



## TECHNICAL FACT SHEET – NANOMATERIALS

### At a Glance

- ❖ Diverse class of substances that have structural components smaller than 100 nanometers (nm) in at least one dimension (Klaine and others 2008). Nanomaterials (NMs) include nanoparticles (NPs), which are particles with at least two dimensions between approximately 1 and 100 nm.
- ❖ Have high surface area to volume ratio and the number of surface atoms and their arrangement determines the size and properties of the NM.
- ❖ Can be categorized into three types: natural UFPs, incidental NMs and engineered NMs.
- ❖ Engineered NMs are used in a wide variety of applications, including environmental remediation, pollution sensors, photovoltaics, medical imaging and drug delivery.
- ❖ The mobility of NMs depends on factors such as surface chemistry and particle size, and on biological and abiotic processes in the media.
- ❖ May stay in suspension as individual particles, aggregate, dissolve or react with other materials.
- ❖ Characterization and detection technologies include differential mobility analyzers, mass spectrometry and scanning electron microscopy.

### Introduction

This fact sheet, developed by the U.S. Environmental Protection Agency (EPA) Federal Facilities Restoration and Reuse Office (FFRRO), provides a summary of nanomaterials (NMs), including their physical and chemical properties; potential environmental and health impacts; existing federal and state guidelines; detection and treatment methods; and additional sources of information. This fact sheet is intended for use by site managers and other field personnel who may need to address or use NMs at cleanup sites or in drinking water supplies.

NMs are increasingly being used in a wide range of household, cosmetic and personal use, scientific, environmental, industrial and medicinal applications. NMs may possess unique chemical, biological and physical properties compared with larger particles of the same material (Exhibit 1). NM research is a rapidly growing area; current research is focused on carbon-based, metal and metal oxides, quantum dots and nanosilver. Due to the diverse nature of NMs, this fact sheet presents a high-level summary for NMs in general with specific focus on the NMs of current research interest.

### What are nanomaterials?

- ❖ For purposes of this document, NMs are a diverse class of substances that have structural components smaller than 100 nanometers (nm) in at least one dimension. NMs include nanoparticles (NPs), which are particles with at least two dimensions between approximately 1 and 100 nm (Klaine and others 2008). EPA refers to nano-sized particles that are natural or aerosol as ultrafine particles (UFPs).
- ❖ NMs have high surface area to volume ratio and the number of surface atoms and their arrangement determines the size and properties of the NM (Sarma and others 2015).
- ❖ As of 2014, more than 1,800 consumer products containing NMs are on the market (Vance and others 2015).

**Disclaimer:** The U.S. EPA prepared this fact sheet using the most recent publicly-available scientific information; additional information can be obtained from the source documents. This fact sheet is not intended to be used as a primary source of information and is not intended, nor can it be relied upon, to create any rights enforceable by any party in litigation with the United States. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

## Technical Fact Sheet – Nanomaterials

- ❖ NMs and UFPs can be categorized into three types according to their source:
  - Natural UFPs include combustion products, viruses and sea spray.
  - Incidental NMs are generated by anthropogenic processes and include diesel exhaust, welding fumes and industrial effluents.
  - Engineered NMs are designed with very specific properties and are made through chemical and/or physical processes (Exhibit 1).

### Exhibit 1: Properties and Common Uses of NMs and UFPs

(EPA 2007, 2008a; Klaine and others 2008; Watlington 2005; Gil and Parak 2008; Luoma 2008; Cota-Sanchez and Merlo-Sosa 2015)

| Types of NMs and UFPs (Occurrence)                      | Physical/Chemical Properties  | Uses   | Examples   |
|---|---|--|--|
| <b>Carbon-based</b><br>(Natural or Engineered)          | Stable, limited reactivity, excellent thermal and electrical conductivity.  | Biomedical applications, battery and fuel cell electrodes, super-capacitors, adhesives and composites, sensors and components in electronics, aircraft, aerospace and automotive industries. | Fullerenes, multi-walled and single-walled carbon nanotubes (CNTs) and graphene materials.   |
| <b>Metal-based Materials</b><br>(Natural or Engineered) | High reactivity, varied properties based on type, some have photolytic properties and ultraviolet blocking ability. Capping agents are used in some cases.            | Solar cells, paints and coatings, cosmetics, ultraviolet blockers in sunscreen, environmental remediation.   | Nanogold, nanosilver, metal oxides such as titanium dioxide (TiO <sub>2</sub> ), zinc oxide (ZnO), cerium dioxide (CeO <sub>2</sub> ) and nanoscale zero-valent iron (nZVI). |
| <b>Quantum Dots</b><br>(Engineered)                     | Reactive core composed of metals or semiconductors controls the material's optical properties. Cores are surrounded by an organic shell that protects from oxidation. | Medical Bioimaging, targeted therapeutics, solar cells, photonics and telecommunication.   | Quantum dots made from cadmium selenide (CdSe), cadmium telluride (CdTe), indium phosphide (InP) and zinc selenide (ZnSe).   |
| <b>Dendrimers</b><br>(Engineered)                       | Three-dimensional nanostructures engineered to carry molecules encapsulated in their interior void spaces or attached to the surface.                                 | Drug delivery systems, polymer materials, chemical sensors and modified electrodes.  | Hyperbranched polymers, dendrigraft polymers and dendrons.   |
| <b>Composite NMs</b><br>(Engineered)                    | Composite NMs consist of multifunctional components and have novel electrical, catalytic, magnetic, mechanical, thermal or imaging features.                          | Potential applications in drug delivery and cancer detection. Also used in auto parts and packaging materials to enhance mechanical and flame-retardant properties.                          | Produced using two different NMs or NMs combined with larger, bulk-type materials. They can also be made with NMs combined with synthetic polymers or resins.                |

