MANAGING THE UNKNOWN – THE HEALTH RISKS OF NANOMATERIALS IN THE BUILT ENVIRONMENT

Wendy Jones[1], Alistair Gibb, Chris Goodier and Phil Bust

School of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, UK

The application of nanomaterials, containing particles 1000 times smaller than the thickness of a human hair, is increasing but uncertainties persist regarding their potential health effects. An ongoing study to identify where nanomaterials are used in construction and to assess the impact of demolition processes on particle release has identified difficulties which arise when dealing with the unknown: assessing, and managing the risks of these, and other, new materials. The widespread use of materials whose risks are inadequately understood is clearly unsatisfactory. However, the timing of a detailed health evaluation for a new product or process is not straightforward - a focus on these aspects too early in a developmental lifecycle may derail potentially promising innovations. It is also necessary to carefully balance benefit and risk. A product with moderate risk potential may be tolerated provided there are significant benefits, and adequate control measures are available. Questions also arise regarding who should carry out and fund health risk assessments for new materials. Manufacturers clearly have responsibilities, but there are also advantages in centrally funded, objective assessment. Particular complications arise when assessing the health risks for nanomaterials in view of their wide variability and the lack of adequate exposure data. There is no requirement to label nano-enabled building materials. This makes it difficult to assess the extent of their usage, and hence also to determine the health risks to those working with them, or exposed to them due to demolition or recycling at the end of the product or building life. Manufacturers, researchers, governments and wider society share responsibility for addressing these challenges. However, there are steps which constructors can take in the interim to minimise the impact on those working with these uncertainties.

Keywords: nanotechnology, nanomaterials, demolition, health risk.

INTRODUCTION

Nanomaterials have one or more dimensions between 1 and 100 nm – for comparison, consider that a typical human hair is around 80,000 nm in diameter. Engineered nanomaterials (ENM) are those which have been intentionally produced, rather than occurring naturally or arising as a by-product (e.g. from volcanos or traffic pollution). They can offer exciting properties, sometimes very different from those of materials in their more usual ‘bulk’ form. For example, gold becomes soluble at the nanoscale and titanium dioxide, traditionally used for its whiteness, can appear transparent. Nanomaterials have been identified by the European Union as a Key Enabling Technology, important for future employment, financial growth and technical innovation. There are prospects of flexible phone screens, more efficient solar panels, and advances in lithium ion battery design. In medicine, there is potential for drugs to

[1] w.jones2@lboro.ac.uk

Jones, W, Gibb, A, Goodier, C and Bust, P (2015) Managing the unknown – The health risks of nanomaterials in the built environment *In:* Raidén, A B and Aboagye-Nimo, E (Eds) *Procs 31st Annual ARCOM Conference,* 7-9 September 2015, Lincoln, UK, Association of Researchers in Construction Management, 509-518.

target tumours directly without damaging surrounding tissues, to fight multiple sclerosis and maybe even to repair damaged spinal cords. In construction, nanomaterials (predominantly silicon dioxide and titanium dioxide) are found in 'self-cleaning' windows, often used in conservatory roofs; in self-compacting concrete; and in water resistant coatings (van Broekhuizen and van Broekhuizen 2009). Other applications such as pavements which reduce airborne pollution are also being developed, although not yet in widespread use.

Our ongoing project, sponsored by the UK's Institution of Occupational Safety and Health (IOSH) is looking at the use of nanomaterials in the construction and demolition sectors. The main purpose of the study is to assess the health risks which may arise when buildings which have been built using ENM-enhanced products are demolished. We are addressing this by:

- Developing a database of construction materials which are, or appear to be, nano-enabled
- Assessing sample products using material characterisation techniques (such as scanning electron microscopy, and energy dispersive X ray spectroscopy) to identify whether they are nano-enabled and describe the nanomaterial used
- Interviewing representatives from the construction and demolition sectors to understand where nano-enabled products might be used and also to identify the processes which will be used to demolish buildings at end of life
- Laboratory replication of common demolition techniques to assess their impact on nano-enabled building products, and to explore the likelihood of nanoparticle release

