **USA: Incorporation of HSE aspects of nanotechnologies in the National Nanotechnology Initiative (NNI), established in 2000. Annual budget on risk assessment < 1% of the total (see Guzman et al., 2006).**
- **UK: DEFRA initiatives (on going), and the Royal Society /Royal Academy of Engineering report 'Nanoscience and nanotechnologies: opportunities and uncertainties (2004)**
- **Organisation for Economic Co-operation and Development (OECD): establishment of Working Party on Manufactured Nanomaterials (WPMN). Core objective: To ascertain the environmental and human health impacts of NMs**
- **ISO TC 229: Has a component on Health, safety and environmental aspects of nanotechnology**
- **Other numerous initiatives in Canada, Japan, German, and the European Union**

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Nanotechnology: Risk Assessment Perspective

Setting the scene in the context of developing countries

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Developing Countries Response: The African Initiative

IFCS

Intergovernmental Forum on Chemical Safety
Global Partnerships for Chemical Safety

IFCS/FORUM-VI/07w
Original: English
10 October 2008

Contributing to the 2020 Goal

FORUM VI

SIXTH SESSION
OF THE
INTERGOVERNMENTAL FORUM ON CHEMICAL SAFETY

Dakar, Senegal
15 – 19 September 2008

****

FINAL REPORT

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Developing Countries: Nanotechnology Benefits

- Energy production and storage
- Provision of portable drinking water
- Improving agricultural production
- Storage of agricultural products
- Medical and health care applications
- Enhancement of the economy: exploitation of the nano-biotechnology

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Developing Countries: Challenges of Nanotechnology

- Technological Divide: very little or no ownership of IPs developing countries
- Minimal or none existence of R & D in developing countries on nanotechnology: limited human capacity and infrastructure
- Limited brainpower on HSE aspects of nanotechnology (lack of expertise)
- Lack of financial resources (absence of venture capital)
- Inability of states to address ethical issues of nanotechnology
- Emerging and increasing challenges concerning risk assessment: potential nano-pollution

Developing Countries: Waste Management Perspective

Is there a smoking gun or rather where is the evidence to warrant any form of concern ?

Pictorial Profiling of Waste Management Paradigm in Developing Countries: How will this fair after nanowaste streams reach proportional quantities?

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Current Reality…

And the nano-pollution? It is probable?

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Standing Guard Against Waste Injustice

"There is nothing moral about tempting a starving man with money."
Screens News flash in: Environmental Justice & Nuclear Power Magazine

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Gigantic Quantities of Solid Waste

What would be the impact of nanomaterials in such environmental conditions

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This is reality…

Eke A Living… ?

How can potential adverse effects of NMs be averted?

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Dumping site near a residential area in a certain developing country

Is the toxicological effects of ENMs well understood in such abiotic conditions?

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International Waste Trade

Global distancing of waste from source/generators

Global trotting of ships in search for hazardous & toxic wastes damping states/sites. Possible destination… Cash poor states.

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Modelling of Nanotechnology Impacts: Waste Management in Developing Countries

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Qualitative Modelling of Nanowastes

Risk a function of: hazard (toxicity), and exposure potency

- **Expected hazard (toxicity):** Due to constituent NMs (end-points results of *Bacillus subtilis, Daphnia magna, Oncorhynchus mykiss, P. subsapiata, Micropterus salmoides, etc)*

- **Degree of exposure**: Normally function of bioaccumulation and biopersistence): Present study we employ loci of NMs in products/applications because exposure potency computed using bioaccumulation and persistence data is currently unfeasible.

