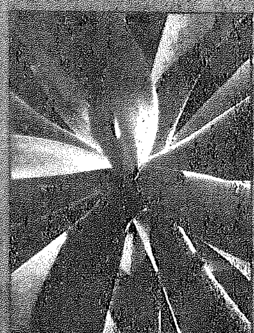
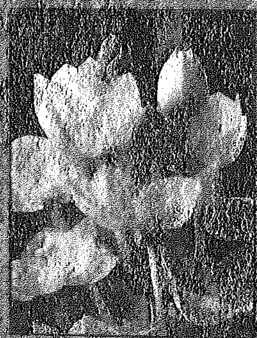
Ecotoxicology Research Developments

Eduardo B. Santos
Editor

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Expert Commentary

Nano(Eco)Toxicology – Giving the Matter Some Thought

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Science is in itself cumulative, draws upon knowledge on knowledge. Ecotoxicology is no exception. The term ecotoxicology was introduced by Truhaut by the end of the sixties, and was defined as "the branch of toxicology concerned with the study of toxic effects, caused by natural or synthetic pollutants, to all levels of biological organization from the molecular to whole communities and ecosystems, in an integral context" (Truhaut, 1977).

Knowledge has been gathered leading to developments in the field of quantifying and measuring effects, ecosystem monitoring or modelling, being prediction of pollution effects, the ultimate goal of ecotoxicology.

In perspective and despite the earliest acute toxicity tests being dated mid nineteenth century, where toxic chemicals in industrial waters were the matter of concern, the first standard method was not published until 1945 (Penny and Adams, 1863; Weigelt, Saare and Schwab, 1885, Hart *et al.*, 1945 *in* Hoffman *et al*, 1995). The crustacean *Daphnia magna* began to be used to evaluate pollution (Ellis, 1937 *in* Hoffman *et al.*, 1995) and the use of aquatic organisms to evaluate wastewaters gave raise to its description as bioassays (Doudoroff *et al.* 1951).

Bioassays were developed, and different assays come up in the field of aquatic toxicology or terrestrial toxicology. Different exposure times were run, from acute to chronic and for different species or different life stages. On the matter "what to measure?" different endpoints were established either at the organism or sub-organism levels e.g. behaviour, feeding rates, growth, immobilization, reproduction, enzyme activities or DNA. Also different matrixes have been studied like water, wastewaters, soils, sediments, elutriates or substances more or less soluble. For non-soluble substances the use of vectors have been used and discussed. Actually there is a large amount of standard procedures involving different species e.g. ISO 10253:1995; ISO 6341:1996; ISO 8692:2000; ISO 10706:2000; ISO 20079:2005; ISO 11348-3:2007. Acquired knowledge gave raise to other issues such as the need to understand persistence and bioaccumulation of substances in organisms, besides toxicology. Related to risk, methodologies have been developed for risk evaluation, assessment and management. National laws and community laws related namely to chemicals or wastes evolved from chemical controls to an integrated approach where physical, chemical, toxicological and ecotoxicological aspects need to be taken into account, e.g. REACH regulation (EC 1907/2006), meaning that there is the need to be able to assess effects besides measuring or characterizing a substance within the spirit of an integrated approach.

Besides the time needed for evolution, terminology goes together and is an issue in itself. On the importance of terminology, Cairns (1989) wrote that the most appropriate definition of ecotoxicologist was "one assessing effects of toxic substances in the ecosystem" but also pointed out that "(...) we have not yet produced a practical toxicological method with true ecosystem-level endpoints and reliable predictive power (...)."

From Ecotoxicology to Nanoecotoxicology – What Is the Matter?

Measuring the effects of emergent pollutants and of nanomaterial-related in particular is a need while we are already facing the new era of nanotechnology. Those emergent materials and processes are in the order of the day. Facing reality, nanomaterials are not new any more as they are involved in hundreds of products already competing in the market, but our limited perception of the risk puts toxicologists and ecotoxicologists in a rush trying to adapt and develop methodologies to assess the effects of Nanoparticles (NP).

Nanoecotoxicology, as a scientific discipline by its own, was born with the purpose of generating data and knowledge about nanomaterials effects on humans and on the environment, and was defined as the "science of engineered nanodevices and nanostructures that deals with their effects in living organisms (Oberdörster *et al.*, 2005).