## Existence of nanomaterials in the environment

- ❖ Engineered NMs may be released into the environment primarily through industrial and environmental applications, improper handling or consumer waste (EPA 2007).
- ❖ NPs fate and transport in the environment are largely dependent on material properties such as surface chemistry, particle size and biological and abiotic processes in environmental media. Depending on these properties, NPs may stay in suspension as individual particles, aggregate, dissolve or react with other materials (EPA 2009; Luoma 2008).
- ❖ NZVI particles are one of the most widely used nanoparticles for environmental remediation because of their ability to degrade a wide range of contaminants. Such an increasingly widespread application of nZVI will lead to its release into the environment. The environmental fate and transport of nZVI is not yet fully understood making it difficult to determine the environmental risk of nZVI injected into the subsurface (Jang and others 2014).
- ❖ Many NMs containing inherently non-biodegradable inorganic chemicals such as ceramics, metals and metal oxides are not expected to biodegrade (EPA 2007).
- ❖ Under conditions of low or no UV exposure, TiO<sub>2</sub> NPs have been shown to cause mortality, reduced growth and negative impacts on cells and DNA of aquatic organisms. Many of these studies, however, neglect environmentally relevant interactions with acute exposure times and high concentrations (greater than 10 milligrams per liter) and thus are difficult to extrapolate to natural ecosystems (Haynes and others 2017).
- ❖ Toxic effects of nanosilver on fish have been observed and nanosilver may induce a stress response in fish; however, the results of a 28-day study on rainbow trout indicated that although nanosilver did engage a stress response in fish, it did not affect growth or condition at environmentally relevant concentrations (0.28 micrograms per liter) and higher concentrations (average 47.6 micrograms per liter) (Murray and others 2017).
- ❖ ZnO NPs affected the growth rate of the algae and suggested that the ZnO NPs were more toxic to the marine algae than bulk ZnO (Manzo and others 2013).
- ❖ Recent studies have shown the following:
  - Carbon fullerenes are insoluble and colloidal aggregates in aqueous solutions are stable for months to years, allowing for chronic exposure to biological and environmental systems (Hegde and others 2015).
  - Single-walled CNTs are not readily degraded by fungal cultures or microbial communities (Parks and others 2015).
  - Coatings on iron oxide NPs caused different toxic effects, which were linked to decreasing colloidal stability, the release of ions from the core material or the ability to form reactive oxygen species in daphnids (Baumann and others 2014).
  - The degradation of a surface coating of nano-TiO<sub>2</sub> resulted in increased phototoxicity to a benthic organism (Wallis and others 2014).

## What are the routes of exposure to nanomaterials?

- ❖ The growing production and use of NMs in diverse industrial processes, construction, and medical and consumer products is resulting in increasing exposure of humans and the environment. Humans encounter NMs from many sources and exposure routes, including ingestion of food, direct dermal contact through consumer products and by inhalation of airborne NMs (Laux and other 2017).
- ❖ The small size, solubility and large surface area of NMs may enable them to translocate from their deposition site (typically in the lungs, if inhaled) and interact with biological systems. Circulation time increases drastically when the NMs are water-soluble (DHHS 2009; SCENIHR 2009). Translocation of NMs was shown to be dependent on material and aggregate size This was demonstrated by translocation of NMs to secondary organs such as the liver, heart, spleen, or kidney, subsequent to pulmonary uptake (Laux and others 2017).
- ❖ Animal studies indicate that nano-TiO<sub>2</sub> may accumulate in the liver, spleen, kidney and brain after it enters the bloodstream through various exposure routes (Chang and others 2013).
- ❖ In humans, although most inhaled NMs remain in the lung, less than 1 percent of the inhaled dose may reach the circulatory system (SCENIHR 2009).
- ❖ Use of sunscreen products on damaged skin may lead to dermal exposure to NMs (TiO<sub>2</sub> and ZnO), (EPA 2010; Mortensen and others 2008; Nel and others 2006).
- ❖ Ingestion exposure may occur from consuming

NMs contained in drinking water or food (for example, fish) or from unintentional hand to

mouth transfer of NMs (DHHS 2009; Wiesner and others 2006).