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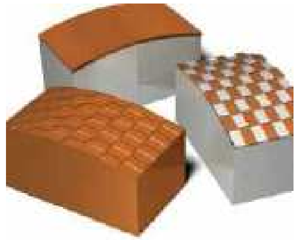
Exposure Potency: Loci of ENMs in Products

Bulk-based NMs

(one or multiphase)

EP: Very low to low



Structured surface, film or

Structured film

EP: Very low to medium

Surface bound

EP: Low to high

NMs suspended

in liquids

EP: Highly likely

NMs suspended in solids

EP: Medium to very high

Airborne/free ENPs

EP: Highly likely

Nanomaterials classification framework (Hansen et al. 2007)

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Qualitative Quantification of ENMs Toxicity

NMs type	Examples	Hazard (toxicity)[1]
Carbon based	Fullerenes	High
	Singled-walled carbon nanotubes (SWCNT)	High
	Multi-walled carbon nanotubes (MWCNT)	High
Metal oxides	Zinc oxide (ZnO)	Medium
	Titanium oxide (TiO_2)	Low
	Aluminium oxide (Al_2O_3)	Medium
	Yttrium iron oxide ($Y_3Fe_5O_{12}$)	Low
	Silicon dioxide (SiO_2)	Low
	Iron oxide (Fe_2O_3)	Medium
Metals	Silver (Ag)	Medium
	Gold (Au)	High
	Silica (Si)	Low
Quantum dots	Cadmium-selenide (CdSe)	High
	Cadmium telluride (CdTe)	High
Others	Silicon nanowires	Low
	Nanoclay particles	Low
	Dendrimers	Medium

[1] Classification based on Globally Harmonized System (GHS, 2003; Silk, 2003) aquatic toxicity can be expressed in five classes namely; extremely toxic (<0.1 mg/l); very toxic (0.1-1 mg/l); toxic (1-10 mg/l); harmful (10-100 mg/l); and none toxic (>100 mg/l) which were reduced into the three classes (high, medium and low).

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Nanowastes Classification

Nanowaste Class	Description	Comments
Class I	• NT: non-toxic • Loci: All loci (low to high exposures)	• May act as Trojan horse/accumulate to high concentrations
Class II	• NT: Harmful to toxic • Loci: Bulk or films (low exposure level) • NMs firmly held in products	• Necessitates to establish chronic effects • Optimal WM approaches should be investigated
Class III	• NT: Toxic to very toxic • Loci: surface or bulk	• Likely to be hazardous, appropriate protocols to be applied
Class IV	• NT: Toxic to very toxic • Loci: suspended solids	• Highly hazardous nanowastes • Efficient and effective technologies yet to be developed • To be disposed off to specialized/designated sites
Class V	NT: very toxic to extremely toxic Loci: free or liquid suspended	• Extremely hazardous waste streams • Efficient and effective technologies yet to be developed • Needs to be handled by specialists • Can cause diverse pollution to diverse ecological systems

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Qualitative Profiling of Nanowastes Risks

Application	NMs	Hazard	Exposure potency	Risk at disposal
Sports equipment	SiO_2	Low	Low	Low
	Ag	Medium	Low	Low
	SWCNT	High	Low	Low
	MWCNT	High	Low	Low
Personal care products	Ag	Medium	High	Medium
	Fullerenes	High	High	High
	Fe_2O_3	Medium	High	Medium
	TiO_2	Low	High	Low
Food/beverages	TiO_2	Low	Medium	Low
	ZnO	Medium	Medium	Medium
	Fullerenes	High	Medium	High
	Dendrimers	Medium	Medium	Medium
Sunscreen lotions	ZnO	Medium	High	Medium
	TiO_2	Low	High	Low
	Fullerenes	High	High	High
	Ag	Medium	High	Medium

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Quantitative Approach: Computer Model

- Exploit computational power to predict or make estimates – based on best available input data
- Make predictions or estimates of quantities (parameters) characterised by:
  - High costs of measurement
  - Limited technologies for actual environmental measurements
  - Provides an effective initial screening mechanism to elucidate whether actual environmental monitoring is justifiable
  - Provides basis for developing a protocol on best representative data for measurements
  - Explore and create different environmental scenarios that would assist in designing and developing mitigating responses

