www.cpwr.com • www.elcosh.org

THE CENTER FOR CONSTRUCTION RESEARCH AND TRAINING

Topics in Construction Safety and Health

Nanomaterials in Construction:

An Interdisciplinary Annotated Bibliography

CPWR - The Center for Construction Research and Training

2020

8484 Georgia Avenue
Suite 1000
Silver Spring, MD 20910

PHONE: 301.578.8500
FAX: 301.578.8572

CPWR is the research and training arm of NABTU. Production of this document was supported by cooperative agreement OH 009762 from the National Institute for Occupational Safety and Health (NIOSH). The contents are solely the responsibility of the authors and do not necessarily represent the official views of NIOSH.

Table of Contents

Nanomaterials: An Interdisciplinary Annotated Bibliography

Part 1: Construction Applications

Arora, S. K., et al. (2014). "Drivers of technology adoption - the case of nanomaterials in building construction." Tech Forcasting Soc Chang **87**: 232-244.

With the building and construction sector contributing significantly to global greenhouse gas emissions, there is great demand for resource- and energy-efficient construction materials. Manufactured nanotechnology products (MNPs) are expected to realize resource and energy efficiency through performance improvements in the strength, lightness and insulating properties of construction materials. However, the actual adoption of MNPs has lagged. This article examines how the construction sector in the United States assesses MNPs for adoption. Through patent analysis and interviews, we gauge the supply of MNPs and identify actors' roles in technology adoption. Results indicate that awareness of MNPs is more extensive than anticipated. Yet, MNP adoption is limited by a multi-component technology assessment process focused primarily on the technology's applicability to project-based outcomes. We conclude that barriers to MNP adoption can be overcome through intermediary activities such as product certification, comprehensive technology assessments, and "real-world" demonstrations.

Ge, Z. and Z. Gao (2008). Applications of nanotechnology and nanomaterials in construction, first international conference on construction in developing countries (ICCIDC-I). Advancing and integrating construction education, research & practice, Karachi, Pakistan, 4-5 Aug 2008.

Nanotechnology is one of the most active research areas with both novel science and useful applications that has gradually established itself in the past two decades. Expenditure on nanotechnology research is significant; however, the research is continuously moving forward motivated by immediate profitable return generated by high value commercial products. The Architecture, Engineering, and Construction (A/E/C) industry might accommodate broad applications of nanotechnology and nanaomaterials. It has been demonstrated that nanotechnology generated products have many unique characteristics, and can significantly fix current construction problems, and may change the requirement and organization of construction process. This paper examines and documents applicable nanotechnology based products that can improve the overall competitiveness of the construction industry. The areas of applying nanotechnology in construction will be mainly focused on: (1) lighter and stronger structural composites, (2) low maintenance coating, (3) better properties of cementitious materials, (4) reducing the thermal transfer rate of fire retardant and insulation, and (5) construction related nano-sensors.

Hanus, M. J. and A. T. Harris (2013). "Nanotechnology innovations for the construction industry." Prog Mater Sci **58**(7): 1056-1102.

A broad range of challenges faced by the construction industry, ranging from the performance of the materials to environmental and safety issues, relate to materials and their properties. Recent developments in various areas of nanotechnology show significant promise in addressing many of these challenges. Research and developments have demonstrated that the application of nanotechnology can improve the performance of traditional construction materials, such as concrete and steel. Noteworthy improvements in concrete strength, durability and sustainability are being achieved with considered use of metal/metal oxide nanoparticles and engineered nanoparticles (carbon nanotubes and carbon nanofibres), and environment-responsive anticorrosion coatings formed using nanoencapsulation techniques are showing promise in laboratory settings. Developments in nanotechnology are also improving the accuracy and commercial viability of sensor-based structural health monitoring; a task rapidly gaining importance as the structures that comprise many countries' most expensive investments near the end of their design life. As energy usage worldwide continues to grow, a focus on the potential for nanotechnology developments to reduce energy consumption has become evident. Research demonstrates that nanotechnology can contribute to novel cooling systems, and improve the functionality of solar cells and insulation. A range of nanomaterials are also being used to add new functionalities, such as self-cleaning properties, to traditional construction industry products, for example paint and cement. First generation products are available on the market and further advances are evident in the academic literature.

Hincapié, I., et al. (2015). "Use of engineered nanomaterials in the construction industry with specific emphasis on paints and their flows in construction and demolition waste in Switzerland." Waste Manag **43**: 398-406.

One sector where the use of engineered nanomaterials (ENMs) is supposed to offer novel or improved functionalities is the construction industry. During the renovation or demolition of buildings, ENMs contained in former construction materials will enter recycling systems or become construction waste. Currently, information about ENM flows in these processes is insufficient. The potential for the release of ENMs from this waste into the environment is unknown, as are the environmental impacts. To evaluate whether there is currently any nano-relevant construction and demolition waste (C&DW) originating from buildings, we evaluated the sources and flows of ENMs in C&DW and identified their potential exposure pathways. A survey of business representatives of Swiss companies in this sector found that ENMs are mainly used in paints and cement. The most frequently used ENMs in the Swiss housing construction industry are nano-TiO_2, nano-SiO_2, nano-ZnO, and nano-Ag. Using a bottom-up, semi-quantitative approach, we estimated the flows of ENMs contained in paints along the product's life cycle from buildings to recycling and landfill. The flows of ENMs are determined by their associated flows of building materials. We estimated an annual amount of ENMs used in paints of 14t of TiO_2, 12t of SiO_2, 5t of ZnO, and 0.2t of Ag. The majority of ENMs contained in paints in Switzerland enter recycling systems (23t/y), a smaller amount is disposed directly in landfills (7t/y), and a tiny fraction of ENM waste is incinerated (0.01t/y). Our results allow a qualitative determination of the potential release of ENMs into technical or environmental compartments, with the highest potential release expected during recycling.

Iavicoli, I., et al. (2014). "Opportunities and challenges of nanotechnology in the green economy." Environ. Health **13**: 78.

In a world of finite resources and ecosystem capacity, the prevailing model of economic growth, founded on ever-increasing consumption of resources and emission pollutants, cannot be sustained any longer. In this context, the "green economy" concept has offered the opportunity to change the way that society manages the interaction of the environmental and economic domains. To enable society to build and sustain a green economy, the associated concept of "green nanotechnology" aims to exploit nano-innovations in materials science and engineering to generate products and processes that are energy efficient as well as economically and environmentally sustainable. These applications are expected to impact a large range of economic sectors, such as energy production and storage, clean up-technologies, as well as construction and related infrastructure industries. These solutions may offer the opportunities to reduce pressure on raw materials trading on renewable energy, to improve power delivery systems to be more reliable, efficient and safe as well as to use unconventional water sources or nano-enabled construction products therefore providing better ecosystem and livelihood conditions.However, the benefits of incorporating nanomaterials in green products and processes may bring challenges with them for environmental, health and safety risks, ethical and social issues, as well as uncertainty concerning market and consumer acceptance. Therefore, our aim is to examine the relationships among guiding principles for a green economy and opportunities for introducing nano-applications in this field as well as to critically analyze their practical challenges, especially related to the impact that they may have on the health and safety of workers involved in this innovative sector. These are principally due to the not fully known nanomaterial hazardous properties, as well as to the difficulties in characterizing exposure and defining emerging risks for the workforce. Interestingly, this review proposes action strategies for the assessment, management and communication of risks aimed to precautionary adopt preventive measures including formation and training of employees, collective and personal protective equipment, health surveillance programs to protect the health and safety of nano-workers. It finally underlines the importance that occupational health considerations will have on achieving an effectively sustainable development of nanotechnology.

Lee, J., et al. (2010). "Nanomaterials in the construction industry: a review of their applications and environmental health and safety considerations." ACS Nano **4**(7): 3580-3590.

The extraordinary chemical and physical properties of materials at the nanometer scale enable novel applications ranging from structural strength enhancement and energy conservation to antimicrobial properties and self-cleaning surfaces. Consequently, manufactured nanomaterials (MNMs) and nanocomposites are being considered for various uses in the construction and related infrastructure industries. To achieve environmentally responsible nanotechnology in construction, it is important to consider the lifecycle impacts of MNMs on the health of construction workers and dwellers, as well as unintended environmental effects at all stages of manufacturing, construction, use, demolition, and disposal. Here, we review state-of-the-art applications of MNMs that improve conventional construction materials, suggest likely environmental release scenarios, and summarize potential adverse biological and toxicological effects and their mitigation. Aligned with multidisciplinary assessment of the environmental implications of emerging technologies, this review seeks to promote awareness of potential benefits of MNMs in construction and stimulate the development of guidelines to regulate their use and disposal to mitigate potential adverse effects on human and environmental health.

Ridi, F., et al. (2011). "Cement: a two thousand year old nano-colloid." J Colloid Interface Sci **357**(2): 255-264.

Since Roman times, cement is one of the synthetic materials with the largest production and usage by mankind. Its properties allowed the expansion of the Roman Empire and the building of still fascinating works. In spite of the diverse use of cement and the abundant literature accumulated during a century of systematic scientific research on this material, the understanding of its properties is still far from complete. Several issues are still open, ranging from the understanding of the hydration kinetics and the influence of the modern industrial additives, to the deep comprehension of the atomic arrangement and nanostructure of disordered hydrated calcium silicate phase (C-S-H) formed by hydration. This feature article briefly summarizes recent results in the field, highlighting the necessity for a colloidal model of the cement microstructure that, combined with the layer-like structure of the colloidal units, is the most effective approach to fully describe the characteristics of this peculiar material.

Zhu, W., et al. (2004). Application of nanotechnology in construction. Mat. Struct Materials and Structures, Kluwer Academic Publishers. **37:** 649-658.

The paper is an extended summary of the state-of-the-art report on Application of Nanotechnology in Construction, which is one of the main tasks of a European project - Towards the setting up of a Network of Excellence in Nanotechnology in Construction (NANOCONEX). The paper first presents background information and current developments of nanotechnology in general. Then, the current activities and awareness of nanotechnology in the construction industry are examined by analysing results of a survey of construction professionals and leading researchers in the field. This is followed by results of a desk study of nanotechnology development and activities focussing on key areas relevant to construction and the built environment. Examples of nanotechnology-enabled materials and products that are either on the market or ready to be adopted in the construction industry are provided. Finally, the future trend/potential and implications of nanotechnology development in construction are discussed.

