Journal of Basic and Applied Engineering Research
Print ISSN: 2350-0077; Online ISSN: 2350-0255; Volume 2, Number 1; January-March, 2015, pp. 73-78

http://www.krishisanskriti.org/jbaer.html

Thematic Intervention of Nanotechnology in Water Sector Opportunities and Risks

Madhulika Bhati[1], Saurabh Ram Kumar[2] and Pushkar Bansal[3]

[1]CSIR-NISTADS Dr. K.S. Krishnan Marg, Pusa Gate, New Delhi
[2]INRS-ETE PhD Student, Water Science, Quebec, G1K9A9, Canada
[3]CSIR-NISTADS K.S. Krishnan Marg Pusa Gate, New Delhi
E-mail: [1]madhupratya@gmail.com, [2]saurabh_kumar.ram@ete.inrs.ca, [3]pushkarbansal3010@gmail.com

Abstract—*In the last decade nanotechnology entered the policy arena as a technology that is presumably well known promising candidate for solving one of the most important issues such as ensuring the quality and quantity of potable water for the world society in the 21st century.*

This research paper gives the comprehensive overview of state of art technologies available for water purification, worldwide. It draw insight the recent contamination scenario of water and challenges ahead and how nanotechnology is developing in country like India across the this water sector from the beginning to end of value chain to solve this pressing concern. It also addresses the potential nanotechnology risks and outlines risk data gaps challenges for existing regulatory framework. This paper also identified some ways to integrating nanotechnology in water industry in a responsible manner.

1. INTRODUCTION

Nanotechnology like Information and Communication Technologies, Renewable resources, Biotechnologies is persuaded as a major wave of economy in 21st century and drives our 5th innovation wave of Kondratieff, an important building block of three cycle schema given by Schumpeter. In the last decade nanotechnology entered the policy arena as a technology that is presumably well known promising candidate for solving important issues such as ensuring the quality and quantity of potable water for the world society in the 21st century.

Most of the studies till now mainly emphasis on the overall nanotechnology development but as a broad impact technology, nanotechnology penetrates various industrial sectors. In this bulletin we focused our analysis on thematic intervention of nanotechnology in water sector. It is a first kind of study which focused on nanotechnology applications in one sector and providing insight how it is developing in country like India through the lens of R & D programmes and policy environment specific to water sector.

This bulletin gives the comprehensive overview of state of art technologies available for water purification, worldwide. It draw insight the recent contamination scenario of water and challenges ahead and how nanotechnology is developing in country like India across the water sector from the beginning to end of value chain to serve for Bottom of Pyramid society. It also addresses the potential nanotechnology risks and outlines risk data gap challenges for existing regulatory framework. In summary, we suggest some ways in which government agencies can move forward responsibly so that ultimately nanotechnology and its products can succeed in the eyes of developers, researchers, regulators, and the public.

2. THE CURRENT CONCERN AND THE GLOBAL PICTURE: WATER CRISIS CAUSES

Water is not as abundant and readily available as it appears. Various reports published by World Health Organization put forward alarming facts about water availability. 17-19 million people in the world lack access to clean water. 3.4 million people die every year from water scarcity, sanitation and hygiene related problems out of which 99% death occur in developing countries [1]. In South Africa alone 5.7 million people lack potable drinking water which adds to the hardship of their lives.

In India 1.2 billion people live with a very minimal per capita consumption of 1820 cubic meter which was 5177 cubic meter in 1951[2]. This decreasing trend of water availability hints to water crisis situations in coming future. It has been reported that only 68% of Indian population has access to safe drinking water. 21% of communicable diseases in India are from unsafe drinking water [3]. India is ranked at 124th position out of 174 countries in terms of Environmental Pollution Index. This is really an alarming situation and the need of efficient actions can't be overemphasized further. It is essential to have a long term vision for water conservation and management. Main causes of this situation are global population expansion or specifically in Indian context have been rapid for the past few decades. It's not just the population alone. Water is not scarce, but the efficient methods to make it available are.