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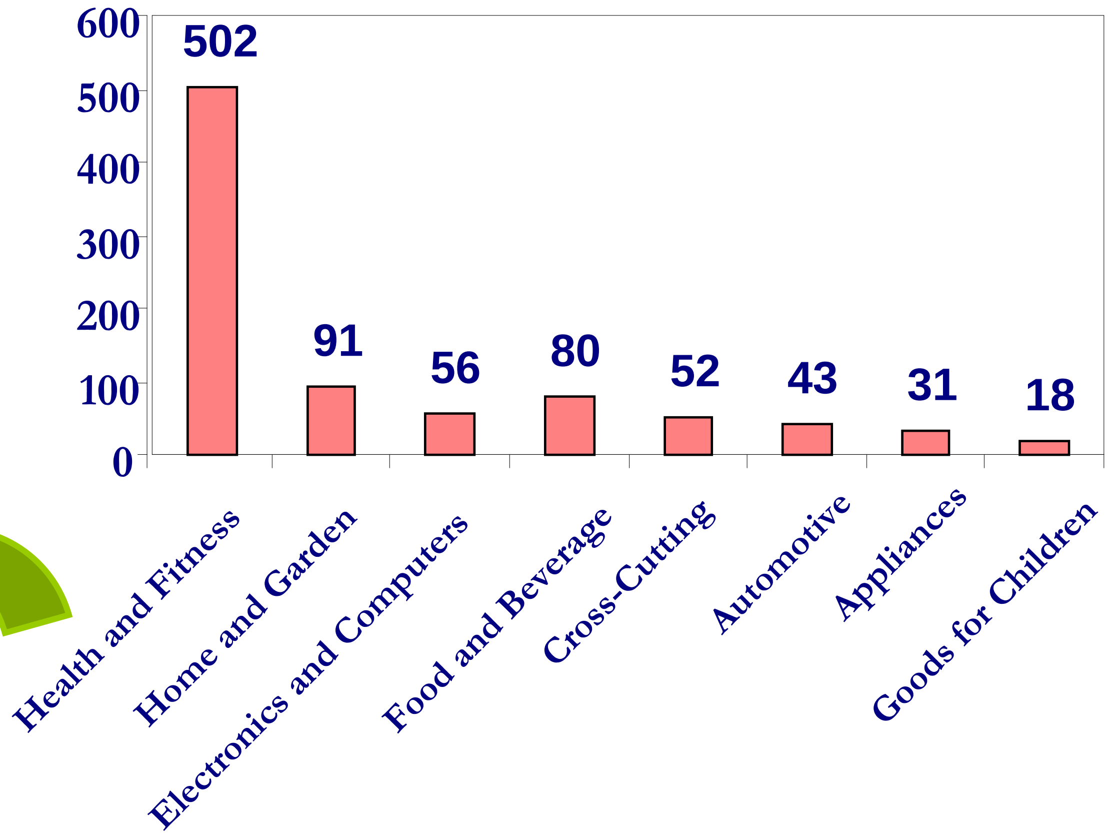
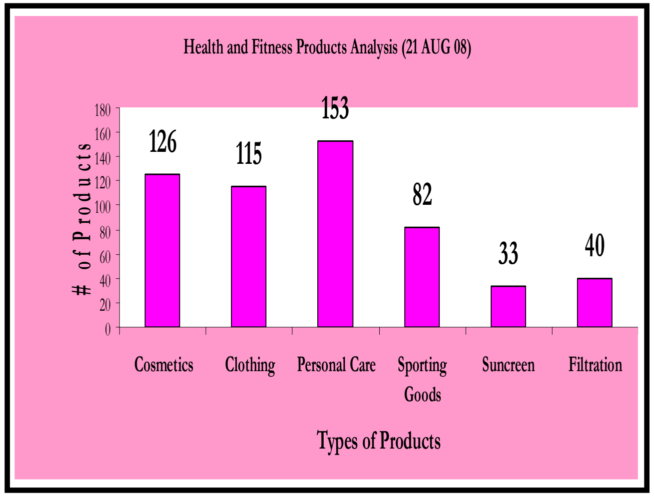
Cosmetics Products: a case study products