### What are the potential health effects of nanomaterials?

- ❖ Potential health effects of NMs vary across different types of NMs.
- ❖ Clinical and experimental animal studies indicate that NMs can induce different levels of cell injury and oxidative stress, depending on their charge, particle size and exposure dose. In addition, particle coatings, size, charge, surface treatments and surface excitation by ultraviolet (UV) radiation can modify surface properties and thus the aggregation and potential biological effects of NMs (Chang and others 2013; Nel and others 2006).
- ❖ Metallic NPs have been linked to chromosomal aberrations and oxidative damage to DNA due to the generation of reactive oxygen species. An in vivo study showed that exposure to silver, titanium, iron or copper NPs leads to genotoxicity (Dayem and others 2017).
- ❖ CNTs possess attributes similar to asbestos fibers and have been shown to cause inflammation and lesions as well as allergic immune responses in mice and rats. Several studies also report cellular DNA damage after exposure to single-walled CNTs (Hegde and others 2015).
- ❖ Several toxicological studies suggest fullerenes induce oxidative stress in living organisms (Hegde and others 2015).
- ❖ Biomarker responses were characterized following multi-walled CNT exposure to human liver cells (Henderson and others 2016).
- ❖ Toxicity of TiO<sub>2</sub> NPs have been studied extensively in recent years due to their use in sunscreen and cosmetics. Studies have shown exposure resulted in micoglia activation, reactive oxygen species production, activation of signaling pathways that result in cell death, both in vitro and in vivo (Czajka and others 2015).
- ❖ The aging of nano-TiO<sub>2</sub> in swimming pool water redistributed the coating and reduced its protective properties, thereby increasing reactivity and potential phototoxicity (Al-Abed and others 2016).
- ❖ A recent study showed that titanium was distributed to and accumulated in the heart, brain, spleen, lung, and kidney of mice after nano-TiO<sub>2</sub> exposure, in a dose-dependent manner. High doses of nano-TiO<sub>2</sub> significantly damaged the functions of liver and kidney and glucose and lipid metabolism, as showed in the blood biochemistry tests. Nano-TiO<sub>2</sub> caused damages in mitochondria and apoptosis of hepatocytes, generation of reactive oxygen species, and expression disorders of protective genes in the liver of mice (Jia and others 2017).
- ❖ Metal-containing NMs, such as quantum dots and nanometals, may cause toxicity to cells by releasing harmful components such as heavy metals or ions (Klaine and others 2008; Luoma 2008; Powell and Kanarek 2006).
- ❖ Research has shown that NMs may stimulate or suppress immune responses (or both) by binding to proteins in the blood (Dobrovolskaia and McNeil 2007).
- ❖ Study results suggest that certain NMs may pose a respiratory hazard after inhalation exposure. For example, rodent studies indicate that single-walled CNTs may cause pulmonary inflammation and fibrosis. Exposures to TiO<sub>2</sub> NPs have also resulted in persistent pulmonary inflammation in rats and mice (EPA 2007; NIOSH 2011, 2013).
- ❖ Based on the results of available animal inhalation and epidemiologic studies, the National Institute for Occupational Safety and Health (NIOSH) has concluded that TiO<sub>2</sub> NPs may have a higher mass- based potency than larger particles and should be considered as a potential occupational carcinogen (NIOSH 2011).

### Are there any federal and state guidelines or health standards for nanomaterials?

- ❖ Federal standards and guidelines:
  - The U.S. Food and Drug Administration (FDA) has finalized guidelines on the evaluation and use of NMs in FDA-regulated products. These guidelines focus on assessing safety, effectiveness and quality of products containing NMs, although the FDA does not make a categorical judgment on the safety or hazard of NMs (FDA 2014a, 2014b, 2014c and 2015a).
  - Many NMs are regarded as “chemical substances” under the Toxic Substances Control Act (TSCA) and therefore are subject to the requirements of the Act. EPA has already determined that CNTs are subject to



reporting under Section 5 of TSCA. Under TSCA Section 8(a), EPA issued a one-time reporting rule for NMs that are existing chemicals (EPA 2008b and 2016; FDA 2015b).