Indian municipal water infrastructure has been under criticism for a very long time. Every heavy rainfall or natural catastrophe like Tsunami (2004) exposes the weak links in age old water channeling systems. Water treatment technologies have to evolve one step ahead of the demands.

Waste water quality has been degraded due to rapid industrialization in past 4-5 decades. Contaminated waste water can cause severe damage to ecology by eutrophication, GHG emission. The current treatment capacities are not sufficient enough, only 60% of Industrial waste water is treated while as low as just 26% of domestic waste water is treated. The following table [4] shows the difference between our waste water generation capacities and treatment infrastructure availability.

This emergent perception of an imminent water crisis in the country entail a pressing need for the best potential use of water as well as technological advances to augment the fresh water by various means like desalination process, water treatments, etc. Nanotechnology has the potential to provide a long term solution for water quality, availability and viability of water resources, such as through the use of advanced filtration materials that make possible greater water reuse, recycling, and desalinization [5, 6].

Nanotechnology provides an answer to cost and efficiency problems. It proposes new functionality, products and systems as a promising technology in water and waste-water sector worldwide. Nanotechnologies will create immense environmental benefits in terms of water management and treatment by convalescing filtering, decontamination, desalination, conservation, recycling, analysis & monitoring of Sewerage system.

Table 1: Waste water generation and treatment, Source: Jindal ITF 2011

Period	Waste water generation (MLD)	Waste water treated (MLD)
2004-05	26254	7044
2005-06	29129	6190
2007-08	33000	7044
2008-09	38254	11787
2009-10	41131	13066
2010-11	51232	14484

2.1 Potential of Nanotechnology in Water Treatment

Nanotechnology based application has many advantage their conventional counterparts. Nanotechnology facilitates a very low level detection of contaminants and hazardous materials in water streams due to its intrinsic abilities. Toxin and contaminants levels vary with geographical variations but nanotech based sensors provide a wide range of sensitivity making it applicable in all kind of geological conditions and contamination types. Trace toxicity and refractory contaminants are major concern for conventional purification methods. Broadly nanotechnology materials are combined in conventional technologies to result into four kinds of technologies for multitude of purposes viz. Nanofiltration systems made of carbon nanotubes, zeolites, nanofibers and nanosponges; Nanocatalysts which can catalytically attack chemical contaminants and toxins to degrade them; Magnetic nanoparticles, they can remove metals like arsenic due to their innate interaction abilities and Nanoparticles that are used to develop sensitive sensors with enhanced detection abilities of molecular levels.

Nanotechnology can improve the desalination abilities of filtration membranes which can provide potable water at substantially low cost from brackish water or sea water. Nanotechnology has potential to treat acid mine drainage and other industrial effluents at very low cost.

In- depth analysis of BCC research (2011) has estimated the global value of nanotechnology products used in water treatment procedures of worth $1.4 billion in 2010 and is projected to reach $2.2 billion by 2015 showing 9.7 % increases at a compound annual growth rate (CAGR). The market is made up of two segments: established products (including reverse- osmosis, nanofiltration, and ultrafiltration membrane modules) and emerging products (nanofiber filters, carbon nanotubes). Established products were valued at nearly $1.4 billion in 2010 and are expected to reach $2.1 billion by 2015, at a CAGR of 9.2%. Emerging products were valued at $45 million in 2010 and, with a CAGR of 20%, reaches $112 million in 2015.

2.2 Prominent Technologies available in water remediation worldwide

Some interesting membrane technologies are now emerging from developed and developing nations that are highly relevant to the needs of the developing as well as under developed countries.