Part 2: Managing Risk

WHO guidelines on protecting workers from potential risks of manufactured nanomaterials. Geneva: World Health Organization; 2017. Licence: CC BY-NC-SA 3.0 IGO. (c)

The term nanomaterials refers to materials that have at least one dimension (height, width or length) that is smaller than 100 nanometres (10(-7) metre), which is about the size of a virus particle. This particular size dimension represents a major characteristic of manufactured nanomaterials (MNMs). The unique properties of MNMs may result in better paints, better drugs and faster electronics. However, for the same reason, MNMs may also present health hazards that differ from those of the substance in bulk form, and may require different test methods for hazard, exposure and risk assessment from their bulk material counterparts. There is currently a paucity of precise information about human exposure pathways for MNMs, their fate in the human body and their ability to induce unwanted biological effects such as generation of oxidative stress. Data from in vitro, animal and human MNM inhalation studies are available for only a few MNMs. So far, no long-term adverse health effects in humans have

been observed. This could be due to the recent introduction of MNMs, the precautionary approach to avoid exposure and ethical concerns about conducting studies on humans. Health recommendations must, therefore, be based on extrapolation of the evidence from in vitro, animal or other studies from fields that involve exposure to nanoscale particles, such as air pollution, to the possible effects in humans. Workers in all countries will be at the front line of exposure to these materials, placing them at increased risk for potential adverse health effects. Therefore, WHO proposes these guidelines to policy makers and professionals in the field of occupational health and safety with recommendations on how best to protect workers from the potential risks of MNMs.

De Ipiña, J. L., et al. (2015). Strategies, methods and tools for managing nanorisks in construction. Journal of Physics: Conference Series, IOP Publishing.

This paper presents a general overview of the work carried out by European project SCAFFOLD (GA 280535) during its 30 months of life, with special emphasis on risk management component. The research conducted by SCAFFOLD is focused on the European construction sector and considers 5 types of nanomaterials (TiO2, SiO2, carbon nanofibres, cellulose nanofibers and nanoclays), 6 construction applications (Depollutant mortars, selfcompacting concretes, coatings, self-cleaning coatings, fire resistant panels and insulation materials) and 26 exposure scenarios, including lab, pilot and industrial scales. The document focuses on the structure, content and operation modes of the Risk Management Toolkit developed by the project to facilitate the implementation of "nano-management" in construction companies. The tool deploys and integrated approach OHSAS 18001 - ISO 31000 and is currently being validated on 5 industrial case studies.

Díaz-Soler, B. M., et al. (2016). "Emerging risk in the construction industry: Recommendations for managing exposure to nanomaterials." Dyna **83**(196): 48-54.

Nanotechnology has aroused great interest in the construction industry because new materials with outstanding properties are being designed, and the features of traditional materials can be improved. However, exposure to nanomaterials is the most recent new emerging risk in the construction industry and the current knowledge about this topic is limited. This paper aims to identify the main aspects regarding the exposure to and use of nanomaterials in the construction sector from a risk prevention perspective. This starting point allows authors to establish a set of recommendations structured in order to identify how and where to act in order to manage the risk of exposure to nanomaterial on construction sites.

Eastlake, A., et al. (2016). "Can Control Banding be Useful for the Safe Handling of Nanomaterials? A Systematic Review." Journal of nanoparticle research : an interdisciplinary forum for nanoscale science and technology **18**: 169.

OBJECTIVES: Control banding (CB) is a risk management strategy that has been used to identify and recommend exposure control measures to potentially hazardous substances for which toxicological information is limited. The application of CB and level of expertise required for implementation and management can differ depending on knowledge of the hazard potential, the likelihood of exposure, and the ability to verify the effectiveness of exposure control measures. A number of different strategies have been proposed for using CB in

workplaces where exposure to engineered nanomaterials (ENMs) can occur. However, it is unclear if the use of CB can effectively reduce worker exposure to nanomaterials. A systematic review of studies was conducted to answer the question "can control banding be useful to ensure adequate controls for the safe handling of nanomaterials." METHODS: A variety of databases were searched to identify relevant studies pertaining to CB. Database search terms included 'control', 'hazard', 'exposure' and 'risk' banding as well as the use of these terms in the context of nanotechnology or nanomaterials. Other potentially relevant studies were identified during the review of articles obtained in the systematic review process. Identification of studies and the extraction of data were independently conducted by the reviewers. Quality of the studies was assessed using the Methodological Index for Non-Randomized Studies (MINORS). The quality of the evidence was evaluated using Grading of Recommendations Assessment, Development and Evaluation (GRADE). RESULTS: A total of 235 records were identified in the database search in which 70 records were determined to be eligible for full-text review. Only two studies were identified that met the inclusion criteria. These studies evaluated the application of the CB Nanotool in workplaces where ENMs were being handled. A total of 32 different nanomaterial handling activities were evaluated in these studies by comparing the recommended exposure controls using CB to existing exposure controls previously recommended by an industrial hygienist. It was determined that the selection of exposure controls using CB were consistent with those recommended by an industrial hygienist for 19 out of 32 (59.4%) job activities. A higher level of exposure control was recommended for nine out of 32 (28.1%) job activities using CB while four out of 32 (12.5%) job activities had in place exposure controls that were more stringent than those recommended using CB. After evaluation using GRADE, evidence indicated that the use of CB Nanotool can recommend exposure controls for many ENM job activities that would be consistent with those recommended by an experienced industrial hygienist. CONCLUSION: The use of CB for reducing exposures to ENMs has the potential to be an effective risk management strategy when information is limited on the health risk to the nanomaterial and/or there is an absence of an occupational exposure limit (OEL). However, there remains a lack of evidence to conclude that the use of CB can provide adequate exposure control in all work environments. Additional validation work is needed to provide more data to support the use of CB for the safe handling of ENMs.

Jones, W., et al. (2017). "Managing the unknown – Addressing the potential health risks of nanomaterials in the built environment." Construction Management and Economics **35**(3): 122-136.

Nanomaterials offer significant potential for high performing new products in the built environment and elsewhere. However, there are uncertainties regarding their potential adverse health effects and the extent to which they are currently used. A desk study and interviews with those working across the construction, demolition and product manufacture sectors (n = 59) identified the current state of knowledge regarding nanomaterial use within the built environment. Some nanomaterials are potentially toxic, particularly those based on fibres; others are much less problematic but the evidence base is incomplete. Very little is known regarding the potential for exposure for those working with nano-enabled construction materials. Identifying which construction products contain nanomaterials, and which nanomaterials these might be, is very difficult due to inadequate labelling by product manufacturers. Consequently, those working with nano-enabled products typically have very limited knowledge or awareness of this. Further research is required regarding the toxicology of nanomaterials and the potential for exposure during construction and demolition. Better sharing of the information which is already available is also required through the construction, demolition and manufacture/supply chains. This is likely to be important for other innovative products and processes in construction, not just those which use nanomaterials.

Kuempel, E. D., et al. (2012). "Risk assessment and risk management of nanomaterials in the workplace: translating research to practice." Ann Occup Hyg **56**(5): 491-505.

In the last decade since the rise in occupational safety and health (OSH) research focusing on nanomaterials, some progress has been made in generating the health effects and exposure data needed to perform risk assessment and develop risk management guidance. Yet, substantial research gaps remain, as do challenges in the translation of these research findings to OSH guidance and workplace practice. Risk assessment is a process that integrates the hazard, exposure, and dose-response data to characterize risk in a population (e.g. workers), in order to provide health information needed for risk management decision-making. Thus, the research priorities for risk assessment are those studies that will reduce the uncertainty in the key factors that influence the estimates. Current knowledge of OSH in nanotechnology includes the following: (i) nanomaterials can be measured using standard measurement methods (respirable mass or number concentration), (ii) workplace exposures to nanomaterials can be reduced using engineering controls and personal protective equipment, and (iii) current toxicity testing and risk assessment methods are applicable to nanomaterials. Yet, to ensure protection of workers' health, research is still needed to develop (i) sensitive and quantitative measures of workers' exposure to nanomaterials, (ii) validation methods for exposure controls, and (iii) standardized criteria to categorize hazard data, including better prediction of chronic effects. This article provides a state-of-the-art overview on translating current hazard research data and risk assessment methods for nanomaterials to the development and implementation of effective risk management guidance.

NIOSH (2009). Approaches to safe nanotechnology: Managing the health and safety concerns associated with engineered nanomaterials. Department of Health and Human Services (CDC/NIOSH), Cincinnati.

Nanotechnology has the potential to dramatically improve the effectiveness of a number of existing consumer and industrial products and could have a substantial impact on the development of new products in all sectors, ranging from disease diagnosis and treatment to environmental remediation. Because of the broad range of possible nanotechnology applications, continued evaluation of the potential health risks associated with exposure to nanomaterials is essential to ensure their safe handling. Engineered nanoparticles are materials purposefully produced with at least one dimension between 1 and 100 nanometers. Nanoparticles* often exhibit unique physical and chemical properties that impart specific characteristics essential in making engineered materials, but little is known about what effect these properties may have on human health. Research has shown that the physicochemical characteristics of particles can influence their effects in biological systems. These characteristics include particle size, shape, surface area, charge, chemical properties, solubility, oxidant generation potential, and degree of agglomeration. Until the results from research studies can fully elucidate the characteristics of nanoparticles that may pose a health risk, precautionary measures are warranted.

Schulte, P., et al. (2008). "Occupational risk management of engineered nanoparticles." J Occup. Environ. Hyg **5**(4): 239-249.

The earliest and most extensive societal exposures to engineered nanoparticles are likely to occur in the workplace. Until toxicologic and health effects research moves forward to characterize more broadly the potential hazards of nanoparticles and to provide a scientific basis for appropriate control of nanomaterials in the workplace, current and future workers may be at risk from occupational exposures. This article reviews a conceptual framework for occupational risk management as applied to engineered nanomaterials and describes an associated approach for controlling exposures in the presence of uncertainty. The framework takes into account the potential routes of exposure and factors that may influence biological activity and potential toxicity of nanomaterials; incorporates primary approaches based on the traditional industrial hygiene hierarchy of controls involving elimination or substitution, engineering controls, administrative controls, and use of personal protective equipment; and includes valuable secondary approaches involving health surveillance and medical monitoring

Schulte, P. A., et al. (2013). "Overview of Risk Management for Engineered Nanomaterials." Journal of Physics: Conference Series **429**: 012062.