- If NMs enter drinking water or are injected into a well, they may be regulated under the Safe Drinking Water Act (EPA 2007). However, currently no maximum contaminant level goals (MCLGs) or maximum contaminant levels (MCLs) have been established for NMs.
- NMs that are used as pesticides are subject to the requirements of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA section 2(u) and 3(a)). If their use as a pesticide will result in residues in food or animal feed, a tolerance (maximum residue level) must be established under the Federal Food, Drug and Cosmetic Act (FFDCA).
- NMs may be regulated under various programs such as Comprehensive Environmental Response, Compensation, and

Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA), Clean Water Act (CWA) and Clean Air Act on a site-specific basis or if their use results in emissions of pollutants that are or could be hazardous (EPA 2007).

- ❖ State and local standards and guidelines:
  - In 2006, Berkeley, California, adopted the first local regulation specifically for NMs, requiring all facilities manufacturing or using manufactured NMs to disclose current toxicology information, as available (Berkeley 2006).
  - In 2010 and 2011, the California Department of Toxic Substances Control (CA DTSC) issued formal request letters to the manufacturers of certain CNTs, nanometal oxides, nanometals and quantum dots requesting information related to chemical and physical properties, including analytical test methods and other relevant information (CA DTSC 2013).

## What detection and characterization methods are available for nanomaterials?

- ❖ The analysis of NMs in environmental samples often requires the use of multiple technologies in tandem. Characterization methods include spectroscopy, microscopy, chromatography centrifugation, filtration and others (Gmiza and others 2015).
- ❖ Single-particle mass spectrometry provides chemical analysis of NMs suspended in gases and liquids (SCENIHR 2009).
- ❖ Aerosol fractionation technologies (differential mobility analyzers and scanning mobility particle sizers) use the mobility properties of charged NMs in an electrical field to obtain size fractions for subsequent analysis. Multi-stage impactor samplers separate NM fractions based on the aerodynamic mobility properties of the NMs (EPA 2007).
- ❖ Expansion condensation particle counters measure aerosol particle number densities for size diameters as low as 3 nm. (Saghafifar and others 2009).
- ❖ Size-exclusion chromatography, ultrafiltration and field flow fractionation can be used for size fractionation and collection of NM fractions in liquid media (EPA 2007).
- ❖ NM fractions in liquid may be further analyzed using dynamic light scattering for size analysis and mass spectrometry for chemical characterization (EPA 2007).
- ❖ One of the main methods of analyzing single NM characteristics is electron microscopy. Scanning electron microscopy and transmission electron microscopy can be used to determine the size, shape and aggregation state of NMs below 10 nm (EPA 2007; SCENIHR 2006; Sanchis and others 2015).
- ❖ Atomic force microscopy can provide single particle size and morphological information at the nm level in air and liquid media (EPA 2007).
- ❖ Dynamic light scattering is used to characterize manufactured silver NMs and provides information on the hydrodynamic diameter of NMs in suspensions. It is capable of measuring NPs from a few nm in size, but is not suitable for environmental samples (EPA 2010).
- ❖ Other analytical techniques include X-ray diffraction to measure the crystalline phase and X-ray photoelectron spectroscopy to determine the surface oxidation states and chemical composition of NMs (EPA 2010).
- ❖ A recent laboratory study employed absorption-edge synchrotron X-ray computed microtomography to extract silver NM concentrations within individual pores in static and transport systems (Molnar and others 2014).

## What technologies are being used to control nanomaterials?

- ❖ Coagulation is regarded as a critical process for the effective removal of NPs during water and wastewater treatment (Popowich and others 2015).
- ❖ Air filters and respirators are used to filter and remove NMs from air. A study found that membrane-coated fabric filters could provide an NM collection efficiency above 95 percent (Tsai and others 2012; Wiesner and others 2006).
- ❖ NMs in groundwater, surface water and drinking water may be removed using flocculation, sedimentation and sand or membrane filtration (Wiesner and others 2006), but a recent laboratory study using TiO<sub>2</sub> NPs found that these typical treatment methods may be inadequate for particles smaller than 450 nm (Kinsinger and others 2015).
- ❖ A recent study stabilized silver NPs using different capping agents to control the transport of the NPs in porous media (Badawy and others 2013).