Source: Woodrow Wilson International Centre for Scholars, 2009

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Just Few Cosmetic Products… containing ENMs

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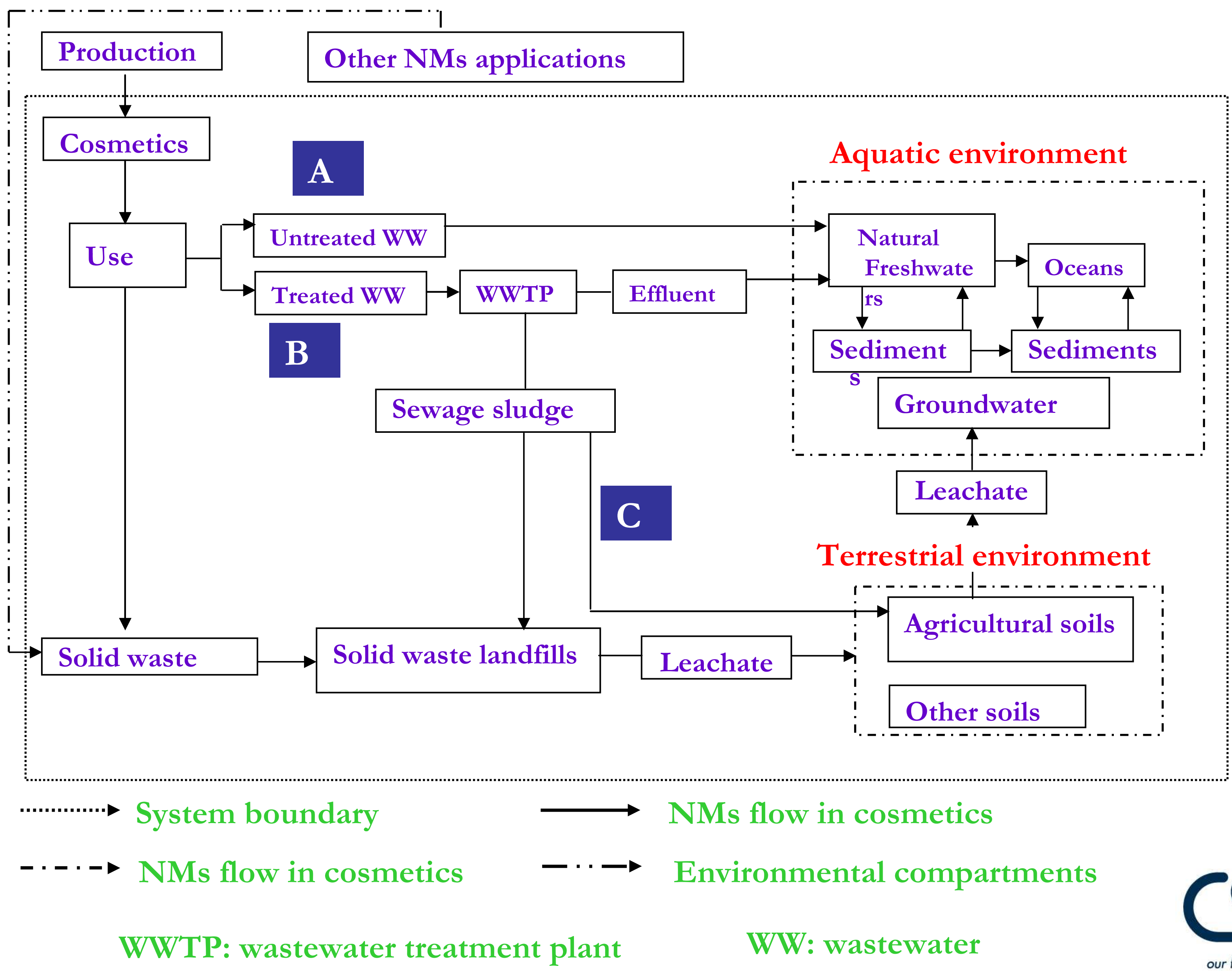
Probable Environmental NMs flows in SA Scenario