Occupational exposure to engineered nanomaterials (ENMs) is considered a new and challenging occurrence. Preliminary information from laboratory studies indicates that workers exposed to some kinds of ENMs could be at risk of adverse health effects. To protect the nanomaterial workforce, a precautionary risk management approach is warranted and given the newness of ENMs and emergence of nanotechnology, a naturalistic view of risk management is useful. Employers have the primary responsibility for providing a safe and healthy workplace. This is achieved by identifying and managing risks which include recognition of hazards, assessing exposures, characterizing actual risk, and implementing measures to control those risks. Following traditional risk management models for nanomaterials is challenging because of uncertainties about the nature of hazards, issues in exposure assessment, questions about appropriate control methods, and lack of occupational exposure limits (OELs) or nano-specific regulations. In the absence of OELs specific for nanomaterials, a precautionary approach has been recommended in many countries. The precautionary approach entails minimizing exposures by using engineering controls and personal protective equipment (PPE). Generally, risk management utilizes the hierarchy of controls. Ideally, risk management for nanomaterials should be part of an enterprise-wide risk management program or system and this should include both risk control and a medical surveillance program that assesses the frequency of adverse effects among groups of workers exposed to nanomaterials. In some cases, the medical surveillance could include medical screening of individual workers to detect early signs of work-related illnesses. All medical surveillance should be used to assess the effectiveness of risk management; however, medical surveillance should be considered as a second line of defense to ensure that implemented risk management practices are effective.

Schulte, P. A., et al. (2014). "Occupational safety and health criteria for responsible development of nanotechnology." J. Nanopart. Res **16**: 2153.

Organizations around the world have called for the responsible development of nanotechnology. The goals of this approach are to emphasize the importance of considering and controlling the potential adverse impacts of nanotechnology in order to develop its capabilities and benefits. A primary area of concern is the potential adverse impact on workers, since they are the first people in society who are exposed to the potential hazards of nanotechnology. Occupational safety and health criteria for defining what constitutes responsible development of nanotechnology are needed. This article presents five criterion actions that should be practiced by decision-makers at the business and societal levels-if nanotechnology is to be developed responsibly. These include (1) anticipate, identify, and track potentially hazardous nanomaterials in the workplace; (2) assess workers' exposures to nanomaterials; (3) assess and communicate hazards and risks to workers; (4) manage occupational safety and health risks; and (5) foster the safe development of nanotechnology and realization of its societal and commercial benefits. All these criteria are necessary for responsible development to occur. Since it is early in the commercialization of nanotechnology, there are still many unknowns and concerns about nanomaterials. Therefore, it is prudent to treat them as potentially hazardous until sufficient toxicology, and exposure data are gathered for nanomaterial-specific hazard and risk assessments. In this emergent period, it is necessary to be clear about the extent of uncertainty and the need for prudent actions.

Part 3: Toxicity and Exposure

Adhikari, A., et al. (2018). "Field Evaluation of N95 Filtering Facepiece Respirators on Construction Jobsites for Protection against Airborne Ultrafine Particles." Int J Environ Res Public Health **15**(9).

Exposure to high concentrations of airborne ultrafine particles in construction jobsites may play an important role in the adverse health effects among construction workers, therefore adequate respiratory protection is required. The performance of particulate respirators has never been evaluated in field conditions against ultrafine particles on construction jobsites. In this study, respiratory protection levels against ultrafine particles of different size ranges were assessed during three common construction related jobs using a manikin-based set-up at 85 L/min air flow rate. Two NanoScan SMPS nanoparticle counters were utilized for measuring ultrafine particles in two sampling lines of the test filtering facepiece respirator-one from inside the respirator and one from outside the respirator. Particle size distributions were characterized using the NanoScan data collected from outside of the respirator. Two models of N95 respirators were tested-foldable and pleated. Collected data indicate that penetration of all categories of ultrafine particles can exceed 5% and smaller ultrafine particles of <36.5 nm size generally penetrated least. Foldable N95 filtering facepiece respirators were found to be less efficient than pleated N95 respirators in filtering nanoparticles mostly at the soil moving site and the wooden building frameworks construction site. Upon charge neutralization by isopropanol treatment, the ultrafine particles of larger sizes penetrated more compared to particles of smaller sizes. Our findings, therefore, indicate that N95 filtering facepiece respirators may not provide desirable 95% protection for most categories of ultrafine particles and generally, 95% protection is achievable for smaller particles of 11.5 to 20.5 nm sizes. We also conclude that foldable N95 respirators are less efficient than pleated N95 respirators in filtering ultrafine particles, mostly in the soil moving site and the wooden building framework construction site.

Azarmi, F., et al. (2014). "The exposure to coarse, fine and ultrafine particle emissions from concrete mixing, drilling and cutting activities." J Hazard. Mater **279**: 268-279.

Building activities generate coarse (PM10</=10mum), fine (PM2.5</=2.5mum) and ultrafine particles (<100nm) making it necessary to understand both the exposure levels of operatives on site and the dispersion of ultrafine particles into the surrounding environment. This study investigates the release of particulate matter, including ultrafine particles, during the mixing of fresh concrete (incorporating Portland cement with Ground Granulated Blastfurnace Slag, GGBS or Pulverised Fuel Ash, PFA) and the subsequent drilling and cutting of hardened concrete. Particles were measured in the 5-10,000nm size range using a GRIMM particle spectrometer and a fast response differential mobility spectrometer (DMS50). The mass concentrations of PM2.5-10 fraction contributed approximately 52-64% of total mass released. The ultrafine particles dominated the total particle number concentrations (PNCs); being 74, 82, 95 and 97% for mixing with GGBS, mixing with PFA, drilling and cutting, respectively. Peak values measured during the drilling and cutting activities were 4 and 14 times the background. Equivalent emission factors were calculated and the total respiratory deposition dose rates for PNCs for drilling and cutting were 32.97+/-9.41x10(8)min(-1) and 88.25+/-58.82x10(8)min(-1). These are a step towards establishing number and mass emission inventories for particle exposure during construction activities.

Bekker, C., et al. (2013). "Industrial production and professional application of manufactured nanomaterials-enabled end products in Dutch industries: potential for exposure." Ann. Occup. Hyg **57**(3): 314-327.

BACKGROUND: In order to make full use of the opportunities while responsibly managing the risks of working with manufactured nanomaterials (MNM), we need to gain insight into the potential level of exposure to MNM in the industry. Therefore, the goal of this study was to obtain an overview of the potential MNM exposure scenarios within relevant industrial sectors, applied exposure controls, and number of workers potentially exposed to MNM in Dutch industrial sectors producing and applying MNM-enabled end products in the Netherlands. METHODS: A survey was conducted in three phases: (i) identification of MNM-enabled end products; (ii) identification of relevant industrial sectors; and (iii) a tiered telephone survey to estimate actual use of the products among 40 sector organizations/knowledge centres (Tier 1), 350 randomly selected companies (Tier 2), and 110 actively searched companies (Tier 3). RESULTS: The most dominant industrial sectors producing or applying MNM-enabled end products (market penetration >5%) are shoe repair shops, automotive, construction, paint, metal, and textile cleaning industry. In the majority of the companies (76%), potential risks related to working with MNM are not a specific point of interest. The total number of workers potentially exposed to MNM during the production or application of MNM-enabled end products was estimated at approximately 3000 workers in the Netherlands. The results of this study will serve as a basis for in-depth exposure and health surveys that are currently planned in the Netherlands. In addition, the results can be used to identify the most relevant sectors for policy makers and future studies focussing on evaluating the risks of occupational exposure to MNM.

Bishop, L., et al. (2017). "In Vivo Toxicity Assessment of Occupational Components of the Carbon Nanotube Life Cycle To Provide Context to Potential Health Effects." ACS Nano **11**(9): 8849-8863.

Pulmonary toxicity studies on carbon nanotubes focus primarily on as-produced materials and rarely are guided by a life cycle perspective or integration with exposure assessment. Understanding toxicity beyond the as-produced, or pure native material, is critical, due to modifications needed to overcome barriers to commercialization of applications. In the first series of studies, the toxicity of as-produced carbon nanotubes and their polymer-coated counterparts was evaluated in reference to exposure assessment, material characterization, and stability of the polymer coating in biological fluids. The second series of studies examined the toxicity of aerosols generated from sanding polymer-coated carbon-nanotube-embedded or neat composites. Postproduction modification by polymer coating did not enhance pulmonary injury, inflammation, and pathology or in vitro genotoxicity of as-produced carbon nanotubes, and for a particular coating, toxicity was significantly attenuated. The aerosols generated from sanding composites embedded with polymer-coated carbon nanotubes contained no evidence of free nanotubes. The percent weight incorporation of polymer-coated carbon nanotubes, 0.15% or 3% by mass, and composite matrix utilized altered the particle size distribution and, in certain circumstances, influenced acute in vivo toxicity. Our study provides perspective that, while the number of workers and consumers increases along the life cycle, toxicity and/or potential for exposure to the as-produced material may greatly diminish.

Broekhuizen, P., et al. (2011). Use of nanomaterials in the European construction industry and some occupational health aspects thereof. J Nanopart Res, Springer Netherlands. **13:** 447-462.

In the European construction industry in 2009, the use of engineered nanoparticles appears to be confined to a limited number of products, predominantly coatings, cement and concrete. A survey among representatives of workers and employers from 14 EU countries suggests a high level of ignorance about the availability and use of nanomaterials for the construction industry and the safety aspects thereof. Barriers for a large-scale acceptance of products containing engineered nanoparticles (nanoproducts) are high costs, uncertainties about long-term technical material performance, as well as uncertainties about health risks of nanoproducts. Workplace measurements suggest a modest exposure of construction workers to nanoparticles (NPs) associated with the use of nanoproducts. The measured particles were within a size range of 20–300 nm, with the median diameter below 53 nm. Positive assignment of this exposure to the nanoproduct or to additional sources of ultrafine particles, like the electrical equipment used was not possible within the scope of this study and requires further research. Exposures were below the nano reference values proposed on the basis of a precautionary approach.

Cooper, M. R., et al. (2017). "Inhalation exposure during spray application and subsequent sanding of a wood sealant containing zinc oxide nanoparticles." J Occup Environ Hyg **14**(7): 510-522.

