Sensors & Transducers, Vol. 169, Issue 4, April 2014, pp. 265-270

www.sensorsportal.com

Sensors & Transducers

http://www.sensorsportal.com

Microbiology and Nanotechnology: Focus on the Negative Impacts of Nanomaterials on Human Health and Environment

Ying Jian Chen
Institute of Scientific and Technical Information of China,
No. 15 Fu Xing Road Beijing, 100038, China
Tel.: +86 10 58882110, fax: +86 10 58882015
E-mail: cyjmail123@163.com

Received: 14 March 2014 Accepted: 14 April 2014 Published: 30 April 2014

Abstract: Microbiology, the multidisciplinary science of microorganisms, relates to nanotechnology at a number of levels. For example, many nanotechnology applications, including biomaterials, vaccines, chemical tools, and molecular electronic materials, have been approached using viruses. In the present study, some latest research progresses on the potential negative impacts of engineered nanomaterials on human health and the environment are reviewed. Open problems about such aspects are addressed. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Microbiology, Engineered nanomaterials, Potential impacts, Human health, Environment.

1. Introduction

Microbiology has a major impact on the world. With its roots in the 19th century, it matured into a scientific discipline concerned with the structure, function, and classification of these organisms and with ways of controlling and using their activities. It continued to evolve into the major subdivisions of microbiology, which include medical, industrial, agricultural, food and dairy. Microbiology is used to treat major pandemics and common infections. It also has an impact on the food people consume and the manufacture of key industrial products. The tools used to deal with microbiology are as varied as their multitude of uses [1].

In recent years, nanotechnology (NT) research has begun making tremendous progress in the biomedical field, and researchers are now focusing their attention on analyzing the events at the molecular and cellular level. NT tools are already advancing our understanding of how bacteria work, while providing new opportunities to probe the dynamic and physical aspects of molecules, molecular assemblies, and intact microbial cells, whether in isolation or under in vivo conditions. On the other hand, NT tools applied to microbiology are likely also to have a major impact on the emerging fields of systems biology. Ultimately, researchers seek to understand the orchestrated interplay of molecules in regulating cell functions — a complicated and difficult task that will require us learning how to reconstitute functional modules *ex vivo* [1-2].

NT is concerned with the study of processes at the nano-scale by objects that are generally smaller than 100 nm. Much of the study of NT relates to the phenomenon of self-assembly in which nano-scale building blocks self associate to form complex structures. A quintessential tenet of NT is the precise self-assembly of nanometer-sized components into ordered devices.

Microbiology relates to NT at a number of levels. For example, many bacterial entities are nano-machines in nature, including molecular motors like pili. Bacteria also form biofilms by the process of self-assembly. The formation of virus capsids is a classical process of molecular recognition and self-assembly at the nano-scale [3-5].

Engineered nanomaterials (ENMs) are generally regarded as man-made materials with at least one dimension below 100 nm. Nanoparticles (NPs) can occur naturally (e.g. ash, colloids, large biomolecules) or can be produced unintentionally (e.g. diesel exhaust) but concern over the potential adverse environ- mental and healthy impacts of NPs has been directed at ENMs.

ENMs can be divided into four different classes:

• Carbon-based materials (e.g. fullerenes),
• Metal-based materials (e.g. TiO_2 NPs),
• Dendrimers (e.g. nano-sized polymers),
• Composites (i.e. mixtures of NPs).

NPs typically have different physicochemical properties compared to their respective bulk material, including different optical properties, thermal behavior, material strength, solubility, conductivity and catalytic activity [6]. Probably the most significant change in the properties of NPs is the increase in surface to volume ratio. The proportion of atoms at the particle surface increases inversely with particle size, so that the surface properties of NPs can dominate the properties of the bulk material. These particles can also transfer energy to nearby oxygen molecules. Exposure to oxyradicals can lead to cell damage and death. NPs are similar in size to biological macromolecules such as proteins, DNA and phospholipids, so it is possible that NPs can cause disruptions at the molecular and cellular level. Many other physical and chemical factors can influence the toxicity of NPs, including surface reactivity, the dissolution ratio and particle shape.

2. The Potential Impacts of Engineered Nanoparticles (ENPs) on Human Health

NPs may be small, but they are at the center of a huge debate. Nanotechnology has great potential for industry and society, but we need more awareness of the potential impact of ENPs on human health and the environment to ensure that its products are safe. Nanotechnology is expanding quickly and research is needed to understand its associated risks.