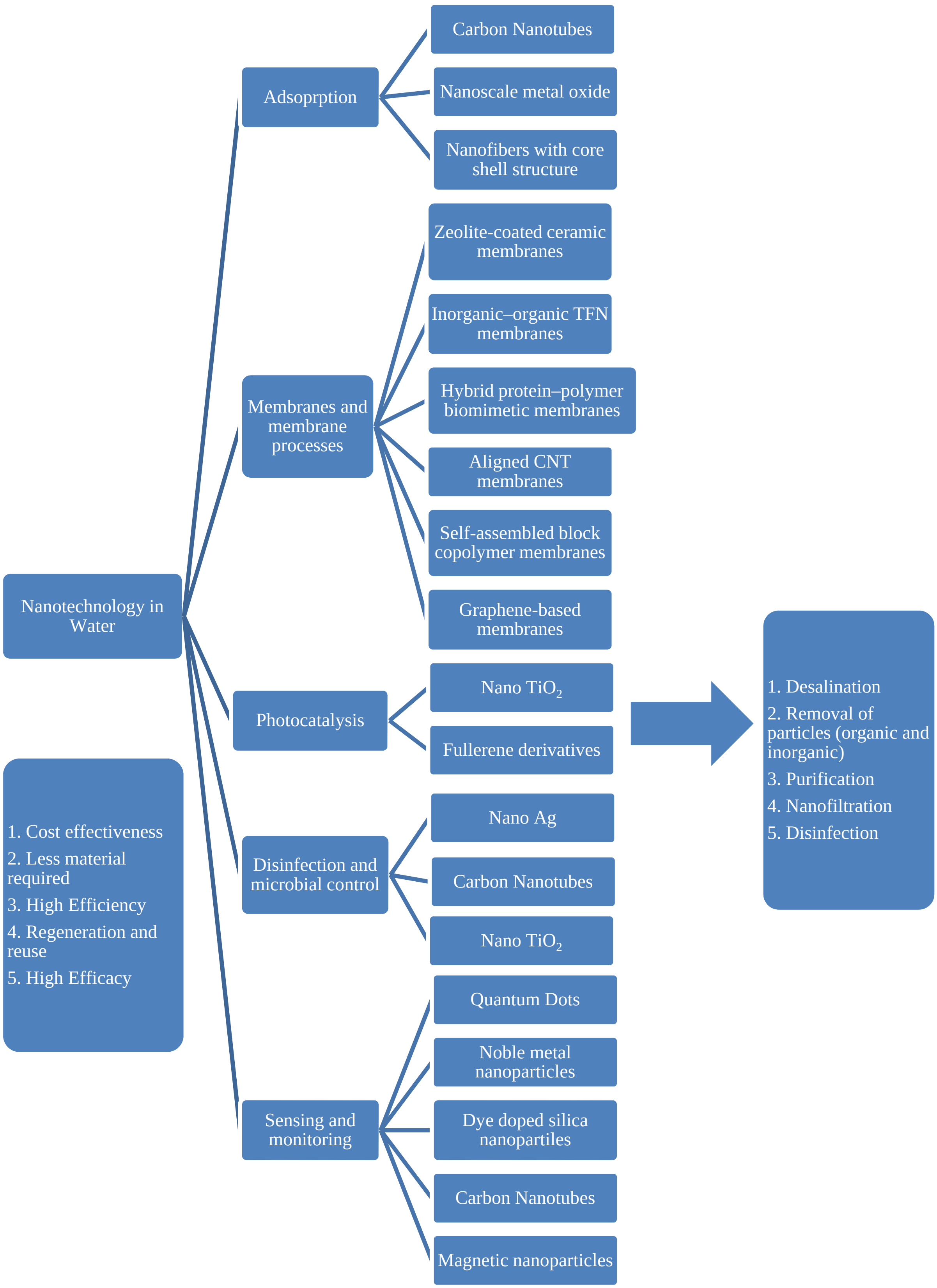

Fig. 1: Prominent Technologies available in Nano Water [7, 8]

3. CURRENT STATE OF RESEARCH AND DEVELOPMENT (R & D) ENVIRONMENT: AN INDIAN CONTEXT

3.1 Nanotechnology R & D Environment

India has taken a major drive to create capacity and capability in Nanotechnology [9]. Department of Science and Technology articulated and implemented Nano Science and Technology Initiative (NSTI) in 2001 with an allocation of ☐60 crore (15 million USD). In 2007, this programme was further strengthened with another major initiative known as 'Nano Mission' with a budgetary allocation of ☐1000 crore (250 million USD) for five years.