Nano-enabled construction products have entered into commerce. There are concerns about the safety of manufactured nanomaterials, and exposure assessments are needed for a more complete understanding of risk. This study assessed potential inhalation exposure to ZnO nanoparticles during spray application and power sanding of a commercially available wood sealant and evaluated the effectiveness of local exhaust ventilation in reducing exposure. A tradesperson performed the spraying and sanding inside an environmentally-controlled chamber. Dust control methods during sanding were compared. Filter-based sampling, electron microscopy, and real-time particle counters provided measures of exposure. Airborne nanoparticles above background levels were detected by particle counters for all exposure scenarios. Nanoparticle number concentrations and particle size distributions were similar for sanding of treated versus untreated wood. Very few unbound nanoparticles were detected in aerosol samples via electron microscopy, rather nano-sized ZnO was contained within, or on the surface of larger airborne particles. Whether the presence of nanoscale ZnO in these aerosols affects toxicity merits further investigation. Mass-based exposure measurements were below the NIOSH Recommended Exposure Limit for Zn, although there are no established exposure limits for nanoscale ZnO. Local exhaust ventilation was effective, reducing airborne nanoparticle number concentrations by up to 92% and reducing personal exposure to total dust by at least 80% in terms of mass. Given the discrepancies between the particle count data and electron microscopy observations, the chemical identity of the airborne nanoparticles detected by the particle counters remains uncertain. Prior studies attributed the main source of nanoparticle emissions during sanding to copper nanoparticles generated from electric sander motors. Potentially contrary results are presented suggesting the sander motor may not have been the primary source of nanoparticle emissions in this study. Further research is needed to understand potential risks faced by construction workers exposed to mixed aerosols containing manufactured nanomaterials. Until these risks are better understood, this study demonstrates that engineering controls can reduce exposure to manufactured nanomaterials; doing so may be prudent for protecting worker health.

De Paoli, F., et al. (2018). "Number concentrations and size distributions of nanoparticles during the use of hand tools in refurbishment activities." Journal of Nanoparticle Research **20**(10): 264.

Hand tools, such as a sledgehammer, are widely used in refurbishment activities; nonetheless, there is very little knowledge on nanoparticle generation. We measured particle number size distributions (PSDs) and concentrations (PNCs) in the 10–420 nm using a NanoScan scanning mobility particle sizer (SMPS) during the use of hand tools (i.e., sanding and removal of wall) in a real indoor refurbishment environment. Results indicated that refurbishment activities from removal of wall increased average PNCs by ~ 6 times over the background while it was ~ 1.5 times higher than sanding. The highest total PNC was 1.9 × 105 particles cm−3 that corresponded to removal of wall activities. For sanding activities, PNC was lower as the coat of the plaster was probably slightly wet. Moreover, comparison between the two principal activities showed a similar peak in the accumulation mode (~ 65 nm), with a monomodal pattern. Results suggest that removal of wall activities emitted nanoparticles with a 59% of contribution in the Aitken mode. According to these data, it can be inferred that the application of hand tools in refurbishment activities generates lower total PNC than using electromechanical equipment. This study may contribute to our understanding of nanoparticle generation in refurbishment activities.

Duncan, T. V. (2015). "Release of engineered nanomaterials from polymer nanocomposites: the effect of matrix degradation." ACS Appl. Mater. Interfaces **7**(1): 20-39.

Polymer nanocomposites-polymer-based materials that incorporate filler elements possessing at least one dimension in the nanometer range-are increasingly being developed for commercial applications ranging from building infrastructure to food packaging to biomedical devices and implants. Despite a wide range of intended applications, it is also important to understand the potential for exposure to these nanofillers, which could be released during routine use or abuse of these materials so that it can be determined whether they pose a risk to human health or the environment. This article is the second of a pair that review what is known about the release of engineered nanomaterials (ENMs) from polymer nanocomposites. Two roughly separate ENM release paradigms are considered in this series: the release of ENMs via passive diffusion, desorption, and dissolution into external liquid media and the release of ENMs assisted by matrix degradation. The present article is focused primarily on the second paradigm and includes a thorough, critical review of the associated body of peer-reviewed literature on ENM release by matrix degradation mechanisms, including photodegradation, thermal decomposition, mechanical wear, and hydrolysis. These release mechanisms may be especially relevant to nanocomposites that are likely to be subjected to weathering, including construction and infrastructural materials, sporting equipment, and materials that might potentially end up in landfills. This review pays particular attention to studies that shed light on specific release mechanisms and synergistic mechanistic relationships. The review concludes with a short section on knowledge gaps and future research needs.

Dylla, H. and M. M. Hassan (2012). "Characterization of nanoparticles released during construction of photocatalytic pavements using engineered nanoparticles." Journal of Nanoparticle Research **14**(4): 1-15.

With the increasing use of titanium dioxide (TiO2) nanoparticles in self-cleaning materials such as photocatalytic concrete pavements, the release of nanoparticles into the environment is inevitable. Nanoparticle concentration, particle size, surface area, elemental composition, and surface morphology are pertinent to determine the associated risks. In this study, the potential of exposure to synthetic nanoparticles released during construction activities for application of photocatalytic pavements was measured during laboratory-simulated construction activities of photocatalytic mortar overlays and in an actual field application of photocatalytic spray coat. A scanning mobility particle sizer system measured the size distribution of nanoparticles released during laboratory and field activities. Since incidental nanoparticles are released during construction activities, nanoparticle emissions were compared to those from similar activities without nano-TiO2. Nanoparticle counts and size distribution suggest that synthetic nanoparticles are released during application of photocatalytic pavements. In order to identify the nanoparticle source, nanoparticles were also collected for offline characterization using transmission electron microscopy. However, positive

identification of synthetic nanoparticles was not possible due to difficulties in obtaining high-resolution images. As a result, further research is recommended to identify nanoparticle composition and sources.

Fichera, O., et al. (2019). "Characterization of water-based paints containing titanium dioxide or carbon black as manufactured nanomaterials before and after atomization." Applied Nanoscience **9**(4): 515-528.

The study aims to bring more knowledge about risk assessments of paint aerosol exposure to the human body. Raw manufactured nanomaterials (MNMs), either titanium dioxide or carbon black, were introduced into water-based paint formations. The evaluation of the acute and subacute potential toxicity of these samples in a whole-body (mice) exposure model was performed. Inhalation aspects are especially regarded and description of the results obtained from each characterization stage of paint materials (raw MNMs, suspensions of MNMs, paint containing them and paint aerosol produced) is reported. Several techniques such as X-ray photoelectron spectroscopy, centrifugal liquid sedimentation, transmission electron microscopy, scanning electron microscopy, energy-dispersive X-ray spectroscopy and electrical low impactor were used to this objective. The modification of physicochemical properties of MNMs, incorporated into paint formulation before and after atomization process, was shown. The evidence of MNMs agglomerates inside micro-sized paint droplets in the overspray was highlighted and findings revealed that MNMs are strongly embedded into the paint matrix. This behavior indicates that minor or no potential toxicity exerted by MNMs in this type of complex products may be observed.

Freund, A., et al. (2012). "Submicron particle monitoring of paving and related road construction operations." J Occup Environ Hyg **9**(5): 298-307.

This study identified activities and sources that contribute to ultrafine and other submicron particle exposure that could trigger respiratory symptoms in highway repair workers. Submicron particle monitoring was conducted for paving, milling, and pothole repair operations in a major metropolitan area where several highway repair workers were identified as symptomatic for respiratory illness following exposures at the 2001 World Trade Center disaster site. Exposure assessments were conducted for eight trades involved in road construction using a TSI P-Trak portable condensation particle counter. Direct readings near the workers' breathing zones and observations of activities and potential sources were logged on 7 days on 27 workers using four different models of pavers and two types of millers. Average worker exposure levels ranged from 2 to 3 times background during paving and from 1 to 4 times background during milling. During asphalt paving, average personal exposures to submicron particulates were 25,000-60,000, 28,000-70,000, and 23,000-37,000 particles/ cm(3) for paver operators, screed operators, and rakers, respectively. Average personal exposures during milling were 19,000-111,000, 28,000-81,000, and 19,000 particles/cm(3) for the large miller operators, miller screed operators, and raker, respectively. Personal peak exposures were measured up to 467,000 and 455,000 particles/cm(3) in paving and milling, respectively. Several sources of submicron particles were identified. These included the diesel and electric fired screed heaters; engine exhaust from diesel powered construction vehicles passing by or idling; raking, dumping, and paving of asphalt; exhaust from the hotbox heater; pavement dust

or fumes from milling operations, especially when the large miller started and stopped; and secondhand cigarette smoke. To reduce the potential for health effects in workers, over 40 recommendations were made to control exposures, including improved maintenance of paver ventilation systems; diesel fume engineering controls; reduced idling; provision of cabs for the operators; and improved dust suppression systems on the milling machine.

Froggett, S. J., et al. (2014). "A review and perspective of existing research on the release of nanomaterials from solid nanocomposites." Part Fibre. Toxicol **11**: 17.

Advances in adding nanomaterials to various matrices have occurred in tandem with the identification of potential hazards associated with exposure to pure forms of nanomaterials. We searched multiple research publication databases and found that, relative to data generated on potential nanomaterial hazards or exposures, very little attention has focused on understanding the potential and conditions for release of nanomaterials from nanocomposites. However, as a prerequisite to exposure studying release is necessary to inform risk assessments. We identified fifty-four studies that specifically investigated the release of nanomaterials, and review them in the following release scenario groupings: machining, weathering, washing, contact and incineration. While all of the identified studies provided useful information, only half were controlled experiments. Based on these data, the debris released from solid, non-food nanocomposites contains in varying frequencies, a mixture of four types of debris. Most frequently identified are (1) particles of matrix alone, and slightly less often, the (2) matrix particles exhibit the nanomaterial partially or fully embedded; far less frequently is (3) the added nanomaterial entirely dissociated from the matrix identified: and most rare are (4) dissolved ionic forms of the added nanomaterial. The occurrence of specific debris types appeared to be dependent on the specific release scenario and environment. These data highlight that release from nanocomposites can take multiple forms and that additional research and guidance would be beneficial, allowing for more consistent characterization of the release potential of nanomaterials. In addition, these data support calls for method validation and standardization, as well as understanding how laboratory release scenarios relate to real-world conditions. Importantly, as risk is considered to be a function of the inherent hazards of a substance and the actual potential for exposure, data on nanomaterial release dynamics and debris composition from commercially relevant nanocomposites are a valuable starting point for consideration in fate and transport modeling, exposure assessment, and risk assessment frameworks for nanomaterials.

Gohler, D. and M. Stintz (2014). "Granulometric characterization of airborne particulate release during spray application of nanoparticle-doped coatings." J Nanopart Res **16**: 2520.