Quantitative Risk Assessment of NMs in Environment

- Computation of the Predicted Environmental Concentrations (PEC)
- Determination of Predicted No Effect Concentration (PNEC)
- Risk profile of a given NM pollutant

$$RQ = \frac{PEC_{NMi}}{PNEC_{NMi}}$$

RQ: Risk Quotient

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Cosmetics in SA: Model assumptions

- Use of surrogate data exploited. Switzerland (SW) published data used
- Economic, social, GDP figures used in computation equations to map SW values into SA scenario
- Companies operating in the cosmetic industry are multi-international – likely to market the same form of products in SA as in other parts of the world (concentration of NMs in products constant)

Map of JHB: Case Study

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Case Study: City of Johannesburg

Quantities of NM in JHB computed based on the expression:

$$JHB_{NM} = SW_{NM} \bullet cf_1 \bullet cf_2 \bullet cf_3 \bullet \frac{GDP_{JHB}}{GDP_{SA}}$$

cf: correction factor

$$cf_1 = \frac{POP_{SA}}{POP_{SW}}$$:Population ratio of SA to SW

$$cf_2 = \frac{GDP / capita(SA)}{GDP / capita(SW)}$$: GDP ratio of SA to SW (0.391) -2007

$$cf_3 = Market - penetration$$: 3 scenarios (0.1, 0.25, 0.40)

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Quantitative Computer Model Results

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Computed NMs Quantities in JHB (total nAg)

Values in tonnes per annum

Scenarios	GP[1]	Factor[2]	SW	SA	JHB
Minimum	300	0.007	2.100	0.256	**0.038**
Probable	500	0.007	3.500	0.427	**0.085**
Maximum	1230[3]	0.007	8.600	1.050	**0.263**

(Computed nAg quantities in cosmetics: 0.009, 0.021, and 0.063 t/a)

[1] **Global production of nAg in 2007**

[2] **Ration of Switzerland population to major nanotechnology-based countries**

[3] **Values by Muller (2007) and Blasser (2006) Thesis based on scenarios in Switzerland and EU, respectively**

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nAg Distribution in Nanoproducts

Values in tons/annum (t/a)

Nano-based products	**Switzerland**			**South Africa**			**Johannesburg**		
	MIN-E_{SW}	**PRO E_{SW}**	**MAX E_{SW}**	**MIN-E_{SA}**	**PRO-E_{SA}**	**MAX-E_{SA}**	**MIN-E_{JHG}**	**PRO-E_{JHB}**	**MAX-E_{JHB}**
Plastics	0.244	0.407	1.001	0.025	0.128	0.594	0.004	0.026	0.148
Metal products	0.056	0.093	0.228	0.006	0.029	0.135	0.001	0.006	0.034
Cosmetics+	0.506	0.843	2.070	0.052	0.264	1.228	**0.008**	**0.053**	**0.307**
Sprays#	0.360	0.600	1.473	0.037	0.188	0.874	0.006	0.038	0.218
Textiles	0.222	0.371	0.911	0.023	0.116	0.540	0.003	0.023	0.135
Paint/Sealings	0.712	1.187	2.917	0.073	0.372	1.730	0.011	0.074	0.432

+ In addition with supplements

 # In addition to cleaning agents

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Computed NMs Quantities in JHB (total $nTiO_2$)

Values in tons/annum (t/a)

Scenarios	GP	Factor	SW	SA	JHB
Minimum	3000	0.007	21.00	2.153	**0.323**
Probable	5000	0.007	35.00	10.969	**2.193**
Maximum	--	--	400[+]	236.931	**59.233**

[+]Schmid, K., and Riedieker, M. Use of Nanoparticles in Swiss Industry: A Targeted Survey, Environ. Sci. Technol. 2008: 42(7); 2253 - 2260

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$nTiO_2$ Distribution in Nanoproducts

Values in tons/annum (t/a)