This funding has been utilized to sponsor 90 research projects and create 19 Centres of Excellence (CoE). The CoE consist of eleven “Unit of Nanoscience (UN) that pursue the basic research in several broad areas of Nano science and Technology whereas seven “Centres of Nanotechnology” is mainly focus on R & D in niche areas or in specific dimensions such as water remediation and purification (IIT, Madras).

3.2 Nanotechnology R & D Initiatives specific to Water Sector

In the eleventh plan period (2007-2012) more ambitious programmes and targets were set keeping in view different domains where nanotechnology can play a key role in enhancing the sector.

In the same period, water technology initiatives has carved out with an aim to provide affordable and indigenous safe drinking water using processes which uses nanomaterials and filtration technologies. Since the inception of the programme in 2007, 145 projects have been sanctioned by funding approximately ☐150 Crore [10]. The programme has been successful in terms of developing point of use drinking water system, field assessments of technology solution for metals of major concern like Arsenic (As), Fluoride (F), Iron (Fe) and desalinization of brackish water as well as sea water in different parts of India.

Recently in 2011 Department of Science and Technology approved a grant to Central of Excellence to open 8 Thematic Units of Excellence. It is important at this critical juncture to assess the status of research and innovation in nanotechnology in different industrial sectors in India.

By recognizing the capability of India to develop innovation for bottom of pyramid 12th five year plan (2013-2017) gave more emphasis in designing solutions to the challenges in water sectors such as membrane technologies and nanotechnology based sensors including biosensor [11].

Table 2: Major Programmes/Initiatives on Nano Water Research during Five Year Plans

• Tenth Five year plan (2002-2007)	• National Science and Technology Initiatives spending • Establishment of Centre of Excellence • National Program for Smart Materials • Establishment of Characterization Facilities
• Eleventh five Year Plan (2007-2012)	• launch and commission an intensive Nano Science and Technology mission mode program • Water Technology Initiatives (2007) under cross disciplinary area working group of steering committee of Planning commission has been started (300 crore) • Eight new Thematic Units of Excellence on focused themes
• Twelfth Five Year Plan (2013-2018)	• Two identified Programme related to water : • Test beds to take forward indigenous membrane technologies and build up capability in “Membranes technology platform” • Nanotechnology based sensors including biosensors for real time field analysis of water contaminants such as microbes, fluoride, arsenic, chromium, heavy metal ions, etc.

3.3 Nanotechnology Market

Intensive research in nanotechnology is going on to develop technologies to provide safe potable water from various resources. Most of the research institutes in India like IIT's, BARC, IISc are involved in developing nanomaterials and their integration into conventional treatment technologies. Table 2 list key nanomaterials developed by some premiere Indian research institutes [3].

Table 3: Nanotech research in Various Research Institutes

Technology	Application	Institute
Fe-Oxide	As removal	IIT KGP India
Carbon Nanotube Filter	Toxin Removal	BHU India-Renssaelaer Polytechnic USA
Carbon nanotube filters	Pathogen removal	BARC India
Gold Nanoparticles	Pathogen Detection	Agharkar Research Institute
Nanoparticle	Toxic metal detection and removal	IIT Bombay
Nanosensor	Low level toxin detection	IIT Delhi

