

COMMENTARY

The multi-facets of sustainable nanotechnology – Lessons from a nanosafety symposium

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Abstract

An international symposium for nanosafety was held recently at the Nanyang Technological University in Singapore. Topics relating to understanding nanomaterial properties, tools, and infrastructure required for predicting hazardous outcomes, measuring nanomaterial exposure levels, systems approach for risk assessment and public's perception of nanotechnology were covered. The need for a multidisciplinary approach, across both natural and social sciences, for developing sustainable nanotechnology solutions was heavily emphasized. This commentary highlights the major issues discussed and the commitment of the nanosafety research community in Singapore to contribute collectively to realise the vision of sustainable nanotechnology.

Keywords

Nanoparticles, nanotechnology, nanotoxicology, occupational health, risk assessment

History

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It has been a decade since the health and safety concerns over the applications of nanotechnology and nanomaterials were recognized by the scientific community (The Royal Society and The Royal Academy of Engineering, 2004). A plethora of potential risks has been suggested (Donaldson, et al., 2004; Juillerat-Jeanneret, et al., 2015) while cutting edge innovations and advances in nanotechnology continue to flourish. As nanotechnology advances, we have to strive to find, maintain, and continuously improve an approach of sustainable nanotechnology wherein the technology is designed to improve the quality of life, without causing any unintentional harm to human health and the environment. Strategies to achieve this objective were recently discussed at “*The International Symposium for Nanosafety: Social, Environmental and Health Impacts*”, organized by Nanyang Technological University, Singapore, during 17–18 November 2014 (<http://conference.ntu.edu.sg/nanosafe>). The

symposium was attended by over 100 participants, bringing together researchers and practitioners of nanotechnology, materials science, nanotoxicology, nanomedicine, exposure assessment, occupational health and safety, and social sciences. Realizing the importance of a multidisciplinary approach for developing sustainable nanotechnology solutions, topics relating to the nanomaterial properties that dictate their beneficial and hazardous outcomes, tools, and infrastructure required for predicting hazardous outcomes and for measuring nanomaterial exposure levels, systems approach for risk assessment over the value chain of nanotechnology development and public's perception of nanotechnology were covered in this symposium. This commentary highlights the major issues discussed and new understandings that emerged during the symposium.

What can we learn from the social sciences?

Technological innovations become more meaningful when they are positively perceived and accepted by society. History has shown us that neglecting public sentiment could severely impede the development and adoption of emerging technologies. It was emphasized at the symposium that nanotechnology is generally perceived as beneficial by societies although regional differences in acceptance do exist (Scheufele et al., 2009), which are likely driven by differences in social values and beliefs, rather than knowledge about nanotechnology itself. Nonetheless, there are conflicting information on the promises and perils of

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nanotechnology. The challenge is in balancing risk and benefit information in an environment where often, “the best story sells” remains. It is, therefore, necessary to engage social scientists to understand and foster effective science communication with the public, governments, and regulatory bodies. In fact, the need to align scientific efforts with societal concerns and aspirations is becoming more evident as nanotechnology enters the ‘translation phase’ in its growth curve.

Nanotoxicology: what have we achieved so far?

It has been a decade since nanotoxicology was recognized as a sub-discipline of toxicology dealing with the potential hazardous properties of nanomaterials (Oberdörster et al., 2005). Since then, our understanding of various properties that determine biological outcomes has improved. Unlike many of the chemicals that are used in industrial processes, the majority of nanomaterials are scrutinized for toxicity at the pre-market stage. Identification of properties that could potentially lead to adverse effects in humans and the environment has in some instances helped to frame control measures and formulate exposure limits. For instance, high aspect ratios and bio-persistence were identified as potential injury inducers of carbon nanotubes. Based on the outcomes of controlled studies, regulatory bodies could identify permissible exposure levels and suggest precautionary measures to minimize work-place exposure specifically to carbon nanotubes. Unfortunately for the majority of other nanomaterials, there exist a significant amount of uncertainties in data generated from controlled toxicology studies, due to non-standardization in methodologies, making it difficult for regulatory bodies to make prompt decisions. There is, thus, a pressing need to improve and harmonize methods and measures to better facilitate future decision making.

What do we need to keep up with innovations in nanotechnology?

It was recognized that conventional toxicology tools for safety screening of the rapidly growing list of nanomaterials have inherent limitations. As such there is increasing demand for safety screening strategies that could be adopted by industries during the product development phase so that the chances for passing subsequent toxicology testing are high, in order that earlier investments are not wasted. Therefore, we need to develop

screening platforms and governance agendas that can cope with the growing list of nanomaterials. A paradigm shift in using *in vitro* and small animal models with high-throughput capability as the first line of screening was proposed, as opposed to the conventional strategy of using animal models (Kathawala et al., 2013). The rationale is the use of cellular and molecular pathways that are predictive of possible pathology conditions in the whole organism. While promising, it will be a challenge for the scientific community to identify and develop appropriate validation strategies for the inclusion of predictive nanotoxicity testing methods as accepted models for governance and regulatory purposes. Separately, unlike conventional chemical testing, nanotoxicology screening platforms will need to specifically consider physico-chemical properties of nanomaterials because these will directly affect dosimetry profiles and interaction mechanisms. Another major challenge in the risk assessment of nanotechnology is the limited data on the exposure levels of nanomaterials. Advancements in analytical techniques and validated protocols for the detection and quantification of nanomaterials in complex scenarios and matrices are urgently required for proper risk assessment. Finally, the mechanistic understanding of nanomaterials’ properties in relation to their hazard potential should constitute working principles for designing safer nanomaterials and nanotechnology applications.

How are nanosafety issues different in relation to demographics?