Our work has highlighted the difficulties of managing the health and safety risks of materials which are at a relatively early stage of development. In this paper we use examples from our research to explore these issues, many of which will arise when managing risks from novel materials and processes more widely. First, we discuss the challenges of assessing the hazard and exposure risk from nanomaterials. We then consider the need to balance benefit and risk. We address practical issues of risk assessment – including the timing of such assessment, and whose responsibility it should be to carry out appropriate hazard evaluation. Finally, we consider the importance of disseminating the right information to the right individuals. In each section, we suggest how these challenges might be addressed, including intervention at government or societal levels. We also consider how constructors can continue to manage their work safely despite the lack of clarity in some areas.

A particular complication with nanotechnology is that there are many different definitions. Some discussions focus only on materials which contain nanoparticles. Alternate definitions encompass materials which have internal dimensions (spaces or pores) at the nanoscale even though they do not contain nanoparticles. Our research for this paper has taken a broad approach, considering any material which has some dimension at the nanoscale or which is described by the manufacturer as using nanotechnology.

ASSESSING THE HAZARD FROM NANOMATERIALS

Hazard relates to potential impact on workers, other people, and the wider environment – for new substances, the question is, 'how toxic or dangerous is this material to those who may come into contact with it?' A key concern about the health risk from nanomaterials relates to their relatively high surface area, which increases their reactivity. For example, non-nano titanium dioxide might have a surface area of around 2m2/g, compared to nano titanium dioxide with a surface area of perhaps 175m2/g depending on the particle size and structure (Xiong *et al*. 2013). Surface area however, is only one part of the equation, as there are substantial differences between materials in their toxicity. In fact, to talk about the health risk of 'nanomaterials' is no more meaningful than to refer in generic terms to the health risk of 'chemicals' or 'gases'. Health risk varies with chemical composition, but also differs between materials with the same chemistry. For example, one type of nanomaterial which has caused concern is carbon nanotubes (CNTs), largely because of their fibre like structure and their bio persistence, factors which they share with asbestos. Carbon in the form of carbon black, by comparison, has a very different structure. It has been used in tyres for around 100 years and is considered to be one of the lower risk nanomaterials, carrying toxicity comparable to that of other respirable dusts.

CNTs themselves show wide variation – they may be single walled (a single, rolled sheet of graphene, with a diameter of around 1 nm) or multi walled (multiple tubes inside one another, and a diameter between 2 and 100 nm). They may also be short (<5 µm in length) or long (typically 5-50 µm but potentially much longer); straight or tangled; and may or may not encapsulate additional substances such as heavy metals. All of these characteristics influence toxicity, and there is similar variation for other nanomaterials. For example silica (silicon dioxide) exists in two forms – crystalline, which is found in its non-nano form in cementitous products and is a major cause of ill-health in the construction industry; and amorphous which is a less hazardous material, and is the form more commonly used at nanoscale proportions (for example as 'silica fume' used in many high performing mortars and concretes). Other materials such as titanium also exist in multiple forms. The hazardousness of each nanomaterial can therefore be influenced by many characteristics including size, shape, solubility, aggregation state (whether and how the particles clump together), surface charge, and many other factors. This makes it difficult to draw firm conclusions regarding health effects, particularly as many health risk studies do not describe the nanoparticles used to this level of detail. Consequently, many authorities, including the HSE in the UK advocate a precautionary approach – in the absence of evidence that nanomaterials are safe, action should be taken to avoid harm which could plausibly occur.

Applying this approach to construction management is made difficult by uncertainties over which nanomaterials might be used and where. Most products which contain nanomaterials are not required to be labelled as such, and safety data sheets do not typically include this level of detail. Our current study initially identified around 150 products which were believed to contain nanomaterials (based, for example, on the name, properties or description of the product, or on manufacturers' claims). We have tested 20 of these so far and found that 16 contain either a small or very small number of nanoparticles and the remaining four contain none. A database in the United States (CPWR 2015) has identified around 400 construction products which might be nano-enabled based upon similar criteria, but is unable to identify the nanomaterial supposedly contained in most of these.