In fact, there are huge differences between conventional/bulk and nanomaterial-related scenarios. In addition, due to the challenges and possible negative impacts concerning the latter, if it comes to nanoparticles and the environment on a life cycle perspective (Figure 1), it makes sense to organize an agenda addressing issues like the following:

(a) Unbound materials; functionalized forms; sub products;
(b) Emissions: sources and Dispersion;
(c) Environmental Control;
(d) Ecotoxicology;
(e) Partition and Transformation;
(f) Transport and Fate;
(g) Persistence and Bioaccumulation;
(h) Life cycle assessment;
(i) Sustainable production and consumption;

(j) End of life processing and disposal.

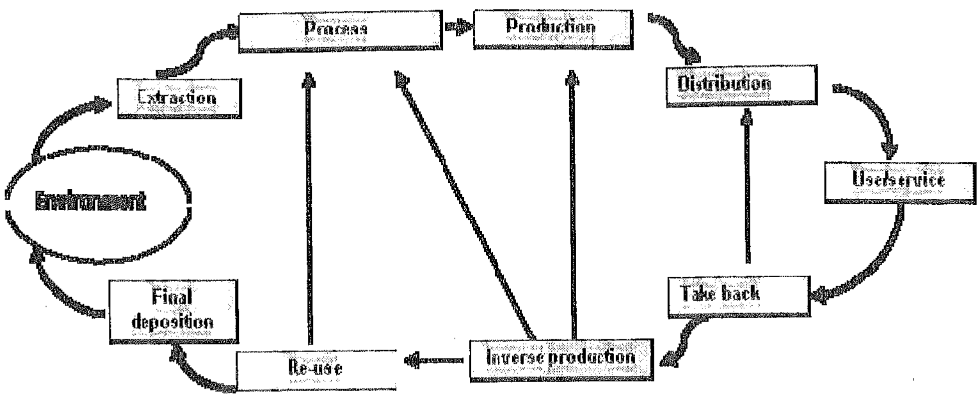

Figure 1. Diagram of a system's life cycle, illustrating their different stages and the need to close loops.

Still due to the sense of risk, adjectives to qualify properties of NP are being used, such as "small length scales dramatically alter the properties of nanoscale objects compared to their bulk counterparts (...)" (Brown *et al.*, 2007). The need of a major revision of how basic physical properties are understood is referred by the same authors as well.

Expressions like "multiple stressors", "relationship among stressors"or "bio-interaction" gain new life due to the different properties of NP and the measure of effects is hardly meaningful in the absence of particle chemical characterization more than mass concentration, e.g. surface area, number of particles, particle size or reactivity properties. What about fate, interaction with organisms or mode of action? It is claimed that little progress is being made towards determining fate, transport, transformation, and ecotoxicological behaviour of these materials once released into the environment.

As Colvin (2002) stated "it is a new development that potential negative health and environmental impacts of a technology or a material is given attention at the developing stage and not after years of application".

Toxicological information and data on nanomaterials are limited and ecotoxicological data is even more limited. Some toxicological studies have been done on biological systems with metals, metal oxides, selenium and carbon in the form of NP; however the majority of toxicological studies have been done with carbon fullerenes.

Only a very limited number of ecotoxicological studies have been performed on the effects of NP on environmentally relevant species, e.g. bacteria (Sayes *et al.*, 2004; Oberdörster, 2004; Brayner *et al.*, 2006; Heinlaan *et al.*, 2008), algae (Hund-Rinke and Simon, 2006), crustaceans (Hund-Rinke and Simon, 2006; Lovern and Klaper, 2006; Oberdörster *et al.*, 2006; Lovern *et al.*, 2007; Heinlaan *et al.*, 2008), fish (Oberdörster, 2004; Kashiwada, 2006; Smith *et al.*, 2007; Handy and Shaw, 2007; Usenko *et al.*, 2008), and plants (Yang and Watts, 2005).

Discussions have been held about integrated and multidisciplinary approaches but we need to go deeper into the real meaning of these words to face this new paradigm and to put the precautionary principle in practice (Raffensberger and Tickner, 1999). Though nanotechnology is presented as a panacea (smaller; cheaper; lighter; faster; less raw materials, less energy consuming) offering real and potential benefits, NP brings serious challenges when entering the environment and the knowledge we have to manage that is certainly not enough. There is no sound knowledge on the nano-bio interactions as well as on its environmental fate. New, innovative strategic approaches need to come out fulfilling the real meaning of nanoecotoxicology viewing the evaluation of risk associated to NP.

As it is commonly perceived for technology in broad sense, it is part of the problem and also part of the solution. New problems bring new challenges and also the need for innovative ways of thinking as well as for holistic methods to tackle these problems in particular if they are of a complex nature. In addition, for innovation to happen, ability is needed to break the current patterns and to explore alternatives that might add value. Building that ability requires enrolling the right people in creative processes, as it is increasingly being demonstrated that the ability of people with different backgrounds, different perspectives and knowledge in different domains to collaborate, increases the creativity process within a group, and in the society as a whole.