4. POLICY ENVIRONMENT FOR RESPONSIBLE DEVELOPMENT OF NANOTECHNOLOGY IN WATER SECTOR

There are several organizations involved in developing health & environment regulations for nanotechnology; the Ministry of Environment & Forest (MoEF), the Ministry of Chemical & Fertilizers, the Ministry of Health & Family Welfare, and the Ministry of Labour and Employment. Ministry of Environment & Forests is playing lead role in implementing policies & programs relating to prevention & abatement of pollution in water and air. Over the years, number of laws has been enacted to achieve the objective of the Ministry of which, water (Prevention & Control of Pollution) Act, 1974 was the first environment specific statute in the country. Environment (Protection) Act, 1986, Hazardous Wastes (Management and Handling) Amendment Rules, 2000, are other laws which deals in directly or indirectly with water pollution. Central Pollution Control Board, an apex body of MoEF is responsible to lay down standards for effluents discharged from the industries in order to prevent the pollution of water resources in the country. These standards are termed 'Minimal National Standards' (MINAS). The Ministry of Chemicals & Fertilizers regulates chemical, which means it can be charged with regulation of many nanomaterials. Finally, the labour and Employment regulates Labour Safety Standards, child and women labor policies and laws so it can play major role in determining factory &laboratory conditions for workers in nanotechnology labs. Besides that, Bureau of Indian Standards (BIS) has responsibility for standards of nanotechnology including safety standards. In India development of safety standards for nanotechnology & nanomaterials is in quite nascent stage. In general, BIS follows all the recommendation set by the ISO [12].

India is active in formulating the ISO guidelines & standards. The major conduit between the ISO and the India BIS is the MTD33, a working group set up by the BIS to serve as the liaison to the ISO. ISO has developed 42 standards for nanotechnology. These standards can be divided in four groups. Nomenclature and Terminology (NT) has 10 standards, Measurement and characterization (MC) has 15 standards, Health Safety and Environmental (HSE) has 13 standards and Material Specification (MS) has 4 standards.

Health and Safety standards are mainly dealing with the manufactured nanomaterials like Silver, Gold, Zinc oxide, etc. for their characterization, their potency and risk evaluation. Silver, Gold and Titanium dioxide are generally used to make water filter in India. ISO is also preparing Materials Safety Data Sheet (MSDS) for nanomaterials. It mainly provide the information about the procedures for handling or working with nanomaterials in a safe manner, and includes information such as physical data (melting point, boiling point, flash point, etc.), toxicity, health effects, first aid, reactivity, storage, disposal, protective equipment, and spill-handling procedures. BIS can use these standards to develop Indian standards for nanotechnology in water sector according to our country's environment [13].

5. FIGURE 2: POLICY ENVIRONMENT FRAMEWORKRISK GAP AND EXISTING RULES & REGULATIONS

Nanotechnology shows great potential for applications in different sectors due to its novel properties. These extraordinary properties also trigger skepticism about nanotechnology adverse effects on human health & environment. As these properties may also appear on opposite side which means small amount of nanomaterial will have potent toxicity as compared to their bulk counterparts. However, due to lack of adequate data, risk assessments for nanotechnologies and nanomaterials are extremely difficult. It is difficult to extrapolate study results done in controlled setting in labs to complex ecosystem.

Over the years lots of laws & regulations came for abatement of pollution. In India, Ministry of Environment & Forests (MoEF) implements policies & programmes relating to preventions & abatement of pollution in water & air. Water (Prevention & Control of Pollution) Act, 1974 was the first environmental specific enactment in the country. The Pollution Control Board at central with state came into being as a consequence of this act. In 1981, the air (Prevention & Control of Pollution) Act was enacted.

After the inception Water Prevention & Control of Pollution Act as first regulatory statute in 1974, the Air (Prevention & Control of Pollution) Act 1981 was enacted, followed by The Environment (Protection) Act, 1986, etc. The National Environment Policy also set main objectives to integrate environment concern in all relevant development processes. Current Water Prevention & Control of Pollution Act has definitive limitations and capacity to address nanomaterials. Before regulating nanoparticles Ministry have to demonstrate that nanoparticles have potential adverse effects on human health or the environment. Ministry also require to create water quality standards to dispose it in river stream or used as irrigation source in agricultural land, it must need to develop a database covering all known effects of specified nanoparticles in water. Limitations of current technologies for detection and monitoring nanoparticles in water create significant barriers in implementing and imposing various conventional regulatory standards. If a facility uses or manufactures nanoparticles and is discharging its waste water stream in water bodies, CPCB (An apex body of MoEF) could implement its authority to inspect the facility, obtain records, demand discharge monitoring and make reports to gain information on the nature of nanoparticles discharged.

