THE ROYAL SOCIETY

ROYAL ACADEMY of ENGINEERING

Environmental applications and impacts of nanotechnology
8 December 2003

Summary of evidence presented to nanotechnology working group

The views within this document are a summary of discussion and do not necessarily reflect the views of the Nanotechnology working group

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1 Introduction

Following introductions around the table, the chair of the session suggested that participants may like to approach the environmental implications of nanotechnology from a lifecycle approach. In particular, by considering the entire supply chain, including disposal or re-cycling, it may be possible to form an opinion as to whether the proposed benefits of nanotechnology are real or not.

2 Potential environmental applications and impacts

The discussions began with a short briefing by a representative from the paint industry. It was suggested that nanotechnology may enable the production of paints requiring little or no solvent, and that photo-active nanoparticles such as titanium dioxide may be incorporated into paints for hygiene or self cleaning applications. Future paints or coatings may also be able to react to their environment through the use of 'smart' nanoparticles by changing colour when stimulated by temperature, light or chemical exposure for example. Energy-saving applications could include infra-red reflection to minimise heat-loss. It was noted however that nanoparticles are currently more difficult to produce and so more expensive than conventional technologies. Customers would probably be required to pay more for the extra functionality or effect incorporated into paints or coatings. The use of lighter paints for aircraft was discussed and also the possibility of paints which may register impact damage or prevent organisms from adhering to their surface. The question of possible toxicity and testing was raised, and it was noted that EU manufacturers were required to handle some registered chemicals under controlled conditions in a safe manner, eg use personal protective equipment and extraction. Toxicity testing is done with all new chemicals which require notification, however the effect of particle size in the nanometre range was not generally considered unless there was a specific reason for expecting this to be important. Possible environmental effects of nanoparticles were also mentioned. It was noted that paints gradually erode in the environment, particularly outside, and that paints containing nanoparticles may thus become sources for the release of nanoparticles. There was a general feeling, however, that the erosion of paints which contained nanoparticles would be as coarse flakes of dust, and that nanoparticles would probably not be released as fine dispersions. It was also suggested that nanoparticles might possibly enable the manufacture of anti-fouling paints free from dispersible chemicals like TBT (tributyl tin). In relation to this, the question of possible interactions between nanoparticles and environmental microbes was brought up, however little knowledge was though to exist regarding this. Reference was made to Eva Oberdörster's work, presented at Rice University but as yet unpublished, on effects of nanoparticles on simple organisms in soil and water. It is worth noting that there are a lot of naturally occurring (eg clays) and synthetically produced nanoparticles (eg diesel exhaust) which are already present in the environment.

Following this, a representative from the telecom industry gave a broad overview of his vision for nanotechnology, and its potential impacts on the environment. He saw the potential for benefits in specific parts of product lifecycles and imagined that nanotechnology may enable existing products to be more efficient, and also require less raw materials to produce. Whether nanotechnology would create more or less consumption overall however remained an open question. He then spoke about environmental issues, and suggested that advances in mobile technologies, enabled through nanotechnology, may help to reduce traffic congestion by making traffic flow more easily (through monitoring sensors and mobile internet delivery systems). He also felt that through precision monitoring and dosing, the amount of chemicals used in agriculture could be reduced. He predicted that water shortages would give rise to large-scale population migrations in the next century, and believed that nanotechnology has the potential to alleviate this problem through new methods of desalination and filtration. He brought up the issue of privacy and surveillance, but felt it important to note that miniature sensors and transmitters could also be used to track materials and products all through their life cycle from raw material to disposal.

The next brief presentation came from a microbiologist, who focused on the potential applications for bioremediation that nanotechnology may offer. She noted that today's society has inherited a large legacy of contamination in the environment, partly because methods of cost effective detection and removal have not existed. There was a potential, she noted, for the use of a network of nanosensors to detect specific key pollutants in the environment. This would enable the source of a release to be located, and the pathway to be tracked, and would be particularly useful for monitoring deliberate releases of toxic chemicals such as in a terrorist attack. While sensors do currently exist for the detection of pollution, she felt that nanotechnology would enable a much enhanced, higher density sensor capability. She noted that it would be possible for these sensors to be contained, without release into the environment.

Besides detection, nanoparticles could also be utilised in filters for pollution clean-up. These particles could be fixed on a surface, and hence not dispersed, and due to the large surface area may be more efficient than current techniques for inactivating toxic chemicals. The point was also made that removal of contaminates like arsenic is possible by existing mobilised ligand technology, and it was not clear whether nanoparticles would offer an overall advantage. It was noted that the majority of environmental pollution is currently dealt with by digging and dumping, which is clearly not sustainable. One answer may be the use of bioremediation, in which biological organisms are used to clean up pollution. The problem with the bio-remediation of soil however is that most the pollution particles are not bioavailable, but are locked up within pores in the soil structure. Using nanoparticles, it may be possible to deliberately mobilise pollutants, so that they are bioavailable, allowing organisms to clean them up. In addition, it may be possible to control the rate at which pollutants are released, thus ensuring that the clean-up organisms are not killed by a rapid release.