Airborne particle release during the spray application of coatings was analyzed in the nanometre and micrometre size range. In order to represent realistic conditions of domestic and handcraft use, the spray application was performed using two types of commercial propellant spray cans and a manual gravity spray gun. Four different types of coatings doped with three kinds of metal-oxide tracer nanoparticle additives (TNPA) were analyzed. Depending on the used coating and the kind of spray unit, particulate release numbers between 5 x 10(8) and 3 x 10(10) particles per gram ejection mass were determined in the dried spray aerosols. The nanoparticulate fraction amounted values between 10 and 60 no%. The comparison

between nanoparticle-doped coatings with non-doped ones showed no TNPA-attributed differences in both the macroscopic spray process characteristics and the particle release numbers. SEM, TEM and EDX-analyzes showed that the spray aerosols were composed of particles made up solely from matrix material and sheathed pigments, fillers and TNPAs. Isolated ZnO- or Fe2O3-TNPAs could not be observed.

Gohler, D., et al. (2010). "Characterization of nanoparticle release from surface coatings by the simulation of a sanding process." Ann. Occup. Hyg **54**(6): 615-624.

Nanoparticles are used in industrial and domestic applications to control customized product properties. But there are several uncertainties concerning possible hazard to health safety and environment. Hence, it is necessary to search for methods to analyze the particle release from typical application processes. Based on a survey of commercial sanding machines, the relevant sanding process parameters were employed for the design of a miniature sanding test setup in a particle-free environment for the quantification of the nanoparticle release into air from surface coatings. The released particles were moved by a defined airflow to a fast mobility particle sizer and other aerosol measurement equipment to enable the determination of released particle numbers additionally to the particle size distribution. First, results revealed a strong impact of the coating material on the swarf mass and the number of released particles.

Golanski, L., et al. (2011). "Characterization of abrasion-induced nanoparticle release from paints into liquids and air." J Phys Conf Ser **304**(1).

Two standard methods for the characterization of the abrasion nanoparticle release into air and liquid from coatings containing nanoparticles were developed. Details of the abrasion processes and the measurement methods are shown. Paints were formulated in an industrial facility. Standard abrasion conditions in wet environments were simulated. The size distribution of the particles abraded into liquid was analyzed by a laser granulometer: submicrometric and micrometric particles were observed, but no nanometric particles. The nanoparticles released in liquid were deposited on filters for SEM (Scanning Electron Microscopy) analysis. No free or agglomerated nanoparticles were observed by SEM: nanoparticles seem to remain embedded in the paint matrix. The same coatings were abraded in the air using another standard method. The ELPI (Electrical Low Pressure Impactor) was used to determine the number size distribution of the dust generated. Abrasion is found to produce submicrometric and micrometric particles in the air but no nanoparticles. Further characterizations by SEM confirmed that no free or agglomerated nanoparticles were emitted: nanoparticles seem to remain embedded in the paint matrix.

Gomez, V., et al. (2014). "Comparison of Dust Release from Epoxy and Paint Nanocomposites and Conventional Products during Sanding and Sawing." Annals of Occupational Hygiene.

The release of dust generated during sanding or sawing of nanocomposites was compared with conventional products without nanomaterials. Epoxy-based polymers with and without carbon nanotubes, and paints with different amounts of nano-sized titanium dioxide, were machined in a closed aerosol chamber. The temporal evolution of the aerosol concentration and size distribution were measured simultaneously. The morphology of collected dust by scanning electron microscopy was different depending on the type of nanocomposites: particles from carbon nanotubes (CNTs) nanocomposites had protrusions on their surfaces and aggregates and agglomerates are attached to the paint matrix in particles emitted from alkyd paints. We observed no significant differences in the particle size distributions when comparing sanding dust from nanofiller containing products with dust from conventional products. Neither did we observe release of free nanomaterials. Instead, the nanomaterials were enclosed or partly enclosed in the matrix. A source strength term Si (cm(-3) s(-1)) that describes particle emission rates from continuous sources was introduced. Comparison between the Si parameters derived from sanding different materials allows identification of potential effects of addition of engineered nanoparticles to a composite.

González-Gálvez, D., et al. (2017). The Life Cycle of Engineered Nanoparticles. Modelling the Toxicity of Nanoparticles. L. Tran, M. A. Bañares and R. Rallo. Cham, Springer International Publishing**:** 41-69.

The first years in the twenty-first century have meant the inclusion of nanotechnology in most industrial sectors, from very specific sensors to construction materials. The increasing use of nanomaterials in consumer products has raised concerns about their potential risks for workers, consumers and the environment. In a comprehensive risk assessment or life cycle assessment, a life cycle schema is the starting point necessary to build up the exposure scenarios and study the processes and mechanisms driving to safety concerns. This book chapter describes the processes that usually occur at all the stages of the life cycle of the nano-enabled product, from the nanomaterial synthesis to the end-of-life of the products. Furthermore, release studies reported in literature related to these processes are briefly discussed.

Kaiser, J. P., et al. (2013). "Human health risk of ingested nanoparticles that are added as multifunctional agents to paints: an in vitro study." PLoS One **8**(12): e83215.

Microorganisms growing on painted surfaces are not only an aesthetic problem, but also actively contribute to the weathering and deterioration of materials. A widely used strategy to combat microbial colonization is the addition of biocides to the paint. However, ecotoxic, non-degradable biocides with a broad protection range are now prohibited in Europe, so the paint industry is considering engineered nanoparticles (ENPs) as an alternative biocide. There is concern that ENPs in paint might be released in run-off water and subsequently consumed by animals and/or humans, potentially coming into contact with cells of the gastrointestinal tract and affecting the immune system. Therefore, in the present study we evaluated the cytotoxic effects of three ENPs (nanosilver, nanotitanium dioxide and nanosilicon dioxide) that have a realistic potential for use in paints in the near future. When exposed to nanotitanium dioxide and nanosilicon dioxide in concentrations up to 243 microg/mL for 48 h, neither the gastrointestinal cells (CaCo-2) nor immune system cells (Jurkat) were significantly affected. However, when exposed to nanosilver, several cell parameters were affected, but far less than by silver ions used as a control. No differences in cytotoxicity were observed when cells were exposed to ENP-containing paint particles, compared with the same paint particles without ENPs. Paint particles containing ENPs did not affect cell morphology, the release of reactive oxygen species or cytokines, cell activity or cell death in a different manner to the same paint

particles without ENPs. The results suggest that paints doped with ENPs do not pose an additional acute health hazard for humans.

Kang, J., et al. (2017). "Generation and characterization of aerosols released from sanding composite nanomaterials containing carbon nanotubes." NanoImpact **5**: 41-50.

An adaptable system was developed to generate and characterize particles released from composite materials containing carbon nanotubes (CNTs). The system was tested with a belt sander by sanding 1) glass fiber/epoxy resin, 2) acrylonitrile butadiene styrene (ABS), and 3) ABS with carbon black. Each material was tested with fine and coarse sandpaper in its neat form and with CNT additives. Total number concentrations, respirable mass concentrations, and particle number/mass distributions of the released particles were measured with a combination of direct-read instruments. Airborne particle samples for electron microscopy analysis were collected on polycarbonate filters, and onto a transmission electron microscopy grid supported carbon film using a thermophoretic sampler. Using automated microscopy analysis and a newly developed method, over 200 particles from each filter sample were analyzed for chemical composition, size, and the presence of CNT protrusions. Direct-read instruments revealed that the highest number and mass concentrations were generated with Material 1 (6×104particles/cm3 and 0.5mg/m3 with coarse sandpaper) and that the addition of C'NTs decreased number concentrations (4.5×104particles/cm3 with coarse sandpaper). Respirable concentrations of the materials containing CNTs were higher than the respective base materials without additives with the exception of Material 1 with coarse sandpaper. Microscopy analysis results indicated that particles were primarily micrometer-sized and some particles had protruding features. From the chemical analysis, the percentages of particles generated during sanding that were attributable to the deterioration of sandpaper were 59–83% for Material 1 and 6–27% for Materials 2 and 3. The highest number of protrusions were found in Material 3 with CNT additive and fine sandpaper (3.71 average protrusions per particle) while the lowest number or protrusions were found in Material 2 with short CNTs and fine sandpaper (0.66 average protrusions per particle). No free-standing CNTs were observed in the samples. The combination of direct-read instruments and automated electron microscopy provides greater insights in particle chemistry, size measurements and CNT associations.

Koivisto, A. J., et al. (2018). "Particle emission rates during electrostatic spray deposition of TiO2 nanoparticle-based photoactive coating." J Hazard. Mater **341**: 218-227.

Here, we studied the particle release rate during Electrostatic spray deposition of anatase-(TiO2)-based photoactive coating onto tiles and wallpaper using a commercially available electrostatic spray device. Spraying was performed in a 20.3m(3) test chamber while measuring concentrations of 5.6nm to 31mum-size particles and volatile organic compounds (VOC), as well as particle deposition onto room surfaces and on the spray gun user hand. The particle emission and deposition rates were quantified using aerosol mass balance modelling. The geometric mean particle number emission rate was 1.9x10(10)s(-1) and the mean mass emission rate was 381mugs(-1). The respirable mass emission-rate was 65% lower than observed for the entire measured size-range. The mass emission rates were linearly scalable (+/-ca. 20%) to the process duration. The particle deposition rates were up to 15h(-1) for <1mum-size and the deposited particles consisted of mainly TiO2, TiO2 mixed with Cl and/or

Ag, TiO2 particles coated with carbon, and Ag particles with size ranging from 60nm to ca. 5mum. As expected, no significant VOC emissions were observed as a result of spraying. Finally, we provide recommendations for exposure model parameterization.

Koponen, I. K., et al. (2009). "Sanding dust from nanoparticle-containing paints: Physical characterisation." J. Phys. : Conf. Ser **151**(1): 012048.

Increasing use of nanoparticles in different industrial applications has raised a new potential health risk to the workers as well as to the consumers. This study investigates the particle size distributions of sanding dust released from paints produced with and without engineered nanoparticles. Dust emissions from sanding painted plates were found to consist of five size modes; three modes under 1 μm and two modes around 1 and 2 μm. We observed that the sander was the only source of particles smaller than 50 nm and they dominated the number concentration spectra. Mass and surface area spectra were dominated by the 1 and 2 μm modes. Addition of nanoparticles caused only minor changes in the geometric mean diameters of the particle modes generated during sanding of two paints doped with 17 nm TiO2 and 95 nm Carbon Black nanoparticles as compared to the size modes generated during sanding a conventional reference paint. However, the number concentrations in the different size modes varied considerably in between the two NP-doped paints and the reference paint. Therefore, from a physical point of view, there may be a difference in the exposure risk during sanding surfaces covered with nanoparticle-based paints as compared to sanding conventional paints.

Koponen, I. K., et al. (2011). "Comparison of dust released from sanding conventional and nanoparticle-doped wall and wood coatings." J. Expo. Sci. Environ. Epidemiol **21**(4): 408-418.