This lack of clarity is uncomfortable and it is important that research continues to identify more conclusively the hazardousness of the particular nanomaterials which are most likely to be found in construction products. However, the uncertainty needs to be considered in context. There are significant risks already present in the construction industry, including silica dust, sensitising agents and solvents; whilst the literature so far has failed to show significant evidence of harm for most nanomaterials, with the exception of quantum dots (which are unlikely to be used in construction) and carbon nanotubes (Krug 2014). Good implementation of standard control measures (such as ventilation and extraction systems, high standards of hygiene and welfare, and provision of suitable protective equipment when necessary) remain the most effective route to protect against the known hazards in the industry as well as new (or unrecognised) hazards, in the absence of evidence to the contrary.

ASSESSING EXPOSURE TO NANOMATERIALS

To understand the risks which might arise from the use of nanotechnology, we need a good understanding not just of how hazardous particular materials are, but also what the potential is for exposure in construction. We need to know the quantities of materials being used and the likelihood of particle release at various stages of a building's life – construction, maintenance and modification, demolition, and recycling. Unfortunately, the evidence regarding potential exposure to nanomaterials is even less substantial and conclusive than that relating to their hazard profile (Savolainen *et al*. 2010).

Assessment of particle release needs to be performed on real construction products, as it is influenced by many factors such as the nature and quality of the materials themselves and the matrix in which the nanomaterials are contained, as well as the methods and tools used. Planning such experiments is made more difficult by the lack of certainty over which products are nano-enabled.

A particular issue in exposure assessment is how to take account of degradation over time. Epoxy resins, often used in paints and coatings for example, can break down under the influence of ultra violet light, potentially leading to embedded particles being more easily released from the matrix that they are secured in. There is evidence that the combination of weathering and machining processes (as might occur from sanding or drilling) can lead to free CNTs being released from composite materials (Hirth *et al*. 2013). This is of particular concern in demolition where materials may have been exposed to the elements for many years, but it is difficult and expensive to replicate these processes accurately in a laboratory environment.

Finally, there are challenges regarding the actual measurement of nanoparticle release, particularly differentiating between released particles and background levels. Broekhuizen (2011) measured particle release from a task involving the drilling of nano-enabled concrete but found that cigarette smoking in the vicinity had a far higher impact on particle counts. Also, nanoparticles may be released from products even though they were not added during manufacture. For example, the demolition of ordinary (non-nano) concrete results in the release of particles of all sizes, including a high proportion of nano sized ones (Kumar and Morawska 2014). Again, this emphasises the importance of those working in construction continuing to implement good practices to protect workers against both the familiar and unknown risks.

It is essential that constructors keep accurate records of the products used in their buildings, for example using the health and safety file required under the UK's Construction (Design and Management) Regulations (2015). This will make risk assessment easier for those who modify or demolish the buildings in future years, once more detailed guidance is available. However, for such guidance to be produced in due course, action at a national and international level will be important. Firstly, improved labelling of products would make it easier to identify candidate materials for exposure testing, and also to understand the potential for exposure more widely. The EU is currently consulting on possible changes to REACH legislation (Registration, Evaluation, Authorisation and Restriction of Chemicals, 2007) to improve the availability of information to those who use nano-enabled products. There is reluctance within the EU to introduce legislation specific to nano-labelling and registration, although France, Belgium and Denmark have all introduced their own (widely varying) regulations to this effect (Bochon 2015), all of which may contribute to increased availability of information about the extent of usage. In addition, it is important that ongoing and future research considers exposure potential and particle release from real construction products during standard building processes. For those working in demolition, the results of testing which includes weathering and life cycle approaches are particularly important.

BALANCING RISK AND BENEFIT

As a society we are familiar with the concept of balancing benefit and risk. Drugs with severe side effects are approved, but only for use in life threatening diseases; the armed forces prepare their recruits for battle situations using rigorous training methods unlikely to be considered acceptable in other sectors. In construction too these judgements are made – paint with a slightly higher level of toxicity might be used if it lasts twice as long as a safer product, and thus will reduce the need for repainting. Decisions are sometimes made in construction which are more questionable, for example working at height without proper fall protection, to enable work to proceed more quickly and cheaply: but at a high risk for those doing the work.