Another use of nanoparticles in energy generation was discussed. Many microbes can produce hydrogen which can be used as a renewable fuel. However, the localised build-up of hydrogen can inhibit further production by the microbes and it has been proposed that carbon nanotubes could be used to channel away hydrogen from the surface of the bacteria thus enhancing the productivity of hydrogen generation. The question of whether nanoparticles may increase the mutation rate in bacteria was posed, however it was thought that insufficient knowledge existed which could provide an answer.

Thirdly, the effect of nanotechnology on catalysis was introduced. It was noted that catalysts utilising nanoparticles have been used for quite some time. The difference now is in the degree of control in the production of the nanoparticles, and the support structure on which they reside. This allows more uniformity in the size and chemical structure of the catalyst, which in turn leads to greater catalytic activity and the production of fewer by-products. Traditionally, metal-based catalysts were synthesised by breaking down larger pre-cursor molecules, which results in a relatively large size distribution of the metallic catalyst nanoparticles. Now, it is possible to synthesise metal nanoparticles in solution in the presence of a surfactant to form highly ordered mono-disperse films of the catalyst nanoparticles on a surface. Within fuel cells, nanotechnology may enable improvements not only in the fuel cell catalyst, but also in the structures of solid electrolytes. It was noted that as fuel cells run on hydrogen which is produced by the catalytic re-forming of petrochemicals, improvements in catalyst design may also open up the range of petrochemicals which may be utilised in fuel cells.

3 Discussion

The discussion was then opened up to all participants, to raise items of particular interest.
Regarding the filtration of pollutants using nanoparticles, a question was asked as to how close technology is now to designing a surface which can identify and pick out a specific pollutant chemical. Given a choice between 2 and 10 years, it was felt that this would be closer to 2. A question was then asked on whether we are close to dealing with the problem of arsenic contamination in groundwater. The point was made that organic pollutants are easier to deal with as they can be broken down, while inorganic pollutants are generally much more problematic as they have to be removed or immobilised. However, it was thought that, should it be possible for nanoparticles to trap arsenic, there may be a danger that changing conditions (e.g. soil pH) may cause a re-release. A related point was made that it would be likely that organic and inorganic nanoparticles should be regarded differently from an environmental point of view, as the organics would probably be seen as a foodstuff by microbes, while the inorganics would not.

The question was then raised on whether a quantitative lifecycle analysis on the production relative to the potential benefits had been done for nano-engineered catalysts. It was thought that this had not been carried out, although it was believed that enough was known regarding the processes in order to carry out such a study.

On the issue of regulations, the question was raised as to whether to regard nanoparticles as new chemicals. The point was made that definition of the nanoparticle may be difficult, and it was suggested that it may be characterised according to its response to various known chemicals. The issue of measurement was then raised, and it was pointed out that no standards exist for the measurement of nanoparticle size. Indeed, should standards become available, the question was then raised whether testing should be done for a particular type of nanoparticle at all possible size scales (e.g. 4 nm, 5 nm, 6 nm, 7 nm…). This was regarded as impractical. It was pointed out that standards did exist for the measurement of asbestos, however it was noted that the size scales of asbestos fibres generally fell within a single range . For toxicological studies, it was stated that surface area and intrinsic reactivity/toxicology appeared to be the important parameters, not purely size. It was then noted that the reactivity of a nanoparticle will be partly determined by the environment in which it is found. The absence of any toxicological studies on particles of less than 10 nm in size was also noted. In addition, the point was made that the tests currently required for new chemicals, which are used to assess toxicity to humans, may not have any validity for nanoparticles. An example was given for welding fumes, which are regulated in mass terms, however are now known to contain a large number of nanoparticles.

List of attendees

Mike Brown, Boots plc
Ken Donaldson, Edinburgh University
Steve Downing, ICI
Graham Dransfield, Uniqema
Anne Glover, University of Aberdeen
Stuart Hawksworth, Health and Safety Executive
Vyvyan Howard, Liverpool University
Vic Hyde, Cosmetics Toiletry and Perfumery Association
John Knowland Oxford University
Alistair McLeod, Imperial College
Maureen Meldrum, Health and Safety Executive
Christine Northage, Health and Safety Executive
Francis Quinn, L'Oreal
Bob Rajan, Health and Safety Executive
Sean Semple, University of Aberdeen
Vicki Stone, Napier University
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