Nano Debate: Part 2

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In the final instalment of a two-part series, the discussion of nanotechnology – still relatively untapped despite years of research – develops further. This time, the focus is on its potentially damaging effects on both human health and the environment

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There is no doubting that engineered nanotechnology (ENT) particles have aided the world in a number of ways: from targeted chemotherapy cancer treatments to transistor structures for lightening-quick computer chips, their uses are vast and varied. But ENT is still in its infancy, which means many important safety questions remain unanswered. Do we really know enough about its effects to be confident that we are not creating a nano-nightmare?

It is worrying that a brief online search into just one area of concern about ENTs – the environment – produces a mass of contradictory results. A confusing picture of potentially bad science is combined with momentous leaps forward in the successful application of ENTs, across all areas of society.

This article will prompt thought and discussion about ENT particle interaction with both humans and the environment by posing a series of questions. Examples of extreme scenarios will be employed to highlight the current understanding of ENTs, and give some sense of where the nano-revolution may end up if it is not properly managed.

In its Infancy

Nanotechnology is still a baby; serious research did not begin until 1981, when the development of the scanning tunnelling microscope finally allowed scientists to start creating engineered nanoparticles (1).

Move forward 33 years and nanotechnology is becoming widespread. If the public is expected to accept ENTs as the next big thing, surely now is the time to be asking serious questions about their potential to be environmentally toxic? And demand to see the scientific data that backs up the safety claims being made? Especially as the use of ENTs is only set to increase, year on year, for the foreseeable future.

Environmental Safety

Sadly, the enthusiasm for testing the environmental safety of ENTs has been somewhat lacking in the scientific community, or at least in those who fund the research. Studies examining the environmental, health and safety issues are not nearly as common or well-funded as those that create and develop new products. For example, the 2015 US federal budget allocated over $1.5 billion to R&D in ENTs, taking the total to $21 billion since 2001 (2). However, the total spend on researching nanotechnology-related environmental issues since 2005 is only $900 million. This fact alone raises serious concerns about how well-tested these products are (2).

For the public to be convinced that ENTs are safe to use, there must be solid scientific data to back up the claims. Quantitative and general risk assessments, as well as firm data on potential health impacts for humans, are the very least that is required for the population to embrace the technology (3).

A 2011 congressional report – *Nanotechnology and Environmental, Health, and Safety: Issues for Consideration* – gave a variety of reasons as to why public concerns over the safety of ENTs need to be addressed. These include:

- "Protecting and improving human health, safety, and the environment"
- "Ensuring public confidence in the safety of nanotechnology research, engineering, manufacturing and use"
- "Ensuring that society can enjoy the widespread economic and societal benefits that nanotechnology is believed by many to offer" (4)

Are Fears Unfounded?

Some argue that the public's fears over the environmental impact of ENTs are simply the result of scaremongering, and that the science does not back up the ecotoxicological claims (5). However, this apprehension is not just felt by the public – there are numerous examples of state organisations and governmental bodies voicing their concerns too.

The report mentioned above highlights the potential of ENTs to be ecotoxic, concluding: "Research to date suggests that some products of nanotechnology have the potential to present new or unusual risks to human health and the environment. For instance, nanoscale particles may penetrate to places in the body that are inaccessible to larger particles; radical changes in behaviour at the nanoscale may render harmful materials considered to be safe in larger-scale and more conventional forms" (4).

Prominent environmental campaign groups have also expressed concern over the use of ENTs, advocating a "precautionary approach". In 2008, Friends of the Earth stated their position on the use of ENTs: "The early warning signs surrounding nanotoxicity are serious and warrant a precautionary approach to the commercialization of all products containing nanomaterials... there should be a moratorium on the further commercial release of sunscreens, cosmetics and personal care products that contain engineered nanomaterials, and the withdrawal of such products currently on the market, until adequate public, peer-reviewed safety studies have been completed, and adequate regulations have been put in place" (6).