Introduction of engineered nanoparticles (ENPs) into traditional surface coatings (e.g., paints, lacquers, fillers) may result in new exposures to both workers and consumers and possibly also a new risk to their health. During finishing and renovation, such products may also be a substantial source of exposure to ENPs or aggregates thereof. This study investigates the particle size distributions (5.6 nm-19.8 mum) and the total number of dust particles generated during sanding of ENP-doped paints, lacquers, and fillers as compared to their conventional counterparts. In all products, the dust emissions from sanding were found to consist of five size modes: three modes under 1 mum and two modes around 1 and 2 mum. Corrected for the emission from the sanding machine, the sanding dust, was dominated by 100-300 nm size particles, whereas the mass and surface area spectra were dominated by the micrometer modes. Adding ENPs to the studied products only vaguely affected the geometric mean diameters of the particle modes in the sanding dust when compared to their reference products. However, we observed considerable differences in the number concentrations in the different size modes, but still without revealing a clear effect of ENPs on dust emissions from sanding.

Kumar, P., et al. (2012). "Release of ultrafine particles from three simulated building processes." Journal of Nanoparticle Research **14**(4): 1-14.

Building activities are recognised to produce coarse particulate matter but less is known about the release of airborne ultrafine particles (UFPs; those below 100 nm in diameter). For

the first time, this study has investigated the release of particles in the 5–560 nm range from three simulated building activities: the crushing of concrete cubes, the demolition of old concrete slabs, and the recycling of concrete debris. A fast response differential mobility spectrometer (Cambustion DMS50) was used to measure particle number concentrations (PNC) and size distributions (PNDs) at a sampling frequency of 10 Hz in a confined laboratory room providing controlled environment and near–steady background PNCs. The sampling point was intentionally kept close to the test samples so that the release of new UFPs during these simulated processes can be quantified. Tri–modal particle size distributions were recorded for all cases, demonstrating different peak diameters in fresh nuclei (<10 nm), nucleation (10–30 nm) and accumulation (30–300 nm) modes for individual activities. The measured background size distributions showed modal peaks at about 13 and 49 nm with average background PNCs ~1.47 × 104 cm−3. These background modal peaks shifted towards the larger sizes during the work periods (i.e. actual experiments) and the total PNCs increased between 2 and 17 times over the background PNCs for different activities. After adjusting for background concentrations, the net release of PNCs during cube crushing, slab demolition, and 'dry' and 'wet' recycling events were measured as ~0.77, 19.1, 22.7 and 1.76 (×104) cm−3, respectively. The PNDs were converted into particle mass concentrations (PMCs). While majority of new PNC release was below 100 nm (i.e. UFPs), the bulk of new PMC emissions were constituted by the particles over 100 nm; ~95, 79, 73 and 90% of total PNCs, and ~71, 92, 93 and 91% of total PMCs, for cube crushing, slab demolition, dry recycling and wet recycling, respectively. The results of this study firmly elucidate the release of UFPs and raise a need for further detailed studies and designing health and safety related exposure guidelines for laboratory workplaces and operational building sites.

Lee, J., et al. (2009). Potential Environmental and Human Health Impacts of Nanomaterials Used in the Construction Industry, Berlin, Heidelberg, Springer Berlin Heidelberg.

Nanomaterials and nanocomposites with unique physical and chemical properties are increasingly being used by the construction industry to enable novel applications. Yet, we are confronted with the timely concern about their potential (unintended) impacts to the environment and human health. Here, we consider likely environmental release and exposure scenarios for nanomaterials that are often incorporated into building materials and/or used in various applications by the construction industry, such as carbon nanotubes, TiO2, and quantum dots. To provide a risk perspective, adverse biological and toxicological effects associated with these nanomaterials are also reviewed along with their mode of action. Aligned with ongoing multidisciplinary action on risk assessment of nanomaterials in the environment, this article concludes by discerning critical knowledge gaps and research needs to inform the responsible manufacturing, use and disposal of nanoparticles in construction materials.

Methner, M., et al. (2012). "Field application of the Nanoparticle Emission Assessment Technique (NEAT): task-based air monitoring during the processing of engineered nanomaterials (ENM) at four facilities." J Occup Environ Hyg **9**(9): 543-555.

In early 2006, the National Institute for Occupational Safety and Health created a field research team whose mission is to visit a variety of facilities engaged in the production, handling, or use of engineered nanomaterials (ENMs) and to conduct initial emission and exposure assessments to identify candidate sites for further study. To conduct the assessments, the team developed the Nanoparticle Emission Assessment Technique (NEAT), which has been used at numerous facilities to sample multiple engineered nanomaterials. Data collected at four facilities, which volunteered to serve as test sites, indicate that specific tasks can release ENMs to the workplace atmosphere and that traditional controls such as ventilation can be used to limit exposure. Metrics such as particle number concentration (adjusted for background), airborne mass concentration, and qualitative transmission electron microscopy were used to determine the presence, nature, and magnitude of emissions and whether engineered nanomaterials migrated to the workers' breathing zone. [Supplementary materials are available for this article. Go to the publisher's online edition of Journal of Occupational and Environmental Hygiene for the following free supplemental resource: a PDF file containing information on facilities, a description of processes/tasks, existing controls, and sampling strategy, and a PDF file containing TEM images according to facility and task.]

Methner, M., et al. (2012). "Evaluation of the potential airborne release of carbon nanofibers during the preparation, grinding, and cutting of epoxy-based nanocomposite material." J Occup Environ Hyg **9**(5): 308-318.

The National Institute for Occupational Safety and Health conducted an initial, task-based comparative assessment to determine the potential for release of carbon nanofibers (CNFs) during dry material handling, wet cutting, grinding, and sanding (by machine and hand) of plastic composite material containing CNFs. Using a combination of direct-reading instruments and filter-based air sampling methods for airborne mass and transmission electron microscopy (TEM), concentrations were measured and characterized near sources of particle generation, in the breathing zone of the workers, and in the general work area. Tasks such as surface grinding of composite material and manually transferring dry CNFs produced substantial increases in particle number concentration (range = 20,000-490,000 1-cm(-3)). Concomitant increases in mass concentration were also associated with most tasks. Nearly 90% of all samples examined via TEM indicated that releases of CNFs do occur and that the potential for exposure exists. These findings also indicate that improperly designed, maintained, or installed engineering controls may not be completely effective in controlling releases. Unprotected skin exposure to CNFs was noted in two instances and indicated the need for educating workers on the need for personal protective equipment. [Supplementary materials are available for this article. Go to the publisher's online edition of Journal of Occupational and Environmental Hygiene for the following free supplemental resource: a PDF file containing information on materials, evaluated processes, personal protective equipment, and existing ventilation/engineering controls.]

Mikkelsen, L., et al. (2013). "Cytotoxicity, oxidative stress and expression of adhesion molecules in human umbilical vein endothelial cells exposed to dust from paints with or without nanoparticles." Nanotoxicology **7**(2): 117-134.

Nanoparticles in primary form and nanoproducts might elicit different toxicological responses. We compared paint-related nanoparticles with respect to effects on endothelial oxidative stress, cytotoxicity and cell adhesion molecule expression. Primary human umbilical vein endothelial cells were exposed to primary nanoparticles (fine, photocatalytic or nanosized

TiO(2), aluminium silicate, carbon black, nano-silicasol or axilate) and dust from sanding reference- or nanoparticle-containing paints. Most of the samples increased cell surface expressions of vascular cell adhesion molecule-1 (VCAM-1) and intracellular adhesion molecule-1 (ICAM-1), but paint sanding dust samples generally generated less response than primary particles of TiO(2) and carbon black. We found no relationship between the expression of adhesion molecules, cytotoxicity and production of reactive oxygen species. In conclusion, sanding dust from nanoparticle-containing paint did not generate more oxidative stress or expression of cell adhesion molecules than sanding dust from paint without nanoparticles, whereas the primary particles had the largest effect on mass basis.

NIOSH (2011). Current intelligence bulletin 63: occupational exposure to titanium dioxide. Department of Health and Human Services (CDC/NIOSH), Cincinnati.

Excerpt: In this Current Intelligence Bulletin, the National Institute for Occupational Safety and Health (NIOSH) reviews the animal and human data relevant to assessing the carcinogenicity of titanium dioxide (TiO2) (Chapters 2 and 3), presents a quantitative risk assessment using dose-response data in rats for both cancer (lung tumors) and noncancer (pulmonary inflammation) responses and extrapolation to humans with lung dosimetry modeling (Chapter 4), provides recommended exposure limits (RELs) for fine and ultrafine (including engineered nanoscale) TiO2 (Chapter 5), describes exposure monitoring techniques and exposure control strategies (Chapter 6), and discusses avenues of future research (Chapter 7). This report only addresses occupational exposures by inhalation, and conclusions derived here should not be inferred to pertain to nonoccupational exposures.

NIOSH (2013). Current intelligence bulletin 65: occupational exposure to carbon nanotubes and nanofibers. Department of Health and Human Services (CDC/NIOSH), Cincinnati.

Excerpt: In summary, the findings and recommendations in this Current Intelligence Bulletin are intended to minimize the potential health risks associated with occupational exposure to CNT and CNF by recommending a working lifetime exposure limit (1 µg/m3, 8-hr TWA, 45 years), a sampling and analytical method to detect CNT and CNF, medical surveillance and screening and other guidelines. The expanding use of CNT/CNF products in commerce and research warrants these protective actions.

Oberdörster, G., et al. (2005). "Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles." Environ Health Perspect **113**(7): 823-839.