6. DISCUSSION AND CONCLUSION

It has been 15 year, since the inception of nanotechnology evolution in India Government helps to build a significant network to support scientific and technology progress but policy environments for nanotechnology are lacking importance of risk research. Risk Project which emphasize on nanomaterial exposure & transportation, hazard mechanism on entry in environment & development of tool for risk assessment should be given in priority by Department of science & technology. More funding should be allotted to develop monitoring capabilities so that baseline data about nanomaterial release in different environmental compartments (soil, air & water) can be collected which will helpful to anticipate and prevent potential environmental problems related to nanotechnology developments upstream, rather than reacting to them downstream. Therefore, development for infrastructure of nanosafety is immediate requirement. In India, there are 300 companies who are manufacturing nanomaterials, nano based products. Still there is no legislative requirement to provide data about the nature of nanomaterials produced & emitted during the manufacturing process. Central Pollution Control Board in coordination with other relevant ministries should take step to implement regulations which require nanomaterial manufacturer to submit information about nanomaterial production levels, type of nanomaterial produced & should also require to company to do in-house toxicity test & make them available to regulatory agencies & also public. There is also a generic requirement for labelling the nano based product by nanomaterial based product manufacturers. Government should also couple regulatory framework for engineered nanomaterial with standardization to promote good practices. By implementing suggested ways, government agencies can move forward responsibly so that ultimately nanotechnology and its products can succeed in eyes of developers', researchers', regulators', and the public's eyes.

7. ACKNOWLEDGEMENT

The authors are grateful to Director, CSIR- NISTADS for his support for this research and his valuable suggestions. I would also like to thank you Dr. Sujit Bhattacharya, Senior Principal Scientist, CSIR-NISTADS for his support.

REFERENCES

[1] UNICEF, Diarrhoea: why children are still dying and what can be done. http://www.unicef.org/media/files/Final_Diarrhoea_Report_October_2009_final.pdf, 2010.

[2] Research, A.G., water and wastewater treatment opportunity in India. 2011.

[3] Lakshmi K. V., Nagrath K. & Jha A., Access to Safe Water: Approaches for Nanotechnology Benefits to Reach the Bottom of the Pyramid. Final Technical Report May 2011. 2011.

[4] ITF, J., Private Sector Participation in the Water and Waste Water Industry. Innovative Technologies in Water Sustainability, March 2011.

[5] Agarwal A. and Joshi H., Application of Nanotechnology in the Remediation of Contaminated Groundwater: a short review. Recent Research in Science and Technology, 2(6), 51-57, 2010.

[6] Rajan C. S. Nanotechnology in Groundwater Remediation. International Journal of Environmental Science and Development, 2(3), 40-45, 2011.

[7] Hoek E. M. V., Pendergast M. T. M. and Ghosh A. K. Nanotechnology-Based Membranes for Water Purification, 2009.

[8] Qu X., Alvarez J. J. P. & Li Q., Applications of nanotechnology in water and waste water treatment. Water Research, Volume 47, pp. 3931-3946, 2013.

[9] Bhattacharya S., Shilpa and Bhati, M., China and India: The Two New Players in the Nanotechnology race, 93 (I), 59-87, 2012.

[10] Department of Science and Technology. Water Technology Imitative Programme, 2007 http://dst.gov.in/scientific-programme/t-d-wti.htm

[11] Department of Science and Technology, Nanomission Programme, 2011. http://nanomission.gov.in/

[12] Bureau of Indian Standards. Retrieved from http://www.bis.org.in/sf/nano.htm.

[13] ISO Technical Committee- Nanotechnology. (n.d.). Retrieved from http:www.iso.org/iso/standards_development/technical_comittees/list_of_iso_technical_committees/iso_technical_committee.htm?commid=381983.