## Where can I find more information about nanomaterials?

- ❖ Al-Abed, S.R., Virkutyte, J., Ortenzio, J.N.R., McCarrick, R.M., Degn, L.L., Zucker, R., Coates, N.H., Childs, K., Ma, H., Diamond, S., Dreher, K., and W.K. Boyes. 2016. "Environmental aging alters Al(OH)<sub>3</sub> coating of TiO<sub>2</sub> nanoparticles enhancing their photocatalytic and phototoxic activities." *Environmental Science: Nano*. Volume 3. Pages 593 to 601.
- ❖ Badawy, A.M., Hassan, A.A., Scheckel, K.G., Suidan, M.T., and T.M Tolymat. 2013. "Key Factors Controlling the Transport of Silver Nanoparticles in Porous Media." *Environmental Science and Technology*. Volume 47 (9). Pages 4039 to 4045.
- ❖ Baumann, J., Koser, J., Arndt, D., and J. Filser. 2014. "The coating makes the difference: Acute effects of iron oxide nanoparticles on *Daphnia magna*." *Science of The Total Environment*. Volume 484. Pages 176 to 184.
- ❖ California Department of Toxic Substances Control (CA DTSC). 2013. Nanomaterials Information Call-In. [www.dtsc.ca.gov/pollution\\_prevention/chemical\\_call\\_in.cfm](http://www.dtsc.ca.gov/pollution_prevention/chemical_call_in.cfm)
- ❖ Chang, X., Zhang, Y., Tang, M., and B. Wang. 2013. "Health Effects of Exposure to nano-TiO<sub>2</sub>: a Meta-Analysis of Experimental Studies." *Nanoscale Research Letters*. Volume 8 (51). [nanoscalereslett.springeropen.com/articles/10.1186/1556-276X-8-51](http://nanoscalereslett.springeropen.com/articles/10.1186/1556-276X-8-51)
- ❖ Cota-Sanchez, G., and L. Merlo-Sosa. 2015. Nanomaterial Characterization. *Nanomaterials in the Environment*. Pages 57 to 106.
- ❖ Council of the City of Berkeley, California (Berkeley). 2006. Section 12.12.040 Filing of Disclosure Information and Section 15.12.050 Quantities Requiring Disclosure. Ordinance No. 6,960-N.S. [www.cityofberkeley.info/citycouncil/ordinances/2006/6960.pdf](http://www.cityofberkeley.info/citycouncil/ordinances/2006/6960.pdf)
- ❖ Czajjka, M., Sawicki, K., Sikorska, K., Popek, S., Kruszewski, M., and L. Kapka-Skrzypczak. 2015. "Toxicity of titanium dioxide nanoparticles in central nervous system." *Toxicology in Vitro*. Volume 29 (5). Pages 1042 to 1052.
- ❖ Dayem, A.A., Hossain, M.K., Lee, S.B., Kim, K., Saha, S.K., Yang, G., Choi, H.Y., and S. Cho. 2017. "The Role of Reactive Oxygen Species (ROS) in the Biological Activities of Metallic Nanoparticles." *International Journal of Molecular Sciences*. Volume 18 (1). Page 120. [www.mdpi.com/1422-0067/18/1/120/pdf](http://www.mdpi.com/1422-0067/18/1/120/pdf)
- ❖ Dobrovolskaia, M.A., and S.E McNeil. 2007. "Immunological Properties of Engineered Nanomaterials." *Nature Nanotechnology*. Volume 2. Pages 469 to 478.
- ❖ Gmiza, K., Patricia Kouassi, A., Kaur Brar, S., Mercier, G., and J. Blais. 2015. Quantification and Analyses of Nanoparticles in Natural Environments with Different Approaches. *Nanomaterials in the Environment*. Pages 159 to 177.
- ❖ Gil, P.R., and W.J Parak. 2008. "Composite Nanoparticles Take Aim at Cancer." *ACS Nano*. Volume 2 (11). Pages 2200 to 2205.
- ❖ Haynes, V., Russell, B., Ward, J.E., and A.G. Agrios. 2017. "Photocatalytic effects of titanium dioxide nanoparticles on aquatic organisms – current knowledge and suggestions for future research." *Aquatic toxicology*. Volume 185. Pages 138 to 148.
- ❖ Hegde, K., Goswami, R., Sarma, S., Veeranki, V., Brar, S., and R. Surampalli. 2015. Environmental Hazards and Risks of Nanomaterials. *Nanomaterials in the Environment*. Pages 357 to 382.