Nano-based products	Switzerland			South Africa			Johannesburg		
	$MIN\text{-}E_{SW}$	$PRO\ E_{SW}$	$MAX\ E_{SW}$	$MIN\text{-}E_{SA}$	$PRO\text{-}E_{SA}$	$MAX\text{-}E_{SA}$	$MIN\text{-}E_{JHG}$	$PRO\text{-}E_{JHB}$	$MAX\text{-}E_{JHB}$
Plastics	0.43	0.71	8.13	0.04	0.22	4.82	0.007	0.05	1.20
Metal Products	12.33	20.54	234.80	1.264	6.44	139.10	0.19	1.29	34.77
Cosmetics+	0.46	0.76	8.71	0.05	0.24	5.158	**0.007**	**0.048**	**1.289**
Sprays#	2.57	4.28	48.95	0.26	1.34	28.99	0.04	0.27	7.25
Textiles	0.08	0.13	1.52	0.008	0.04	0.90	0.001	0.008	0.225
Paint/Sealings	5.140	8.567	97.906	0.527	2.684	57.993	0.079	0.537	14.498

+ In addition with supplements

 # In addition to cleaning agents

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Total NMs into Aquatic Environment

$$NM_{Water,input\,i} = NM_{WW,Total\,i} \bullet (1 - f_{STP\,i}) + NM_{WW,Total\,i}(f_{STP\,i} - f_{STP\,i} \bullet f_{\mathrm{Re}moval\,i})$$

Untreated wastewater — **A**

Treated wastewater (effluent) — **B**

$$NM_{Water,input\,i} = NM_{WW,Total\,i} \bullet (1 - f_{STP\,i} \bullet f_{\mathrm{Re}moval\,i})$$

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NMs in JHB Aquatic Environment (Higher Eff)

	Variable	MIN-E_{JHB}	PRO E_{JHB}	MAX E_{JHB}
Ag	Ag_{total} : total silver released into WW (kg/a)	**7.77**	**52.79**	**306.58**
	: fraction of WW treated in WWTPs	0.80	0.70	0.60
	: fraction of Ag removed in WWTPs	0.79	0.70	0.55
	Ag_{STP}: silver entering into WWTPs in (kg/a)	6.22	36.95	183.95
	$Ag_{STP,removed}$: silver removed in WWTP (Ag in sludge) (kg/a)	4.91	25.87	101.17
	$Ag_{STP,removed}$: silver released effluents from WWTPs (kg/a)	3.93	11.09	82.78
	$Ag_{untreated}$: silver in untreated WW (kg/a)	1.55	15.84	122.63
	Ag_{water}: silver that enters into aquatic environment (kg/a)	**2.86**	**26.92**	**205.41**
TiO_2	$TiO2_{total}$: total TiO_2 released into WW (kg/a)	**7.03**	**47.73**	**1 289.38**
	: fraction of WW treated in WWTPs	0.80	0.70	0.60
	: fraction of TiO_2 removed in WWTPs	0.80	0.65	0.60
	TiO_{2STP}: TiO_2 entering into WWTPs in (kg/a)	5.62	33.41	773.63
	$TiO_{2STP,removed}$: TiO_2 removed in WWTP (Ag in sludge) (kg/a)	4.50	21.72	464.18
	$TiO_{2STP,removed}$: TiO_2released effluents from WWTPs (kg/a)	1.12	11.69	309.45
	$TiO_{2, untreated}$: TiO_2 in untreated WW (kg/a)	1.41	14.32	515.75
	TiO_{2water}: TiO_2 entering into the aquatic environment (kg/a)	**2.53**	**26.01**	**825.21**

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JHB WWTP (High Efficient Plants)

WWTP efficiency 20-30% less values reported by Westehoff et al., 2008

JHB WWTP (High Efficient Plants)… cont…

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Calculation of C_{STPs}, PECs & PNECs

$$C_{WW} = C_{STP} = \frac{NM_{i,WW,STP} \times 10^{12}}{WW_{percapita} \bullet f_{STP} \bullet POP}$$

$$PEC_i = \frac{NM_{i,Water} \bullet 10^{12}}{POP \bullet WW_{percapita} \bullet D_k} = C_{STP} \bullet \frac{NM_{i,Water}}{NM_{i,WW,STP}} \bullet \frac{f_{STP}}{D_k}$$