Similar judgements are important with nanomaterials. Nanosilver is a material which has antimicrobial properties and can be used to reduce infection spread in hospitals and care homes. However, it might also have environmental effects as a consequence of its toxicity to microbes, and it may encourage the development of resistant microorganisms. An EU opinion (SCENIHR 2014) notes that there is a gap in our knowledge and observes that some in the peer-reviewed literature recommend usage be limited until this is addressed, particularly in consumer products (such as washing machines, socks and house paints) where the benefits are less tangible.

Construction is often a conservative industry, favouring methods and materials with proven reliability and longevity over new products and processes. Cost is also a key driver and this too has the potential to slow the introduction of new materials regardless of their apparent benefits. However, societal pressures can influence the adoption of new practices. For example in the current work we found a growing use of nano-coatings on windows in response to requirements for greater thermal efficiency of buildings. Other nano-enabled construction products might also contribute to reduced environmental impact such as concretes which use less energy and raw material in production. It is possible therefore, that higher risks from some materials may be tolerated in future if climate change concerns increase and have a greater influence on priorities. It is important that any such decisions are made based on a full understanding of the facts regarding both the benefits and the risks.

Responsibilities for balancing benefit and risk also lie with designers and manufacturers of new nanomaterials: they need to consider this at an early stage, and throughout the development process. An EU-funded project (LICARA, Som *et al*. 2014) recommends that where benefits outweigh risks, development can proceed; where benefits and risks are balanced, steps need to be taken to improve the benefits or to control the risks; and where risks are high, development should not generally proceed, however great the benefits.

TEMPERING INNOVATION WITH CAUTION - ISSUES OF TIMING

Health and safety risk from new materials and processes should be addressed early to ensure that any risks are properly understood before they are introduced on a widespread basis. History contains numerous examples of hazardous materials being identified only in retrospect, when those working with certain substances developed particular diseases. Examples in construction include Chromium VI, lead paints and of course asbestos; examples in wider society include tobacco, 'trans fats' in foods, and environmental pollutants such as chlorofluorocarbons (CFCs).

There is little doubt that nanomaterials are being used in the construction industry and that this is likely to increase - it has been suggested that 50% of building products are likely to be nano-enabled by the year 2025 (AECOM 2014). It is arguable whether this expansion is advisable, given the lack of clarity over the materials in use and the difficulties in predicting the potentials for exposure. The issue of timing is well illustrated by the addition of CNTs to concrete - in the early stages of our study it appeared from the academic literature that this was potentially quite widespread, taking advantage of the strengthening and electrically conductive characteristics of the nanomaterial. This was concerning given the evidence that some forms of CNT are particularly hazardous, and the lack of information regarding exposure potential during the various stages of demolition. It appeared that the technology had progressed without adequate assessment of the risks, and without consideration of the control measures which might be appropriate. However, it became apparent subsequently that the high cost and practical challenges associated with CNTs had delayed their transition from laboratory to industry. Only in recent months have there been reports that field testing of CNT-enhanced concrete is taking place with a view to commercialisation in 2016 (Eden Energy 2014); therefore testing is required now to improve understanding of their risk profile throughout the life cycle of the product and to provide proper guidance to those who might work with them.

It is perhaps inevitable that the use of nanotechnology will continue to develop ahead of detailed information on the hazards of specific materials. As discussed above, the best solution for those working in construction is to adopt a precautionary approach, typically involving the control methods already used to manage known hazards in the industry. More sophisticated risk assessment will become possible as the data become clearer, enabling better distinction between those materials which might or might not give real cause for concern. For example, some characteristics of nanomaterials such as being fibre shaped make them more hazardous, and others such as being soluble make them less so. Work is ongoing to refine such methods for use in nanotechnology (Bergamaschi *et al*. 2015). Guidance specific to the use of nanomaterials in the construction industry is also expected to be published shortly by SCAFFOLD. This is a large European project which has assessed the risks of nanomaterials and the potential of exposure during construction and maintenance tasks.