2.1. Are Carbon Nanotubes (CNTs) the “New Asbestos” ?

The demand for CNTs is increasing because they have unusual properties, such as unique electrical properties. However, their needle-like shape is similar to asbestos, raising questions about their safety. A recent study [7] conducted on mice indicates that a specific type of CNT does have asbestos-like effects.

CNTs are cylindrical carbon molecules, typically a few nanometers in diameter. They are very strong, conduct heat efficiently and have unique electrical properties that make them potentially useful in many fields such as optics and electronics. The demand for CNT is expected to grow. However, there are concerns about their potential health hazards due to their superficial resemblance to asbestos. Exposure to asbestos causes a specific type of cancer called mesothelioma and there are concerns that CNT may also cause this cancer.

The research exposed mice to different types of asbestos, carbon nanoparticles (CNPs) and multi-walled carbon nanotubes (MWNTs). MWNTs consist of many nanotubes stacked inside each other. The mice were exposed to the substances in the lining of their abdominal cavity which is similar to the lining of the human chest cavity which is affected by asbestos and where mesothelioma normally arises. Indicators of the harmful effects usually caused by asbestos were monitored, such as inflammation and the production of scar-like structures or lesions.

The results revealed that only long MWNTs show asbestos-like behavior. However, the authors point out that their test was specific for fibers and that nano-carbon in the form of particles could be harmful in ways that are not addressed in this study. This flags up the importance of choosing the correct method of evaluating toxicity.

Although the results do suggest a link between long CNT and the cancer caused by asbestos, it remains unknown whether there will be sufficient exposure in the environment or workplace to actually cause it. This indicates that there needs to be more in-depth research into exposure levels of long CNT before their use becomes more widespread.

2.2. The Effects of Sunscreen NPs on Skin DNA

Sunscreens, particularly those using ZnO, represent one of the most commonly used nano-technology-based products. In its traditional form, ZnO remains white on the skin, but many sunscreens use its nano-form. ZnO NPs scatter less light so that the sunscreen appears clear. Despite its popularity, there is still a lack of information on possible interactions between ZnO NPs and DNA in the skin.

A new study [8] indicates that ZnO NPs have the potential to cause damage to DNA in human skin cells. These NPs are used as UV filters in sunscreens in many parts of the world. The study exposed human cells from the epidermis (the top layer of skin) to various concentrations of ZnO NPs. A number of responses and changes in the cells were monitored at different periods of time (between 3-48 hours) to evaluate the level of exposure to ZnO NPs that might damage skin cells.

The results revealed significant damage to DNA from ZnO NPs at two of the higher concentrations (0.8 micrograms/ml and 5 micrograms/ml), after six hours of exposure. The data also demonstrated that the NPs caused oxidative stress in the cells, even at low concentrations (0.008 to 0.8 micrograms/ml). Oxidative stress produces “free radicals” and has been implicated in skin cancer. These results are significant as the concentrations studied are much lower than those actually found in sunscreens (quantities vary, but can be around 160 milli-grams/ml). The authors suggest that care should be taken with ZnO NPs used in sunscreens as well as while handling them.

2.3. Testing the Toxicity of NMs

Materials that damage DNA can cause human cells to mutate, which can eventually lead to cancer. The new findings [9] are evidence that precautionary measures need to be put in place to protect manu-facturing workers from these risks.

The researchers investigated two NMs already commercially available: CNTs and graphite nano-fibers (NFs). Previous research has shown that CNTs can cause mesothelioma (a type of cancer) in mice, in a similar way to asbestos. The scientists treated cultured human lung cells with the NTs and NFs, and observed changes in the DNA. Both the NMs caused DNA damage in the cultured cells, and there was a direct link between the dose of CNTs and the amount of damage.

In manufactured goods, NPs are usually permanently bound in a matrix, so they are not a risk via inhalation. However, if NPs are free in the atmosphere (e.g. during manufacture), studies like this suggest they could be hazardous. So it is necessary to introduce regulations to protect human health from the risks of inhaling NPs.

2.4. Predicting the Inflammatory Potential of NPs

Despite the many benefits of using NMs, concerns have been raised about the effects of these particles on human health. Of particular concern is the potential of some of these particles to cause inflammation in the lungs if they are inhaled. Inflammation is the immune system’s response to irritants.

Until now, researchers have largely relied on animal tests to test whether NPs could cause inflammation. A new research [10] explored the potential of a range of simple in *vitro tests* to replace animals as a means of screening NPs for toxicity. The researchers compared the set of tests with findings in rats, to determine whether the in vitro tests produced similar findings.