## Where can I find more information about nanomaterials? (continued)

- ❖ Henderson, W.M., Bouchard, D., Chang, X., Al-Abed, S.R., and Q. Teng. 2016. "Biomarker analysis of liver cells exposed to surfactant-wrapped and oxidized multi-walled carbon nanotubes (MWCNTs)." *Science of the Total Environment*. Volume 565. Pages 777 to 786.
- ❖ Jang, M., Lim, M., and Y. Hwang. 2014. "Potential environmental implications of nanoscale zero-valent iron particles for environmental remediation." *Environmental Health Toxicology*. Volume 29. [www.ncbi.nlm.nih.gov/pmc/articles/PMC4313931/pdf/eh-29-e2014022.pdf](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4313931/pdf/eh-29-e2014022.pdf)
- ❖ Jia, X., Wang, S., Zhou, L., and L. Sun. 2017. "The Potential Liver, Brain, and Embryo Toxicity of Titanium Dioxide Nanoparticles on Mice." *Nanoscale Research Letters*. Volume 12. Page 478. [www.ncbi.nlm.nih.gov/pmc/articles/PMC5540742/pdf/11671\\_2017\\_Article\\_2242.pdf](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC5540742/pdf/11671_2017_Article_2242.pdf)
- ❖ Keller, A.A., Garner, K., Miller, R.J., and H.S. Lenihan. 2012. "Toxicity of Nano-Zero Valent Iron to Freshwater and Marine Organisms." *PLoS One*. Volume 7 (8).
- ❖ Kinsinger N., Honda, R., Keene, V., and S.L. Walker. 2015. "Titanium Dioxide Nanoparticle Removal in Primary Prefiltration Stages of Water Treatment: Role of Coating, Natural Organic Matter, Source Water, and Solution Chemistry." *Environmental Engineering Science*. Volume 32 (4). Pages 292 to 300.
- ❖ Klaine, S.J., Alvarez, P.J.J., Batley, G.E., Fernandes, T.E., Hand, R.D., Lyon, D.Y., Mahendra, S., McLaughlin, M.J., and J.R. Lead. 2008. "Nanoparticles in the Environment: Behavior, Fate, Bioavailability and Effects." *Environmental Toxicology and Chemistry*. Volume 27 (9). Pages 1825 to 1851.
- ❖ Laux, P., Riebeling, C., Booth, A.M., Brain, J.D., Brunner, J., Cerrilo, C., Creutzenberg, O., Estrela-Lopis, I., Gebel, T., Johanson, G., Jungnickel, H., Kock, H., Tentschert, J., Tlili, A., Schaffer, A., Sips, A., Yokel, R.A., and A. Luch. 2017. "Biokinetics of nanomaterials: The role of biopersistence." *NanoImpact*. Volume 6. Pages 69 to 80.
- ❖ Luoma, S.N. 2008. "Silver Nanotechnologies and the Environment: Old Problems or New Challenges?" Woodrow Wilson International Center for Scholars. [mail.nanotechproject.org/process/assets/files/7036/nano\\_pen\\_15\\_final.pdf](http://mail.nanotechproject.org/process/assets/files/7036/nano_pen_15_final.pdf)
- ❖ Manzo, S., Miglietter, M.L., Rametta, G., Buono, S., and G. Di Francia. 2013. "Toxic effects of ZnO nanoparticles towards marine algae *Dunaliella tertiolecta*." *Science of The Total Environment*. Volumes 445 to 446. Pages 371 to 376.
- ❖ Molnar, I.L., Willson, C.S., O'Carroll, D.M., Rivers, M.L., and J.I. Gerhard. 2014. "Method for Obtaining Silver Nanoparticle Concentrations within a Porous Medium via Synchrotron X-ray Computed Microtomography." *Environmental Science Technology*. Volume 48 (2). Pages 1114 to 1122.
- ❖ Mortensen, L.J., Oberdorster, G., Pentland, A.P., and L.A. Delouise. 2008. "In Vivo Skin Penetration of Quantum Dot Nanoparticles in the Murine Model: The Effect of UVR." *Nano Letters*. Volume 8 (9). Pages 2779 to 2787.
- ❖ Murray, L., Rennie, M.D., Enders, E.C., Pleskach, K., and J.D. Martin. 2017. "Effect of nanosilver on cortisol release and morphometrics in rainbow trout (*Oncorhynchus mykiss*)." *Environmental Toxicology and Chemistry*. Volume 36 (6). Pages 1606 to 1613.
- ❖ National Institute for Occupational Safety and Health (NIOSH). 2011. "Occupational Exposure to Titanium Dioxide." *Current Intelligence Bulletin* 63. [www.cdc.gov/niosh/docs/2011-160/pdfs/2011-160.pdf](http://www.cdc.gov/niosh/docs/2011-160/pdfs/2011-160.pdf)
- ❖ NIOSH. 2013. "Occupational Exposure to Carbon Nanotubes and Nanofibers." *Current Intelligence Bulletin* 65. [www.cdc.gov/niosh/docs/2013-145/pdfs/2013-145.pdf](http://www.cdc.gov/niosh/docs/2013-145/pdfs/2013-145.pdf)
- ❖ Nel, A., Xia, T., Madler, L., and N. Li. 2006. "Toxic Potential of Materials at the Nanolevel." *Science*. Volume 311. Pages 622 to 627.
- ❖ Parks, A. N., Chandler, G. T., Ho, K. T., Burgess, R. M., and P.L. Ferguson. 2015. Environmental biodegradability of [<sup>14</sup>C] single-walled carbon nanotubes by *Trametes versicolor* and natural microbial cultures found in New Bedford Harbor sediment and aerated wastewater treatment plant sludge. *Environmental Toxicology Chemistry*. Volume 34 (2). Pages 247 to 251.
- ❖ Popowich, A., Zhang, Q., and X.C. Le. 2015. "Removal of nanoparticles by coagulation." *Journal of Environmental Sciences*. Volume 38. Pages 168 to 171.
- ❖ Powell, M.C., and M.S. Kanarek. 2006. "Nanomaterial Health Effects – Part 2: Uncertainties and Recommendations for the Future." *Wisconsin Medical Journal*. Volume 105 (3). Pages 18 to 23. [www.temas.ch/IMPART/IMPARTProj.nsf/11.pdf](http://www.temas.ch/IMPART/IMPARTProj.nsf/11.pdf)