RESPONSIBILITIES FOR RISK ASSESSMENT OF NEW MATERIALS

There are legal requirements for manufacturers to gather information on the health and safety risks of their products. Under REACH in Europe, for example, manufacturers are required to assess and manage the risk from the materials that they sell and to provide appropriate information for their users through safety data sheets. Similar provisions apply in other countries such as the United States.

It could also be argued that manufacturers have a moral duty to ensure the safety of the products that they market, and to share the relevant data with their customers. For example, Responsible Research and Innovation is an EU approach which expects business to work with researchers and the public to ensure that the needs of all parties are aligned (Sutcliffe 2011). There is evidence that some companies recognise this responsibility. For example Bayer (who developed ‘Baytubes’, one of the early CNT products) states on its website, 'we assess the possible health and environmental risks of a product along the entire value chain. This starts with research and development and continues through production, marketing and use by the customer through to disposal' (Bayer 2015).

In reality it is difficult to evaluate how companies make such judgements, and how they balance these legal and social responsibilities with accountability to their shareholders. For example, the Australian/American company which has started trialling CNT-enhanced concrete reports that it has ‘resolved’ health and safety concerns through the inclusion of the CNT in a ‘liquid admixture’ and by using only a low percentage in its product (Eden Energy 2014). This in itself is not evidence that the material will be safe at various stages of use, although further information may become available before the product reaches commercialisation.

Independent testing of materials ensures a degree of neutrality and provides confidence and reassurance. It is also able to address broader issues rather than being limited to individual products; and findings can be made publically available, without the confidentiality concerns which may inevitably arise at a company level. Thus the EU has spent around €5bn on nano-technology research for the period 2002-2013, including a range of studies specifically addressing health and safety concerns (e.g. Scaffold, NanoMicex, Sanowork, Marina and NanoReg); and the United States committed €15bn over a similar period. However, it can be challenging to undertake testing on targeted products. During our research it has proved difficult to obtain samples of many nano-enabled construction products, particularly those which are sold only to professional users. Some companies have requested non-disclosure agreements; others have simply ignored requests to participate in the research.

There is little that construction mangers can do to directly influence the research agenda at this stage. It is to be hoped that assessment of nano-safety risk will continue at all levels including life cycle studies to take account of the long term risk, the impact of weathering etc. At the same time, improved transparency by producers of new materials will make it easier to interpret and act on research which has been published. For example, data which show the risk profile for silicon dioxide or titanium dioxide are of limited value if poor labelling makes it difficult to identify products which might contain them.

FUNDING OF RESEARCH AND DEVELOPMENT

This question is linked to the previous one: there are potentially high costs associated with evaluating health risks from new products. This may be problematic where small companies are involved in developing a material or product, and may be reluctant (or unable) to commit the necessary resource until they are confident that a product is commercially viable. There is some evidence from France, where all nanomaterials are required to be registered centrally, that this could adversely affect the innovation and development of nanomaterials. The reported costs of registration (including characterisation of nanomaterials in terms of size, shape etc) are around €15 000 per company and some French companies report being asked by partners specifically to provide 'non-nano' products in order to avoid these costs (RPA *et al* 2014).

Where costs are incurred by organisations, they will inevitably be passed on to customers. This has particular implications for the adoption of nanomaterials in construction given the high volumes of materials used and the strong focus in the industry on price and value.

MAKING INFORMATION AVAILABLE

The importance of engaging the public in research outcomes and innovation is a strong theme in Europe, seen for example in funding calls from the EU and other research bodies such as the ESPRC. There is a benefit in sharing research in this way; in the absence of good information, those with concerns may draw their own, potentially erroneous, conclusions. Such misinformation has been suggested for example, as one possible reason for the failure of Europe to accept genetically modified (GM) products (Sutcliffe 2011).