Widespread Exposure

The pro-ENT scientists argue that humans are exposed to nanoparticles every day, and from natural sources too – volcanic eruptions, for example, spew huge plumes of volcanic ash high into the atmosphere, which is then carried around the world by weather systems and into the wider environment (7,8). However, the scientific data on nanoparticle-filled volcanic ash clearly show the hugely devastating environmental effects it can create when deposited in large amounts.

Despite the fact that volcanic deposits contain only natural nanoparticles, they are still problematic when inhaled (22), and can produce ash clouds so dense that they create a worldwide cooling effect. This can result in depleted food stocks and widespread famine, as was the case in the Laki fissure system eruption of 1783 (8).

If naturally occurring nanoparticles can produce such devastating effects, what might the outcome of ENTs in the atmosphere be?

Weather Modification

In addition, ENTs pose a further threat in the form of possible weather alterations. This is not far-fetched, as nanoparticle weather modification technology already exists; cloud seeding with silver iodide particles is regularly used in the US today. Authorities at Lake Almanor, Nevada, have been using the non-engineered form of silver in a ground-based, cloud seeding system since 1953 (10), so there is clear evidence that introducing natural nanoparticles into the atmosphere can create changes.

However, these alterations are controlled and expected, and are created by the perfectly-timed release of precise concentrations of nanoparticles into a specific area. Distribution is organised so as to prevent sedimentation and agglomeration (10).

Clearly, all of these factors would be out of human control if an accumulation of discarded ENTs were to build up in the atmosphere, creating unknown outcomes. Again, it may seem a far-fetched approach, but ENTs are – according to *Nanopollution: Hype or Health Risk?* – a "persistent form of pollution which is too small to detect or contain easily", leaving high potential for them to accumulate in the atmosphere (11).

Nanopollution

ENTs, such as fullerenes, are already used in lots of everyday products – lubricants and sports equipment, for example. This inevitably creates waste, small amounts of which will end up in landfill. When this happens, they are exposed to the environment, contaminating the air, water supply and soil. This is an issue because fullerenes are completely non-biodegradable, as are lots of other commonly used ENTs. And, crucially, at the present time, there are no effective methods for determining the quantity of nanoparticles in the environment (11).

The combination of unknown and potentially ever-changing properties with the non-biodegradable nature of ENTs, along with lack of effective detection and removal techniques (12), makes a build-up of ENTs over time unavoidable. How long would it take to arrive at a scenario where ENTs begin changing the climate of the earth?

Fundamental Differences

Using experiments designed to study natural nanoparticles creates another issue: there are fundamental differences between natural nanoparticles and ENTs. ENTs are uniform in size, structure and shape, made of pure nanomaterial and clustered together in large concentrations (13).

These differences in physical characteristics are what give them their unique properties. For instance, nano-TiO2 displays photocatalytic activity, and carbon nanotubes (CNTs) have high tensile strength. This is what makes ENTs so useful, but also unpredictable (2). Natural nanoparticles, on the other hand, are distributed in a diffuse manner in the environment and structured in a random way (13). Surely, these differences make any extrapolation of experimental results for natural nanoparticles to ENTs impossible?

Current Evidence

At present, there is no credible evidence that nanotechnology has any adverse effect on the environment. However, that does not mean that nanotechnology has no potential for ecotoxicity. In fact, the reason why ENTs appear safe is probably due to the lack of funding for relevant studies; because of this, their effects have not yet become apparent, and experiments lack valid scientific tools (14).

The newness of ENT also accounts for the absence of long-term data. As yet, the data are simply not in existence, at least in any credible form, with the result that science does not know what the effects on the environment might be over the coming years (15).

If ENTs are so persistent, with the potential for build-up, would it not be prudent to conduct a number of long-term studies before allowing widespread use?

Laboratory Testing Problems

The issue with laboratory testing is that standard procedures utilise ENT in far higher amounts than those that would be encountered within the natural environment. For example, nanosilver experiments frequently use concentrations of mg/L, when risk assessments show current water concentrations to be in the range of 0.1μg/L (5). However, these large amounts are necessary in order to promote any kind of response at all (13).