## Where can I find more information about nanomaterials? (continued)

- ❖ Saghafifar, H., Kürten, A., Curtius, J., von der Weiden, S., Hassanzadeh, S., and S. Borrmann. 2009. "Characterization of a Modified Expansion Condensation Particle Counter for Detection of Nanometer-sized Particles." *Aerosol Science and Technology*. [www.tandfonline.com/doi/full](http://www.tandfonline.com/doi/full)
- ❖ Sanchís, J., Farré, M., and D. Barceló. 2015. Analysis of Nanomaterials by Particle Size Distribution Methods. *Nanomaterials in the Environment*. Pages 129 to 157.
- ❖ Sarma, S., Das, R., Brar, S., Verma, M., Tyagi, R., Surampalli, R., and T. Zhang. 2015. Fundamental Characteristics and Their Influence on Fate and Behavior of Nanomaterials in Environments. *Nanomaterials in the Environment*. Pages 1 to 26.
- ❖ Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). 2006. "The Appropriateness of Existing Methodologies to Assess the Potential Risks Associated with Engineered and Adventitious Products of Nanotechnologies." European Commission: Directorate-General for Health and Consumers. [ec.europa.eu/health/ph\\_risk/documents/synth\\_report.pdf](http://ec.europa.eu/health/ph_risk/documents/synth_report.pdf)
- ❖ SCENIHR. 2009. "Risk Assessment of Products of Nanotechnologies." European Commission: Directorate-General for Health and Consumers. [ec.europa.eu/health/ph\\_risk/committees/04\\_scenihr/docs/scenihr\\_o\\_023.pdf](http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_023.pdf)
- ❖ Tsai, C.S., Echevarría-Vega, M.E., Sotiriou, G.A., Santeufemio, C., Schmidt, D., Demokritou, P., and M. Ellenbecker. 2012. "Evaluation of Environmental Filtration Control of Engineered Nanoparticles using the Harvard Versatile Engineered Nanomaterial Generation System (VENGES)." *Journal of Nanoparticle Research*. Volume 14 (5). Page 812. [www.ncbi.nlm.nih.gov/pmc/articles/PMC3569546/](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3569546/)
- ❖ U.S. Department of Health and Human Services (DHHS). Centers for Disease Control and Prevention. 2009. "Approaches to Safe Nanotechnology: Managing the Health and Safety Concerns Associated with Engineered Nanomaterials." [www.cdc.gov/niosh/docs/2009-125/pdfs/2009-125.pdf](http://www.cdc.gov/niosh/docs/2009-125/pdfs/2009-125.pdf)
- ❖ U.S. Environmental Protection Agency (EPA). 2007. "Nanotechnology White Paper." Senior Policy Council. EPA 100/B-07/001. [www.epa.gov/sites/production/files/2015-01/documents/nanotechnology\\_whitepaper.pdf](http://www.epa.gov/sites/production/files/2015-01/documents/nanotechnology_whitepaper.pdf)
- ❖ EPA. 2008a. "Nanotechnology for Site Remediation Fact Sheet." Office of Solid Waste and Emergency Response. EPA 542-F-08-009. [www.clu-in.org/download/remed/542-f-08-009.pdf](http://www.clu-in.org/download/remed/542-f-08-009.pdf)
- ❖ EPA. 2008b. "Toxic Substances Control Act Inventory Status of Carbon Nanotubes." Federal Register. Volume 73 (212). Pages 64946 to 64947. [www.gpo.gov/fdsys/pkg/FR-2008-10-31/pdf/E8-26026.pdf](http://www.gpo.gov/fdsys/pkg/FR-2008-10-31/pdf/E8-26026.pdf)
- ❖ EPA. 2009. "Final Nanomaterial Research Strategy (NRS)." Office of Research and Development. EPA 620/K-09/011. [nepis.epa.gov/Exe/ZyPDF.cgi/P10051V1.PDF?DocKey=P10051V1.PDF](http://nepis.epa.gov/Exe/ZyPDF.cgi/P10051V1.PDF?DocKey=P10051V1.PDF)
- ❖ EPA. 2010. "State of the Science Literature Review: Everything Nanosilver and More." Scientific, Technical, Research, Engineering and Modeling Support Final Report. EPA 600/R-10/084. [cfpub.epa.gov/si/si\\_public\\_record\\_report.cfm?dirEntryId=226785](http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=226785)
- ❖ EPA. 2016. "Control of Nanoscale Materials under the Toxic Substances Control Act." Office of Pollution Prevention and Toxics. [www.epa.gov/reviewing-new-chemicals-under-toxic-substances-control-act-tsca/control-nanoscale-materials-under](http://www.epa.gov/reviewing-new-chemicals-under-toxic-substances-control-act-tsca/control-nanoscale-materials-under)
- ❖ U.S. Food and Drug Administration (FDA). 2014a. "Guidance for Industry Considering Whether an FDA-Regulated Product Involves the Application of Nanotechnology." [www.fda.gov/downloads/RegulatoryInformation/20on/Guidances/UCM401695.pdf](http://www.fda.gov/downloads/RegulatoryInformation/20on/Guidances/UCM401695.pdf)
- ❖ FDA. 2014b. Guidance for Industry Safety of Nanomaterials in Cosmetic Products. [www.fda.gov/downloads/Cosmetics/GuidanceRegulation/GuidanceDocuments/UCM300932.pdf](http://www.fda.gov/downloads/Cosmetics/GuidanceRegulation/GuidanceDocuments/UCM300932.pdf)
- ❖ FDA. 2014c. Guidance for Industry Assessing the Effects of Significant Manufacturing Process Changes, Including Emerging Technologies, on the Safety and Regulatory Status of Food Ingredients and Food Contact Substances, Including Food Ingredients that are Color Additives. [www.fda.gov/downloads/Cosmetics/GuidanceRegulation/GuidanceDocuments/UCM300927.pdf](http://www.fda.gov/downloads/Cosmetics/GuidanceRegulation/GuidanceDocuments/UCM300927.pdf)
- ❖ FDA. 2015a. Guidance for Industry Use of Nanomaterials in Food for Animals. [www.fda.gov/downloads/AnimalVeterinary/GuidanceComplianceEnforcement/GuidanceforIndustry/UCM401508.pdf](http://www.fda.gov/downloads/AnimalVeterinary/GuidanceComplianceEnforcement/GuidanceforIndustry/UCM401508.pdf)