Our interviews revealed very limited awareness of nanomaterials amongst those either working in construction and demolition or those selling building products. A similar situation has been reported in Europe and the United States, with less than half of those potentially working with nanomaterials in construction being aware of this (van Broekhuizen and van Broekhuizen 2009; Lippy 2015). In practice, there is limited benefit in managers and workers in construction knowing simply whether or not particular products are nano-enabled, given the lack of clarity over what this really means in health terms. More important is that those who carry out risk assessment in construction are able to rely on the data provided, for example in safety data sheets. A priority, therefore, should be for material producers and sellers to know that their products are nano-enabled, and to ensure that data sheets are comprehensive, accurate, and based on the most current findings regarding nanomaterial hazard. ISO guidance is available to support them in this (ISO 2012).

Centralised data collection is also a good way forward, assessing risk at an industry level, and then converting it into user-friendly tools for employers and workers. This is the approach of the current research, and also that taken by the SCAFFOLD project mentioned earlier, which will shortly publish an on-line risk assessment tool for those working in construction.

CONCLUSIONS

Nanotechnology is offering exciting opportunities and providing industry with new materials and better performance from existing materials. Construction is one of many areas where there could be great benefit. However, there are concerns regarding potential health risk, and although the knowledge base is developing steadily it is not yet complete. Therefore it is still necessary to adopt a precautionary approach. Health risk for construction workers is particularly difficult to assess, as products are rarely labelled and minimal (or no) information on material composition is provided in many cases. There is even less evidence regarding the potential for exposure, particularly in demolition where it is important to consider the impact of long-term degradation as well as the effects of aggressive demolition techniques.

Those managing construction and demolition should adopt best practice in health and safety to protect workers against existing hazards such as silica dust and a variety of irritants and allergens. These remain important hazards regardless of the introduction of new materials, and similar protective methods are likely to be effective in both cases. However, there is also scope for constructors to ask challenging questions of their suppliers, to encourage them to understand better the products that they supply and to ensure that safety data sheets for nanomaterials are comprehensive, accurate and appropriate.

As nanotechnology has advanced over the last 15-20 years and change continues to accelerate, the information we need to adequately assess and manage risk has failed to develop at the same rate. The same challenges are likely to apply to other processes and materials outside nanotechnology, as developers seek new ways to innovate and differentiate themselves from their competitors. It is unlikely that legislation will be able to keep up with these changes, so designers and developers of new materials must take responsibility for ensuring that the potential risks of these products are properly evaluated and kept under review as new data emerge.

Centrally funded investigation will continue to be important to ensure that such work is comprehensive; and to hold industry to account and ensure that commercial interests are not allowed to take precedence over health and/or safety. There is also an important role for governments and industry bodies to draw together findings from various sources, identify common themes, and translate technical data into user-friendly guidance. This combination of approaches provides the best chance that we can adopt nanomaterials and other new technologies in a safe and successful manner whilst ensuring that disproportionate anxiety and lack of understanding do not detract from the process and reduce innovation.

REFERENCES

AECOM (2014), *"The Blue Book: Property and Construction Handbook International Edition"* [viewed 2014, November 26]. Available: www.aecom.com/deployedfiles/Internet/Geographies/Australia-New%20Zealand/Documents/Blue%20Book%202014.pdf

Bayer (2015) *"Product stewardship"* [viewed 2015 June 16] Available: www.bayer.com/en/product-stewardship.aspx

Bergamaschi E, Murphy F, Poland C A, Mullins M, Costa A L, McAlea, E, Tran, L. and Tofail, S A (2015) *"Impact and effectiveness of risk mitigation strategies on the insurability of nanomaterial production: evidences from industrial case studies"*. Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology.

Bochon A (2015) *"Growing issues in a miniature world: nanomaterials registers in the European Union"* [Homepage of Squire Patton Boggs], [Online] [viewed 2015, Feburary 18]. Available: http://nanofutures.info/sites/default/files/Nano-Registers-in-European-Union.pdf.