Unfortunately, this renders the experiment practically useless, as the properties of some nanoparticles make them prone to agglomerating together. When large amounts of the nanoparticles are used for investigatory purposes, agglomeration is more likely to occur. When this happens, the ENTs can change their properties, and there is the potential for them to become more toxic by altering their bioavailability (5). This makes any results gleaned from experiments designed in this way questionable at best.

Outside the Petri Dish

The external environment is very different to a petri dish in a controlled laboratory. Outside the lab, ENTs could be affected by a number of factors at once, including differences in salinity, concentration, the presence of organic material, and pH values – all of which could cause chemical changes (5).

An example of an ENT and environmental interaction creating an unpredictable situation is demonstrated with C_{60} fullerenes. When C_{60} comes into contact with water-based, naturally-occurring organic materials, it starts to decompose. This alters the C_{60} fullerenes' shape and size, which can also change their properties, making them potentially toxic (5).

In addition, some ENTs are highly polymorphic. This characteristic alone prevents any general statements being made about their behaviour and fate in the environment (16).

The Food Chain

With so little known about ENTs, how can we prevent them from entering the animal and human food chain? And what would happen if they did?

Some testing on animals with CNTs already exists, but unfortunately it is highly contradictory. This difference in the experimental outcomes is likely due to the nature of CNTs. They vary greatly in purity, structure, length, surface chemistry, surface charge and agglomeration behaviours, so consistency in testing techniques is tricky (5).

There is a mouse study, however, that does demonstrate a clear detrimental effect of ENT exposure on animals. The experiment introduced CNTs into the trachea of mice, which caused lung damage (17). Other studies involving fish showed a clear negative impact from CNT exposure (5): spherical fullerenes have been shown to accumulate in cells, potentially damaging the DNA (18), as well as causing brain damage (19).

Obviously, these results raise the question of what then happens when other animals – including humans – eat ENT-contaminated fish. The potential for them to be negatively affected is a very real possibility and could cause issues on a worldwide scale (15). In 2008, the UN Food and Agriculture Organization reported that 115 million tonnes of fish were produced for human consumption, and "globally, fish provides more than 1.5 billion people with almost 20 percent of their average per capita intake of animal protein, and 3.0 billion people with at least 15 percent of such protein" (20). The rapid and potentially devastating contamination of millions of people with ENTs could well become a reality.

Latest Research

From the evidence currently available, a logical conclusion is that, to prove the safety of ENTs, every single one needs to be tested in an agglomerated and singular state; in as close to real-life environments as is possible; under every imaginable climatic variable; and in every scenario the ENT may encounter. Clearly, this is not possible. So, in lieu of this kind of firm data, the public should at least be reassured that science is working on a way to improve the scientific methods used to establish the safety of ENTs and justify their continued use. But is that really the case?

According to a review of US nanotechnology research strategy, it appears to be seriously lacking in a number of areas, and the following assertions were made:

- "Research needs in risk management and exposure assessment were 'poorly defined and incomplete'"
- "Research needs were not presented as 'concrete, measurable objectives' and that no explanation was provided of how success would be measured or the amount of resources required to achieve them"
- The approach used by the Nanoscale Science, Engineering, and Technology Subcommittee for its gap analysis "is flawed and is neither accurate nor complete in laying a foundation for a research strategy" (4)

This fairly damning report of the official strategy for progressing the development and use of ENTs from one of the world's largest producers should have set alarm bells ringing (21). As ENT use progresses unabated, it is imperative that equal amounts of funding and time are invested in creating the right tools for collecting the data needed to adequately evaluate the risks involved with widespread use of ENTs. Otherwise, we could enter a scenario that we are neither prepared for, nor able to, correct.

Future Use?

Looking at the current evidence available and the scientific tools in use, the answer to the first question posed by this article – whether we have enough evidence to ensure we are not creating a nano-nightmare – appears to be a resounding "no". The lack of long-term data, in addition to effective measurement, disposal and testing methods for ENTs, is worrying. This poses a final question: until we have real answers about the multitude of concerns regarding ENTs, surely it would be prudent to consider putting a halt on their development, production and use?

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