From a broad perspective, considerations based on demographic differences are necessary for societies to effectively manage various issues related to nanosafety. As examples, the influence of traditional and social media on publics’ perception to nanotechnology could change depending on a the population’s education level and trust in governing bodies (George et al., 2014); differential prevalence of nanomaterial release into the environment could be influenced by reliance on either incineration or landfills for product end-of-life treatment; exposure risks to nanomaterials found in the same products could vary significantly between populations due to culture or social norm variations, or simply differing consumer preferences.

From the thorough discussions across a wide range of topics covered in the symposium, it was clear that after a decade, we are still far from the goal of formulating relevant strategies to manage risks associated with nanotechnology. The challenge of deriving

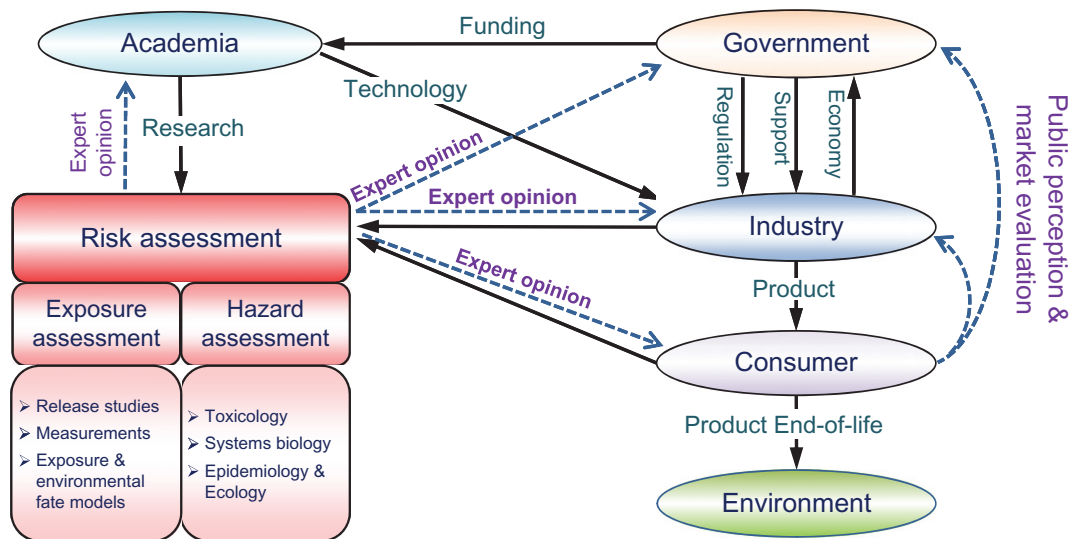


Figure 1. Schematic of the multifaceted crosstalks needed to realize sustainable nanotechnology solutions.

a universally acceptable and practically adaptable definition of a nanomaterial itself remains, although several bodies have made some progress in identifying boundaries to define a nanomaterial (Kreyling et al., 2010). It was also evident that ramping up inter-disciplinary research is a promising way forward and that such efforts should go beyond collaborations between the more obvious disciplines (Figure 1). Notably, greater involvement of social scientists could bring new strategies and knowledge especially in terms of effective communication to mitigate potential public and government concerns and foster positive engagement regarding governance of nanotechnology risks and benefits. In line with this understanding and growing demands to advance our knowledge of Nanosafety, the symposium witnessed the launch of nanOsing [www.nanOsing.org], which is a platform for multidisciplinary collaborations of prominent leading research and consultancy groups in Singapore, dedicated to developing and applying world-class multidisciplinary science for the assessment of health and environmental risks of nanotechnology in Singapore. NanOsing is the first South East Asian attempt of a multifaceted approach to manage nanosafety, inspired by successful examples from Europe (NanoImpactNet) and the USA (NNI, UC-CEIN). The successful organization of the symposium and the launch of nanOsing demonstrate the commitment of the nanosafety research community in Singapore to seek and foster new partnerships across disciplines and to promote critical dialogue between various stakeholders, so as to improve current strategies for managing nanosafety in Singapore and beyond, to realise the vision of sustainable nanotechnology.

Declaration of interest

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References

- Donaldson K, Stone V, Tran CL, Kreyling W, Borm PJ. 2004. Nanotoxicology. *Occup Environ Med* 61:727–8.
- George S, Kaptan G, Lee J, Frewer L. 2014. Awareness on adverse effects of nanotechnology increases negative perception among public: survey study from Singapore. *J Nanopart Res* 16:1–11.
- Juillerat-Jeanneret L, Dusinska M, Fjellsbo LM, Collins AR, Handy RD, Riediker M. 2015. Biological impact assessment of nanomaterial used in nanomedicine. Introduction to the NanoTEST project. *Nanotoxicology* 9(S1):5–12.
- Kathawala MH, Xiong S, Richards M, Ng KW, George S, Loo SCJ. 2013. Emerging *in vitro* models for safety screening of high-volume production nanomaterials under environmentally relevant exposure conditions. *Small* 9:1504–20.
- Kreyling WG, Semmler-Behnke M, Chaudhry Q. 2010. A complementary definition of nanomaterial. *Nano Today* 5:165–8.
- Oberdörster G, Oberdörster E, Oberdörster J. 2005. Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles. *Environ Health Perspect* 113:823–39.
- Scheufele DA, Corley EA, Shih TJ, Dalrymple KE, Ho SS. 2009. Religious beliefs and public attitudes toward nanotechnology in Europe and the United States. *Nat Nanotechnol* 4:91–4.
- The Royal Society and The Royal Academy of Engineering. 2004. Nanoscience and nanotechnologies: opportunities and uncertainties. RS Policy Document 19/04. London: The Royal Society, 116.