Although humans have been exposed to airborne nanosized particles (NSPs; < 100 nm) throughout their evolutionary stages, such exposure has increased dramatically over the last century due to anthropogenic sources. The rapidly developing field of nanotechnology is likely to become yet another source through inhalation, ingestion, skin uptake, and injection of engineered nanomaterials. Information about safety and potential hazards is urgently needed. Results of older biokinetic studies with NSPs and newer epidemiologic and toxicologic studies with airborne ultrafine particles can be viewed as the basis for the expanding field of nanotoxicology, which can be defined as safety evaluation of engineered nanostructures and nanodevices. Collectively, some emerging concepts of nanotoxicology can be identified from

the results of these studies. When inhaled, specific sizes of NSPs are efficiently deposited by diffusional mechanisms in all regions of the respiratory tract. The small size facilitates uptake into cells and transcytosis across epithelial and endothelial cells into the blood and lymph circulation to reach potentially sensitive target sites such as bone marrow, lymph nodes, spleen, and heart. Access to the central nervous system and ganglia via translocation along axons and dendrites of neurons has also been observed. NSPs penetrating the skin distribute via uptake into lymphatic channels. Endocytosis and biokinetics are largely dependent on NSP surface chemistry (coating) and in vivo surface modifications. The greater surface area per mass compared with larger-sized particles of the same chemistry renders NSPs more active biologically. This activity includes a potential for inflammatory and pro-oxidant, but also antioxidant, activity, which can explain early findings showing mixed results in terms of toxicity of NSPs to environmentally relevant species. Evidence of mitochondrial distribution and oxidative stress response after NSP endocytosis points to a need for basic research on their interactions with subcellular structures. Additional considerations for assessing safety of engineered NSPs include careful selections of appropriate and relevant doses/concentrations, the likelihood of increased effects in a compromised organism, and also the benefits of possible desirable effects. An interdisciplinary team approach (e.g., toxicology, materials science, medicine, molecular biology, and bioinformatics, to name a few) is mandatory for nanotoxicology research to arrive at an appropriate risk assessment.

Oberdörster, G., et al. (2004). "Translocation of inhaled ultrafine particles to the brain." Inhal. Toxicol **16**(6-7): 437-445.

Ultrafine particles (UFP, particles <100 nm) are ubiquitous in ambient urban and indoor air from multiple sources and may contribute to adverse respiratory and cardiovascular effects of particulate matter (PM). Depending on their particle size, inhaled UFP are efficiently deposited in nasal, tracheobronchial, and alveolar regions due to diffusion. Our previous rat studies have shown that UFP can translocate to interstitial sites in the respiratory tract as well as to extrapulmonary organs such as liver within 4 to 24 h postexposure. There were also indications that the olfactory bulb of the brain was targeted. Our objective in this follow-up study, therefore, was to determine whether translocation of inhaled ultrafine solid particles to regions of the brain takes place, hypothesizing that UFP depositing on the olfactory mucosa of the nasal region will translocate along the olfactory nerve into the olfactory bulb. This should result in significant increases in that region on the days following the exposure as opposed to other areas of the central nervous system (CNS). We generated ultrafine elemental (13)C particles (CMD = 36 nm; GSD = 1.66) from [(13)C] graphite rods by electric spark discharge in an argon atmosphere at a concentration of 160 microg/m(3). Rats were exposed for 6 h, and lungs, cerebrum, cerebellum and olfactory bulbs were removed 1, 3, 5, and 7 days after exposure. (13)C concentrations were determined by isotope ratio mass spectroscopy and compared to background (13)C levels of sham-exposed controls (day 0). The background corrected pulmonary (13)C added as ultrafine (13)C particles on day 1 postexposure was 1.34 microg/lung. Lung (13)C concentration decreased from 1.39 microg/g (day 1) to 0.59 microg/g by 7 days postexposure. There was a significant and persistent increase in added (13)C in the olfactory bulb of 0.35 microg/g on day 1, which increased to 0.43 microg/g by day 7. Day 1 (13)C concentrations of cerebrum and cerebellum were also significantly increased but the

increase was inconsistent, significant only on one additional day of the postexposure period, possibly reflecting translocation across the blood-brain barrier in certain brain regions. The increases in olfactory bulbs are consistent with earlier studies in nonhuman primates and rodents that demonstrated that intranasally instilled solid UFP translocate along axons of the olfactory nerve into the CNS. We conclude from our study that the CNS can be targeted by airborne solid ultrafine particles and that the most likely mechanism is from deposits on the olfactory mucosa of the nasopharyngeal region of the respiratory tract and subsequent translocation via the olfactory nerve. Depending on particle size, >50% of inhaled UFP can be depositing in the nasopharyngeal region during nasal breathing. Preliminary estimates from the present results show that approximately 20% of the UFP deposited on the olfactory mucosa of the rat can be translocated to the olfactory bulb. Such neuronal translocation constitutes an additional not generally recognized clearance pathway for inhaled solid UFP, whose significance for humans, however, still needs to be established. It could provide a portal of entry into the CNS for solid UFP, circumventing the tight blood-brain barrier. Whether this translocation of inhaled UFP can cause CNS effects needs to be determined in future studies.

Saber, A. T., et al. (2012). "Nanotitanium dioxide toxicity in mouse lung is reduced in sanding dust from paint." Part Fibre. Toxicol **9**: 4.

BACKGROUND: Little is known of how the toxicity of nanoparticles is affected by the incorporation in complex matrices. We compared the toxic effects of the titanium dioxide nanoparticle UV-Titan L181 (NanoTiO2), pure or embedded in a paint matrix. We also compared the effects of the same paint with and without NanoTiO2. METHODS: Mice received a single intratracheal instillation of 18, 54 and 162 mug of NanoTiO2 or 54, 162 and 486 mug of the sanding dust from paint with and without NanoTiO2. DNA damage in broncheoalveolar lavage cells and liver, lung inflammation and liver histology were evaluated 1, 3 and 28 days after intratracheal instillation. Printex 90 was included as positive control. RESULTS: There was no additive effect of adding NanoTiO2 to paints: Therefore the toxicity of NanoTiO2 was reduced by inclusion into a paint matrix. NanoTiO2 induced inflammation in mice with severity similar to Printex 90. The inflammatory response of NanoTiO2 and Printex 90 correlated with the instilled surface area. None of the materials, except of Printex 90, induced DNA damage in lung lining fluid cells. The highest dose of NanoTiO2 caused DNA damage in hepatic tissue 1 day after intratracheal instillation. Exposure of mice to the dust from paints with and without TiO2 was not associated with hepatic histopathological changes. Exposure to NanoTiO2 or to Printex 90 caused slight histopathological changes in the liver in some of the mice at different time points. CONCLUSIONS: Pulmonary inflammation and DNA damage and hepatic histopathology were not changed in mice instilled with sanding dust from NanoTiO2 paint compared to paint without NanoTiO2. However, pure NanoTiO2 caused greater inflammation than NanoTiO2 embedded in the paint matrix.

Saber, A. T., et al. (2012). "Inflammatory and genotoxic effects of sanding dust generated from nanoparticle-containing paints and lacquers." Nanotoxicology **6**(7): 776-788.

Nanoparticles are increasingly used in paints and lacquers. Little is known of the toxicity of nanoparticles incorporated in complex matrices and released during different phases of the life cycle. DNA damaging activity and inflammogenicity of sanding dust sampled during

standardised sanding of boards painted with paints with and without nanoparticles were determined 24 h after intratracheal instillation of a single dose of 54 mug in mice. Dusts from nanoparticle-containing paints and lacquers did not generate pulmonary inflammation or oxidative stress. Sanding dust from both the nanoparticle-containing and the conventional lacquer and the outdoor acrylic-based reference paint increased the level of DNA strand breaks in bronchoalveolar fluid cells. In conclusion, addition of nanoparticles to paint or lacquers did not increase the potential of sanding dust for causing inflammation, oxidative stress or DNA damage, suggesting that the paint/lacquer matrix is more important as determinant of DNA damage than the nanomaterial.

Schug, T. T., et al. (2013). "ONE Nano: NIEHS's strategic initiative on the health and safety effects of engineered nanomaterials." Environ Health Perspect **121**(4): 410-414.

BACKGROUND: The past decade has seen tremendous expansion in the production and application of engineered nanomaterials (ENMs). The unique properties that make ENMs useful in the marketplace also make their interactions with biological systems difficult to anticipate and critically important to explore. Currently, little is known about the health effects of human exposure to these materials. OBJECTIVES: As part of its role in supporting the National Nanotechnology Initiative, the National Institute of Environmental Health Sciences (NIEHS) has developed an integrated, strategic research program-"ONE Nano"-to increase our fundamental understanding of how ENMs interact with living systems, to develop predictive models for quantifying ENM exposure and assessing ENM health impacts, and to guide the design of second-generation ENMs to minimize adverse health effects. DISCUSSION: The NIEHS's research investments in ENM health and safety include extramural grants and grantee consortia, intramural research activities, and toxicological studies being conducted by the National Toxicology Program (NTP). These efforts have enhanced collaboration within the nanotechnology research community and produced toxicological profiles for selected ENMs, as well as improved methods and protocols for conducting in vitro and in vivo studies to assess ENM health effects. CONCLUSION: By drawing upon the strengths of the NIEHS's intramural, extramural, and NTP programs and establishing productive partnerships with other institutes and agencies across the federal government, the NIEHS's strategic ONE Nano program is working toward new advances to improve our understanding of the health impacts of engineered nanomaterials and support the goals of the National Nanotechnology Initiative.

Smulders, S., et al. (2014). "Toxicity of nanoparticles embedded in paints compared with pristine nanoparticles in mice." Toxicol. Sci **141**(1): 132-140.

The unique physical and chemical properties of nanomaterials have led to their increased use in many industrial applications, including as a paint additive. For example, titanium dioxide (TiO2) engineered nanoparticles (ENPs) have well-established anti-UV, self-cleaning, and air purification effects. Silver (Ag) ENPs are renowned for their anti-microbial capabilities and silicon dioxide (SiO2) ENPs are used as fire retardants and anti-scratch coatings. In this study, the toxic effects and biodistribution of three pristine ENPs (TiO2, Ag, and SiO2), three aged paints containing ENPs (TiO2, Ag, and SiO2) along with control paints without ENPs were compared. BALB/c mice were oropharyngeally aspirated with ENPs or paint particles (20 mug/aspiration) once a week for 5 weeks and sacrificed either 2 or 28 days post final aspiration treatment. A bronchoalveolar lavage was performed and systemic blood toxicity was evaluated to ascertain cell counts, induction of inflammatory cytokines, and key blood parameters. In addition, the lung, liver, kidney, spleen, and heart were harvested and metal concentrations were determined. Exposure to pristine ENPs caused subtle effects in the lungs and negligible alterations in the blood. The most pronounced toxic effects were observed after Ag ENPs exposure; an increased neutrophil count and a twofold increase in pro-inflammatory cytokine secretion (keratinocyte chemoattractant (KC) and interleukin-1ss (IL-1ss)) were identified. The paint containing TiO2 ENPs did not modify macrophage and neutrophil counts, but mildly induced KC and IL-1ss. The paints containing Ag or SiO2 did not show significant toxicity. Biodistribution experiments showed distribution of Ag and Si outside the lung after aspiration to respectively pristine Ag or SiO2 ENPs. In conclusion, we demonstrated that even though direct exposure to ENPs induced some toxic effects, once they were embedded in a complex paint matrix little to no adverse toxicological effects were identified.