In this study, rats were exposed to a panel of metal oxides which are used extensively in industry, to determine the inflammatory response of the lungs to each of the NPs. In addition, four separate tests were conducted on tissue cultures exposed to the different NPs. The results of these tests were compared with the actual inflammatory response detected in the rat lungs.

Only two NPs, nickel oxide and alumina 2, showed significant inflammation of the lungs in the rats. The inflammatory potential of nickel oxide had been anticipated but not that for alumina 2. Three types of alumina NPs had been tested, from different sources and of different sizes. As only alumina 2 had the potential to cause lung inflammation, the researchers suggest that testing one variant of a NP might not give a representative result for all the variants of that NM.

Overall, the research found that the tests could be used to predict the inflammatory potential of metal oxides, though single tests alone were not sufficient. This suggests that in vitro tests could be developed for use in screening metal oxide NPs for potential toxicity, allowing particles to be identified that might need further testing.

The results also suggest the NPs tested have low toxicity. This indicates there is little potential to cause lung disease in people working with these materials. While inflammation is an indicator of irritation, it does not necessarily indicate or cause disease.

2.5. Inhaled NPs Can Enter the Bloodstream

It is important to understand how NPs interact with the body, including what happens to NPs in the lungs, and whether they enter the blood- stream or various cells of the body. This information could help us understand how NPs pose a health risk. A new study [11] considers all forms of NPs (defined here as smaller than 100 nanometers in diameter), both engineered and combustion-derived.

The research suggests that when NPs are inhaled, they can enter the deepest part of the lungs and come into contact with the 140 square meters of folded surface present in the lungs. There is then the potential for the NPs to translocate, or move through the cells lining the lungs, and cross into the fine blood vessels of the lungs. From here they could circulate throughout the body.

Previous studies have demonstrated that a small fraction of NPs can translocate from the lungs to the blood stream and be transported to other parts of the body. This was seen, for example, in studies on the effect of TiO_2 NPs on rats. Whilst it is reasonable to suggest that translocation does happen, the extent of this and its importance for human health is not fully understood. The researchers have suggested that the following areas of investigation are required to understand exactly how NPs interact with the body and whether they could cause any health problems:

• Do NPs need to translocate to the circulation of blood to cause adverse cardio- vascular health problems?

• What happens if NPs accumulate in the body ?

• What happens to NPs that translocate in the body ?

• What are the different mechanisms by which NPs enter the different cells of the body and what factors affect cell uptake of NPs ?

Studies addressing these questions could advance the understanding of how exposure to NPs affects human health.

3. The Possible Effects of ENPs on the Environment

In this section, we focus on the possible effects of ENPs on the environment.

3.1. Discovering how NPs Affect the Environment

Although nanotechnology remains at an early stage of development, ENPs are already interacting with fungi, bacteria and algae in natural ecosystems. A recent study [12] identifies gaps in our knowledge about this interaction. The study indicates five key properties of ENPs which remain unknown:

•*At which concentrations do ENPs become problematic in terrestrial, aquatic and atmospheric environments*? Environmental NP quantities and concentrations are unknown, as are the concentrations at which ENPs actually become toxic to organisms.

• *Which physical and chemical characteristics of ENPs determine their behavior*? The high surface area to volume ratio of ENPs increases their reactivity and chances of binding to other molecules or ENPs, but their behavior will change according to their surroundings. For some uses, ENPs are treated to prevent them from clustering with other particles, which can cause them to settle in sediments and reduce their availability to organisms. However, some ENPs are deliberately treated to maintain their separated status, for example, in uses such as environmental remediation of water or land.

•*How do ENPs enter cells*? Some small molecules can pass through the cell walls of fungi, algae and bacteria. Airborne ENPs can accumulate on leaves, where they may be able to penetrate cells. Experiments have revealed that fungi can incorporate ENPs from soil, via their roots.

• *Which properties of ENPs cause toxic effects*? The increased reactivity of ENPs may affect photosynthesis and respiration. Studies have revealed relationships between high concentrations of some ENPs and reduced plant growth, or increased permeability of bacterial cells. Indirect toxic effects due to ENP accumulations include increased cell weight and reduced fertility of seaweeds. They may also prevent photosynthesis by reducing nutrient absorption. The toxicity of other pollutants may also be affected.

• *Do ENPs accumulate in the food chain*? ENPs have been observed to remain within bacterial cells for long periods and so may accumulate in larger organisms. Various environments may cause several different toxic behaviors at different levels of the food chain.