PNECs derived from the literature: 40 & 1 ug/l for nAg and nTiO2, respectively

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Quantitative RQs Results (Higher Eff)

	Parameters	MIN-E_{JHB}		PRO-E_{SW}		MAX-E_{SW}	
nAg	*Concentration in STP (µg/ℓ)*	4.8E-03	7.68E-03	36.28E-03	90.58E-03	23.268E-03	1038.48E-03
	Dilution factor: 10 (PEC, µg/ℓ)	0.2E-03	0.3E-03	1.8E-03	4.6E-03	15.6E-03	69.6E-03
	Dilution factor: 3 (PEC, µg/ℓ)	0.6E-03	0.9 E-03	6.2E-03	15.4 E-03	52E-03	231.9E-03
	Dilution factor: 1 (PEC, µg/ℓ)	1.8E-03	2.8E-03	18.5E-03	46.2E-03	155.9E-03	695.7E-03
	RQ (D=10) (no units)	4.44E-06	7.01E-06	4.62E-05	1.15E-04	3.90E-04	1.74E-03
	RQ (D=3) (no units)	1.48E-05	2.34E-05	1.54E-04	3.85E-04	1.30E-03	5.80E-03
	RQ (no dilution) (no units)	4.44E-05	7.01E-05	4.62E-04	1.15E-03	3.90E-03	1.74E-02
$nTiO_2$	*Concentration in STP (µg/ℓ)*	4.4E-03	6.9E-03	32.7E-03	81.8E-03	977.2E-03	4 361.9E-03
	Dilution factor: 10 (PEC, µg/ℓ)	0.2E-03	0.3E-03	1.8E-03	4.5E-03	62.5E-03	279.2E-03
	Dilution factor: 3 (PEC, µg/ℓ)	0.5E-03	0.8E-03	5.9E-03	14.9E-03	208.5E-03	930.5E-03
	Dilution factor: 1 (PEC, µg/ℓ)	1.6E-03	2.5E-03	17.8E-03	44.6E-03	625.4E-03	2 791.6E-03
	RQ (D=10) (no units)	1.57E-04	2.48E-04	1.78E-03	4.46E-03	6.25E-02	2.79E-01
	RQ (D=3) (no units)	5.24E-04	8.26E-04	5.95E-03	1.49E-02	2.08E-01	9.31E-01
	RQ (no dilution) (no units)	1.57E-03	2.48E-03	1.78E-02	4.46E-02	6.25E-01	2.79E+00

Under each scenario, first column results based on calculated WW per capita, and second column based on values provided by experts in WWT in SA

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JHB WWTP (Low Efficient Plants)

WWTP efficiency 25 – 40% values by experts in WW in SA

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JHB WWTP (Low Efficient Plants)… cont…

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JHB WWTP (Low Efficient Plants)… cont…

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NMs in JHB Aquatic Environment (Lower Eff)

	Variable	MIN-E_{JHG}	$PROE_{JHB}$	MAX-E_{JHB}
nAg	Ag_{total} : total silver released into WW (kg/a)	**7.77**	**52.79**	**306.58**
	: fraction of WW treated in WWTPs	0.80	0.70	0.60
	: fraction of Ag removed in WWTPs	0.45	0.35	0.25
	Ag_{STP}: silver entering into WWTPs in (kg/a)	6.22	37.0	183.95
	$Ag_{STP,removed}$: silver removed in WWTP (Ag in sludge) (kg/a)	2.80	12.90	46.00
	$Ag_{STP,removed}$: silver released effluents from WWTPs (kg/a)	3.40	24.00	138.10
	$Ag_{untreated}$: silver in untreated WW (kg/a)	1.60	15.80	122.80
	Ag_{water}: silver that enters into aquatic environment (kg/a)	**5.00**	**39.90**	**260.90**
nTiO_2	$TiO2_{total}$: total TiO_2 released into WW (kg/a)	**7.03**	**47.73**	**1 289.38**
	: fraction of WW treated in WWTPs	0.80	0.70	0.60
	: fraction of TiO_2 removed in WWTPs	0.45	0.35	0.25
	TiO_{2STP}: TiO_2 entering into WWTPs in (kg/a)	5.60	33.40	773.60
	$TiO_{2STP,removed}$: TiO_2 removed in WWTP (Ag in sludge) (kg/a)	2.50	11.70	193.40
	$TiO_{2STP,removed}$: TiO_2released effluents from WWTPs (kg/a)	3.10	21.70	580.20
	$TiO_{2,\ untreated}$: TiO_2 in untreated WW (kg/a)	1.40	14.30	515.80
	TiO_{2water}: TiO_2 entering into the aquatic environment (kg/a)	**4.50**	**36.00**	**1 096.0**