Som, C., et al. (2011). "Environmental and health effects of nanomaterials in nanotextiles and façade coatings." Environment International **37**(6): 1131-1142.

Engineered nanomaterials (ENM) are expected to hold considerable potential for products that offer improved or novel functionalities. For example, nanotechnologies could open the way for the use of textile products outside their traditional fields of applications, for example, in the construction, medical, automobile, environmental and safety technology sectors. Consequently, nanotextiles could become ubiquitous in industrial and consumer products in future. Another ubiquitous field of application for ENM is façade coatings. The environment and human health could be affected by unintended release of ENM from these products. The product life cycle and the product design determine the various environmental and health exposure situations. For example, ENM unintentionally released from geotextiles will probably end up in soils, whereas ENM unintentionally released from T-shirts may come into direct contact with humans and end up in wastewater. In this paper we have assessed the state of the art of ENM effects on the environment and human health on the basis of selected environmental and nanotoxicological studies and on our own environmental exposure modeling studies. Here, we focused on ENM that are already applied or may be applied in future to textile products and façade coatings. These ENM's are mainly nanosilver (nano-Ag), nano titanium dioxide (nano-TiO2), nano silica (nano-SiO2), nano zinc oxide (nano-ZnO), nano alumina (nano-Al2O3), layered silica (e.g. montmorillonite, Al2[(OH)2/Si4O10]nH2O), carbon black, and carbon nanotubes (CNT). Knowing full well that innovators have to take decisions today, we have presented some criteria that should be useful in systematically analyzing and interpreting the state of the art on the effects of ENM. For the environment we established the following criteria: (1) the indication for hazardous effects, (2) dissolution in water increases/decreases toxic effects, (3) tendency for agglomeration or sedimentation, (4) fate during waste water treatment, and (5) stability during incineration. For human health the following criteria were defined: (1) acute toxicity, (2) chronic toxicity, (3) impairment of DNA, (4) crossing and damaging of tissue barriers, (5) brain damage and translocation and effects of ENM in the (6) skin, (7) gastrointestinal or (8) respiratory tract. Interestingly, some ENM might affect the environment less severely than they might affect human health, whereas the case for others is vice versa. This is especially true for CNT. The assessment of the environmental risks is

highly dependent on the respective product life cycles and on the amounts of ENM produced globally.

Vaquero, C., et al. (2015). "Occupational exposure to nano-TiO2 in the life cycle steps of new depollutant mortars used in construction." J Phys Conf **617**: 012006.

The present work is focused on the measurement of workers exposure to nano-TiO2 in the life cycle steps of depollutant mortars. It has been done in the framework of the SCAFFOLD project, which aims at the management of potential risks arising from the use of manufactured nanomaterials in construction. Main findings can be summarized as follows: (1) The occupational exposure to nano-TiO2 is below 0.3 mg/m3 for all measured scenarios. The highest concentrations were measured during the cleaning task (in the nano-TiO2 manufacturing process) and during the application (spraying) of depollutant coatings on a wall.It was found a high release of particles above the background in several tasks as expected due to the nature of the activities performed. The maximum concentration was measured during drilling and during adding powder materials (mean total particle concentration up to 5.591E+04 particles/cm3 and 5.69E+04 particles/cm3). However, considering data on total particle concentration released, no striking differences have been observed when tasks have been performed using conventional materials in the sector (control) and when using materials doped with nano-objects.

West, G. H., et al. (2019). "Exposure to airborne nano-titanium dioxide during airless spray painting and sanding." Journal of Occupational and Environmental Hygiene **16**(3): 218-228.

The objectives of the study were to measure and characterize exposure to airborne nanoscale titanium dioxide during airless spraying and sanding of a nano-enabled paint, and to evaluate the effectiveness of dust capture methods in reducing airborne nanoparticle concentrations. A tradesperson performed the work activities in an environmentally controlled chamber. Samples were collected in the tradesperson's breathing zone and in surrounding areas to assess bystander exposure. Filter-based samples were analyzed using gravimetric methods, scanning electron microscopy, and energy dispersive spectroscopy. Differential particle count data were obtained by means of a scanning mobility particle sizer. Local exhaust ventilation provided statistically significant reductions of airborne nanoparticle concentrations during sanding. Sanding the paint after drying with a handheld power sander generated relatively low levels of airborne titanium dioxide. In contrast, task-based exposure measurements collected during the initial airless spray application of the nano-enabled paint suggested a potential for occupational exposures to exceed the time-weighted average exposure limit for ultrafine titanium dioxide recommended by the National Institute for Occupational Safety and Health. Painters applying nano-enabled coatings may have little recourse but to rely, in some instances, on lower tiers of the hierarchy of controls, such as personal protective equipment. In light of these findings, employers and industrial hygienists should characterize exposures and implement the hierarchy of controls to ensure painters are sufficiently protected.

West, G. H., et al. (2016). "Toward responsible development and effective risk management of nano-enabled products in the U.S. construction industry." J Nanopart Res **18**(2): 49.

The global construction sector is experiencing major improvements to building materials used in large quantities through commercial applications of nanotechnology. Nano-enabled construction products hold great promise for energy efficiency and resource conservation, but risk assessments lag as new products emerge. This paper presents results from an inventory, survey, and exposure assessment conducted by the authors and explores these findings in the broader context of evolving research trends and responsible development of nanotechnology. An inventory of 458 reportedly nano-enabled construction products provided insight into product availability, potential exposures, and deficiencies in risk communication that are barriers to adoption of proactive safety measures. Seasoned construction trainers surveyed were largely unaware of the availability of nano-enabled construction products. Exposure assessment demonstrated the effectiveness of ventilation to reduce exposures during mechanical abrasion of photocatalytic tiles containing titanium dioxide (TiO2). Dissociated particles of TiO2 just above the nanoscale (138 nm) were detected in the debris collected during cutting of the tiles, but measurements were below recommended exposure limits for TiO2. Exposure assessments remain scarce, and toxicological understanding primarily pertains to unincorporated nanomaterials; less is known about the occupational risks of nano-enabled construction products across their life cycle. Further research is needed to characterize and quantify exposure to debris released from nanocomposite materials for realistic risk assessment, and to ascertain how nanocomposite matrices, fillers, and degradation forces interact to affect release dynamics. Improving risk communication strategies and implementing safe work practices will cultivate responsible development of nanotechnology in construction, as will multidisciplinary research efforts.

Wohlleben, W., et al. (2011). "On the Lifecycle of Nanocomposites: Comparing Released Fragments and their In-Vivo Hazards from Three Release Mechanisms and Four Nanocomposites." Small **7**(16): 2384-2395.

Nanocomposites are the dominating class of nanomaterials to come into consumer contact, and were in general assumed to pose low risk. The first data is now emerging on the exposure from nanocomposites, but little is yet known about their hypothetical nanospecific physiological effects, giving ample room for speculation. For the first time, this comprehensive study addresses these aspects in a systematic series of thermoplastic and cementitious nanocomposite materials. Earlier reports that 'chalking', the release of pigments from weathered paints, also occurs for nanocomposites, are confirmed. In contrast, mechanical forces by normal consumer use or do-it-yourself sanding do not disrupt nanofillers (nanoparticles or nanofibers) from the matrix. Detailed evidence is provided for the nature of the degradation products: no free nanofillers are detected up to the detection threshold of 100 ppm. Sanding powders measuring 1 to 80 mum in diameter are identified with the original material, still containing the nanofillers. The potential hazard from aerosols generated by sanding nanocomposites up to the nuisance dust limit is also investigated. In-vivo instillation in rats is used to quantify physiological effects on degradation products from abraded nanocomposites, in comparison to the abraded matrix without nanofiller and to the pure nanofiller. In this pioneering and preliminary evaluation, the hazards cannot be distinguished with or without nanofiller.

Part 4: Training, Hazard Communication, and Awareness

Boatman, L. and D. Chaplan (2018). Nanotechnology: Assessing Awareness and Training Needs Among California Construction Trades. CPWR Report.

A growing number of construction products incorporate engineered nanoparticles, but little is known about their long-term health effects on exposed workers. The study explored the current understanding and use of nanotechnology applications in heavy industrial/commercial construction among union leaders, apprenticeship program staff and construction contractors. Researchers surveyed 253 contacts representing 24 construction crafts to learn about their knowledge, attitudes and beliefs concerning nano-enabled construction products and about existing health and safety training addressing nanotechnology in construction. Researchers then conducted 21 follow-up interviews with survey respondents and 5 key interviews with California state agency employees.

Castillo, A. P. D. (2019). "Training for Workers and Safety Representatives on Manufactured Nanomaterials." NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy **29**(1): 36-52.

Although nanotechnologies are increasingly present in numerous sectors of the economy, training resources available to workers exposed to them are still rare. In the European Union (EU), some initiatives exist that inform workers about exposure and risks, but they lack two key dimensions: the involvement of workers themselves in designing and implementing training materials and the key role played by safety representatives in improving occupational health and safety in EU member states. Making workers actors of their own training, rather than recipients of it, and empowering them, so that they can collectively question unsafe situations and ask for changes in their working conditions, is how training can positively impact their health and safety. This article describes a training package (materials, infographics, interactive web applet) designed specifically to achieve this objective. Developed under the NanoDiode project, it focuses on six key themes: types of nanomaterials, uses at work, risks, presence in the workplace, exposure, and experience sharing.

Jones, W., et al. (2015). "Nanomaterials in construction and demolition - how can we assess the risk if we don't know where they are?" J Phys Conf **617**: 012031.

This research, funded by the Institution of Occupational Safety and Health in the United Kingdom, has used a combination of literature review, web searching and unstructured interviews with a range of industry professionals to compile a list of products used in construction and the built environment which might contain nanomaterials. Samples of these products have been analysed using Scanning Electron Microscopy and Energy Dispersive X- Ray Spectroscopy to investigate whether nanomaterials are actually present and to what extent. Preliminary results of this testing are presented here. It is concluded that there is a discrepancy between the academic literature and the reality regarding the current application of nanomaterials in the construction industry and the built environment. There are also inaccuracies and deficiencies in the information provided by manufacturers which makes it difficult to accurately assess the location and application of nanomaterials within the industry. Further testing is planned to evaluate the risk of nanoparticle release from nano-enabled building products at their end of life by reproducing common demolition and recycling processes such as crushing, grinding, burning and melting. Results of this will form the basis of practical guidance for the construction, demolition and recycling industries to help them identify where particular protection or control measures may be appropriate as well as providing reassurance where no additional action is required.