3.2. Assessing the Eco-toxicological Risks of NPs

A new study [13] highlights the need for more research aimed at understanding the effects of NPs on the environment. The study discusses ENPs, including NTs and metal oxides. Although certain industrial uses of ENPs are covered under existing regulation, there are currently no specific regulations designed for these materials in the world. This is due to a lack of information on the behavior of ENPs in environmental systems.

In addressing this problem, the researchers consider a range of different methods for characterizing and detecting ENPs in environmental systems. Since eco-toxicity depends on a number of different properties, including size, shape and structure, it is important to understand the exact properties of NPs under scrutiny. Crucially, changes to any of these properties can change the environmental behavior of NPs and this must be taken into account when assessing the risk associated with each type of ENP.

The sheer range and diversity of ENPs, means that no single method can be used for detecting and quantifying such particles. For instance, microscope-based approaches might be suitable for detecting ENPs in water, while combinations of separation methods with sophisticated analytical techniques will need to be employed for systems including sludge, soils and sediments.

The researchers call for environmental testing standards to be agreed that will allow for better comparison and interpretation of data from different studies. This science is in its infancy and requires the cooperation of researchers from many different fields, as well as collaboration between industry and academia.

3.3. How NTs Could be Released into the Environment

CNTs are a group of NPs with remarkable physical and chemical properties. They are a promising material for a wide range of future technologies, including sports equipment, textiles and rechargeable batteries. However, questions have been raised about their safety. It is therefore important to understand how they could be unintentionally released into the environment in order to implement precautionary measures.

A recent study [14] investigated possible ways in which CNT can be released from products leading to exposure of humans. Taking a lifecycle perspective, the researchers assessed two classes of mass produced products that may contain CNT in future. These were rechargeable batteries (used in mobile phones) and synthetic textiles (used in expensive sportswear).

Although the researchers found that CNT are unlikely to be released from batteries during normal use, they could be emitted during the production, recycling and disposal stages of their life-cycle. Improper processing can cause CNT to be released into the air as dust. Battery recycling and recycling of metal from waste incineration residues in particular could cause occupational exposure to CNT. Incinerating batteries together with household waste would probably not degrade the CNT in the batteries. Environmental exposure could also occur if batteries are disposed of in landfills or dumpsites.

Release of NTs from textiles during use cannot be ruled out. Wear- and- tear could release CNT and lead to human exposure as garments are worn close to the body. CNT could also be released during recycling and disposal of used textiles. Used textiles are not subject to hazardous waste management. They are either exported oversees as second hand clothes or disposed of as household waste. While the fate of old textiles in developing countries is uncertain, the researchers assume that they may be disposed of in these regions through open burning. This would cause emissions of CNT since only incineration above 850°C eliminates CNT. Only modern waste incinerators operated properly could reach the required temperatures to degrade CNT.

Both case studies demonstrate that CNT can be released at various stages during the life cycles of products, and in an uncontrolled manner. Unless the adverse health effects of CNT can be ruled out, human exposure represents a risk.

The researchers adopt the precautionary principle and conclude that release of CNT from products should be avoided. Responsible product development is necessary in order to ensure the safety of workers and consumers, and should be implemented at an early stage in the innovation process of nano-technology. Product designers should ensure that CNT are integrated into the product in a way which prevents release throughout the product’s life cycle.

3.4. Managing Exposure to NPs in the Workplace

The manufacture and use of NMs is increasing. Although this is creating more jobs, those working in these industries are likely to experience the earliest and greatest exposures. Little is known about the consequences of exposure to NMs in the workplace, but it is vital that risk management strategies are in place to minimize potential harm.

A new study [15] reviews an existing framework of occupational risk management and describes possible methods for controlling exposure to NMs in workplaces. The study considers a well-known conceptual framework of company health and safety for possible application to the management of NMs. It identifies the primary concerns for exposure as inhalation and skin contact during the manufacture and use of NMs. It also lists possible jobs and operations that have a greater potential exposure after the manufacture of NM containing products, such as machining, sanding or drilling materials containing NPs. As part of this framework, recommendations were made for controlling exposure to NMs. However, control may need to be more rigorous for NPs than for larger particles because they have greater potential toxic effect for a given weight.

The first suggested method of control is to eliminate or substitute NMs. However, since NMs are produced for their unique properties, a more feasible approach might be to coat the particle with a less hazardous material or change its form. Another approach would be to isolate or contain the NPs until they are bound in a product, or use ventilation systems to capture airborne particles that might be released.