CPWR (2015) *"elcosh Nano Construction Nanomaterial Inventory"* http://nano.elcosh.org/ [viewed 2015, June 19] Available: http://nano.elcosh.org/

Eden energy (2014) *"Annual Report for the Year Ended 30 June 2014"* Eden Energy Ltd and Controlled Entities ABN 58 109 200 900 available at http://www.edenenergy.com.au/pdfs/9655b8bc99f0f15e9fa9c3ac46d9ec92.pdf http://www.edenenergy.com.au/pdfs/6afaf9eddd984d978e3e7cd605545531.pdf

Hirth S, Cena L, Cox G, Tomović Ž, Peters T and Wohlleben W (2013) Scenarios and methods that induce protruding or released CNTs after degradation of nanocomposite materials. *"Journal of Nanoparticle Research"*, vol. **15**, no. 4, pp. 1-15.

ISO (2012) *"Nanomaterials — Preparation of material safety data sheet (MSDS)"* ISO/TR 13329:2012 ISO.

Krug H F (2014) Nanosafety Research—Are We on the Right Track? *"Angewandte Chemie International Edition"*, vol **53**,12304-12319.

Kumar P and Morawska L (2014) Recycling concrete: An undiscovered source of ultrafine particles *"Atmospheric Environment"*, vol. **90**, pp. 51-58.

Lippy B and West G (2015) Identifying, assessing and controlling nanoparticle exposures among U.S. construction workers. *"Senn 2015 International Congress on Safety of Engineered Nanoparticles and Nanotechnologies"*, eds. L Pylkkänen, M Nyholm and E Drakvik, Finnish Institute of Occupational Health 12th - 15th April, pp. 38.

RPA *et al* (2014) *"Study to Assess the Impact of Possible Legislation to Increase Transparency on Nanomaterials on the Market, Evaluation Report for DG Enterprise and Industry"*. Loddon, Norfolk, UK.

Savolainen K, Pylkkänen L, Norppa H, Falck G, Lindberg H, Tuomi T, Vippol M, Alenius H, Hämeri K, Koivisto J, Brouwer D, Mark D, Bard D, Berges M, Jankowska E, Posniak M, Farmer P, Singh R, Krombach F, Bihari P, Kasper G and Seipenbusch M (2010) Nanotechnologies, engineered nanomaterials and occupational health and safety – A review. *"Safety Science"*, vol. **48**, no. 8, pp. 957-963.

Scaffold (2015) *"Innovative strategies, methods and tools for occupational risks management of manufactured nanomaterials (NMNs) in the construction industry"* [viewed 2015, June 19]. Available: http://scaffold.eu-vri.eu/

SCENIHR (2014) *"Opinion on Nanosilver: safety, health and environmental effects and role in antimicrobial resistance"* Scientific Committee on Emerging and Newly Identified Health Risks, European Commission.

Som C, Zondervan-van den Beuken E, Van Harmelen T, Güttinger J, Bodmer M, Brouwer D, Buist H E, Carroll R, Coll C, Fransman W, Hartmanis A, Hincapie I, Hischier R, Karachalios T, Kouravelou K, Kuijpers E, Ligthart T, Notter D, Nowack B, Seibold U and Schneider G (2014) *"LICARA Guidelines for the sustainable competitiveness of nanoproducts"*, Dübendorf, St. Gallen, Zeist.

Sutcliffe H (2011) *"A report on Responsible Research and Innovation (On the basis of material provided by the Services of the European Commission. Prepared for DG Research and Innovation, European Commission)"* [viewed 2015, February 18]. Available: http://nanofutures.info/sites/default/files/rri-report-hilary-sutcliffe_en.pdf.

van Broekhuizen F and van Broekhuizen P (2009) *"Nano-products in the European Construction Industry State of the Art"*. Amsterdam European Federation of Building and Wood Workers.

van Broekhuizen P, van Broekhuizen F, Cornelissen R and Reijnders L (2011) Use of nanomaterials in the European construction industry and some occupational health aspects thereof. *"Journal of Nanoparticle Research"*, vol. **13**, no. 2, pp. 447-462.

Xiong S, Tang Y, Ng H S Zhao X, Jiang Z, Chen Z, Ng K W and Loo S C J (2013) Specific surface area of titanium dioxide (TiO2) particles influences cyto- and photo-toxicity. *"Toxicology"*, vol. **304**, no. 0, pp. 132-140.