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Quantitative RQs Results (Lower Eff)

	Parameters	MIN-E_{JHG}		PRO-E_{JHB}		MAX-E_{JHB}	
nAg	***Concentration in STP (µg/ℓ)***	4.8E-03	7.68E-03	36.28E-03	90.58E-03	23.268E-03	1038.48E-03
	Dilution factor: 10 (PEC, µg/ℓ)	0.3E-03	0.5E-03	2.7E-03	6.8E-03	19.8E-03	88.3E-03
	Dilution factor: 3 (PEC, µg/ℓ)	1.0E-03	1.6E-03	9.1E-03	22.8E-03	65.9E-03	294.2E-03
	Dilution factor: 1 (PEC, µg/ℓ)	3.1E-03	4.9E-03	27.3E-03	68.3E-03	197.7E-03	882.6E-03
	RQ (D=10) (no units)	7.72E-06	1.22E-05	6.83E-05	1.71E-04	4.94E-04	2.21E-03
	RQ (D=3) (no units)	2.57E-05	4.06E-05	2.28E-04	5.69E-04	1.65E-03	7.35E-03
	RQ (no dilution) (no units)	7.72E-05	1.22E-04	6.83E-04	1.71E-03	4.94E-03	2.21E-02
$nTiO_2$	***Concentration in STP (µg/ℓ)***	4.4E-03	6.9E-03	32.7E-03	81.8E-03	977.2E-03	4 361.9E-03
	Dilution factor: 10 (PEC, µg/ℓ)	0.3E-03	0.4E-03	2.5E-03	6.2E-03	83.1E-03	370.8E-03
	Dilution factor: 3 (PEC, µg/ℓ)	0.9E-03	1.5E-03	8.2E-03	20.6E-03	276.9E-03	1 235.9E-03
	Dilution factor: 1 (PEC, µg/ℓ)	2.8E-03	4.4E-03	24.7E-03	61.8E-03	830.6E-03	3 707.6E-03
	RQ (D=10) (no units)	2.79E-04	4.41E-04	2.47E-03	6.18E-03	8.31E-02	3.71E-01
	RQ (D=3) (no units)	9.31E-04	1.47E-03	8.24E-03	2.06E-02	2.77E-01	1.24E-00
	RQ (no dilution) (no units)	2.79E-03	4.41E-03	2.47E-02	6.18E-02	8.31E-01	3.71E+00

Under each scenario, first column results based on calculated WW per capita, and second column based on values provided by experts in WWT in SA

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Intervention mechanisms to address short comings in the developing countries

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Possible Intervention Mechanisms…

- *DCs with strong nanotechnology research and commercialization initiatives should develop parallel risk assessment research portfolios*
- *Adopt effective monitoring of scientific and legislative evolution governing risk assessment of nanotechnology – to inform policy formulation*
- *Push for the international community to develop clear protocols and standards to address nanowaste streams*
- *DCs to develop mechanisms of nanoproducts risk assessment before their introduction into the markets*
- *Development of "centres of excellence" to address risk assessment of nanotechnology including post-consumer/production waste streams*

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