Therefore we consider that this matter deserves a structured and systemic thought in the frame of creating sustainable innovations.

New problem formulation is crucial and a new framework is needed: gathering information on engineered nanoparticles, from cradle to grave - including their transport and fate throughout the life cycle of products, and taking three main assessment dimensions: economic, social and environmental.

Understanding and managing emerging complex problems, in the context of society as a whole, has necessarily to integrate risk-related aspects such as: perception, taking, evaluation and management. Focusing on the ecotoxicological context, it has to be stressed, at this stage, that the endpoints need to be revised in order to make it appropriate for effective risk assessments, which in itself needs to break with conventional methodologies.

Producers with actions at a nanoscale will have to assume practices ethically and socially responsible namely regarding safety, health and the environment. In addition, public perception has to be taken into account in order to be managed in due time because of possible risks, and subsequent proactive mitigation or preventive actions. Otherwise if public perception is not conveniently managed an eventual negative perceiveness may happen as it was the case with Genetic Modified Organisms (Vergragt and Brown, 2007). The strategy has to be a holistic, coordinated and enabling approach that integrates the user /consumer into the development process, ensuring highly reliable market evaluation focusing not just on the dynamics of a triple helix made by: people (social), planet (environment) and profit (economy), but on managing as well the technology in Society.

This clearly reduces risk, either in technology development, or in the business environment. SMEs, micro-organisations and other stakeholders working in collaboration with R&D organisations benefit from scientific evaluation methods to test and demonstrate the ideas, concepts, products and services and anticipate market attractiveness.

The Co-design Process by the Living Lab approach, where users and developers actively work together creating the new solutions (Eriksson et al., 2005) takes into account three dimensions: Society, Market and Technology. In this work it was considered that only when the three dimensions are secured the risks of the product/ service having low acceptance, being un-economical or old fashioned, are minimized or disappear (Figure 2). However, research is still needed to create comprehensive models and methods to analyse and measure experiments, as it was pointed out by the Information Society Technical Advisory Group *"The real challenge may lie in involving users in a sociological sense, that is to say, by taking into account the micro-context of their everyday lives" (i2010).*

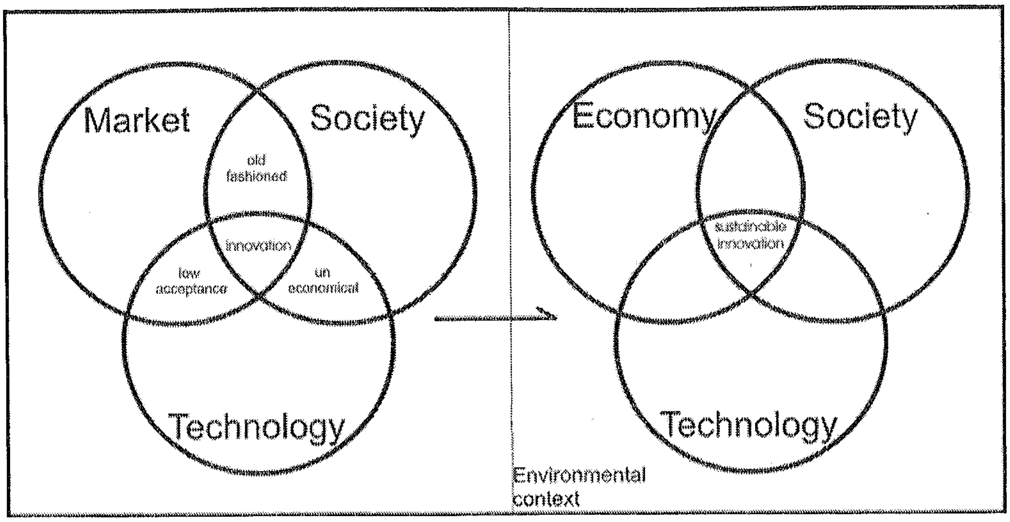

Figure 2. The Eriksson et al., (2005) model and a designed proposal for a new framework for reformulation of nano (eco) technology issues.

The question to be raised is whether this methodological approach could be used to think and to reformulate the complex problems within the frame of nanotechnology and concomitantly the environmental input of the ecotoxicology. Involving all the key stakeholders in the discussion on new methods and endpoints, and bringing into the debate other disciplines and different knowledge, endeavours to fully understand the complexity of this new paradigm.

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