Administrative controls are also possible, for example, limiting the time a worker is exposed to NPs. Personal protective equipment such as respirators, gloves and protective clothing can also be used. Additionally, monitoring the environment and the workers helps ensure that controls are effective in preventing harmful exposure.

Acknowledgements

This work was partly supported by the National Science and Technology Support Program of China under Grant No.2012 BAC20B09.

References

[1]. Colin Harwood and Anil Wipat, Microbial Synthetic Biology, *Academic Press*, 2013.

[2]. Marianne Manchester and Nicole F. Steinmetz, Viruses and Nanotechnology, *Springer*, 2008.

[3]. James Chapman, Timothy Sullivan and Fiona Regan, Nanoparticles in Antimicrobial Materials: Use and Characterization, *Royal Society of Chemistry*, 2012.

[4]. Pratik Singh, Maria J., Gonzalez and Marianne Manchester, Viruses and their uses in nanotechnology, *Drug Development Research*, Vol. 67, Issue 1, 2006, pp. 23-41.

[5]. L. Zhang, D. Pornpattananangkul, C.-M. J. Hu and C.-M. Huang, Development of nanoparticles for anti-microbial drug delivery, *Current Medicinal Chemistry*, Vol. 17, Issue 6, 2010, pp. 585-594.

[6]. Igor Linkov and Jeffery A. Steevens, Nanomaterials: Risks and Benefits, *Springer*, 2009.

[7]. Craig A. Poland, Rodger Duffin, Ian Kinloch, Andrew Maynard, William A. H. Wallace, Anthony Seaton, Vicki Stone, Simon Brown, William MacNee and Ken Donaldson, Carbon nanotubes introduced into the abdominal cavity of mice show asbestos-like pathogenicity in a pilot study, *Nature Nanotechnology*, Vol. 3, Issue 7, 2008, pp. 423-428.
[8]. Vyom Sharma, Ritesh K. Shukla, Neha Saxena, Devendra Parmar, Mukul Das and Alok Dhawan, DNA damaging potential of zinc oxide nanoparticles in human epidermal cells, *Toxicology Letters*, Vol. 185, Issue 3, 2009, pp. 211-218.
[9]. Hanna K. Lindberg, Ghita C.-M. Falck, Satu Suhonen, Minnamari Vippola, Esa Vanhala, Julia Catalán, Kai Savolainen and Hannu Norppa, Genotoxicity of nanomaterials: DNA damage and micronuclei induced by carbon nanotubes and graphite nanofibers in human bronchial epithelial cells in vitro, *Toxicology Letters*, Vol. 186, Issue 3, 2009, pp. 166-173.
[10]. Senlin Lu, Rodger Duffin, Craig Poland, Paul Daly, Fiona Murphy, Ellen Drost, William MacNee, Vicki Stone and Ken Donaldson, Efficacy of simple short-term in vitro assays for predicting the potential of metal oxide nanoparticles to cause pulmonary inflammation, *Environmental Health Perspectives*, Vol. 117, Issue 2, 2009, pp. 241-247.
[11]. C. Mühlfeld, P. Gehr and R. Rutishauser, Translocation and cellular entering mechanisms of nanoparticles in the respiratory tract, *Swiss Medical Weekly*, Vol. 138, Issue 27-28, 2008, pp. 387-391.
[12]. E. Navarro, A. Baun, R. Behra, N. B. Hartmann, J. Filser, A. J. Miao, A. Quigg, P. H. Santschi and L. Sigg, Environmental behavior and ecotoxicity of engineered nanoparticles to algae, plants and fungi, *Ecotoxicology*, Vol. 17, Issue 5, 2008, pp. 372-386.
[13]. K. Tiede, M. Hassellöv, E. Breitbarth, Q. Chaudhry and A. B. Boxall, Considerations for environmental fate and ecotoxicity testing to support environmental risk assessments for engineered nanoparticles, *Journal of Chromatography A*, Vol. 1216, Issue 3, 2009, pp. 503-509.
[14]. Andreas R. Köhler, Claudia Som, Aasgeir Helland and Fadri Gottschalk, Studying the potential release of carbon nanotubes throughout the application life cycle, *Journal of Cleaner Production*, Vol. 16, Issue 8-9, 2008, pp. 927-937.
[15]. P. Schulte, C. Geraci, R. Zumwalde, M. Hoover and E. Kuempel, Occupational risk management of engineered nanoparticles, *Journal of Occupational and Environmental Hygiene*, Vol. 5, Issue 4, 2008, pp. 239-249.