## Where can I find more information about nanomaterials? (continued)

---

- ❖ FDA. 2015b. Chemical Substances When Manufactured or Processed as Nanoscale Materials: TSCA Reporting and Recordkeeping Requirements. [www.regulations.gov/document?D=EPA-HQ-OPPT-2010-0572-0001](http://www.regulations.gov/document?D=EPA-HQ-OPPT-2010-0572-0001)
- ❖ Vance, M.E., Kuiken, T., Vejerano, E.P., McGinnis, S.P., Hochella, M.F., Rejeski, D., and M.S. Hull. 2015. "Nanotechnology in the real world: Redeveloping the nanomaterial consumer products inventory." *Nanotechnology*. Volume 6. Pages 1769 to 1780.
- ❖ Wallis, L.K., Diamond, S.A., Ma, H., Hoff, D.J, Al- Abed, S.R., and S. Li. 2014. "Chronic TiO<sub>2</sub> nanoparticle exposure to a benthic organism, *Hyalella azteca*: impact of solar UV radiation and material surface coatings on toxicity." *Science of Total Environment*. Volume 499. Pages 356 to 362.
- ❖ Watlington, K. 2005. "Emerging Nanotechnologies for Site Remediation and Wastewater Treatment." [www.clu-in.org/download/studentpapers/K\\_Watlington\\_Nanotech.pdf](http://www.clu-in.org/download/studentpapers/K_Watlington_Nanotech.pdf)
- ❖ Wiesner, M.R., Lowry, G.V., Alvarez, P., Dionysiou, D., and P. Biswas. 2006. "Assessing the Risks of Manufactured Nanoparticles." *Environmental Science & Technology*. Volume 40 (14). Pages 4336 to 4365. [pubs.acs.org/doi/pdf/10.1021/es062726m](http://pubs.acs.org/doi/pdf/10.1021/es062726m)

## Contact Information

---

If you have any questions or comments on this fact sheet, please contact: Mary Cooke, FFRRO, at [cooke.maryt@epa.gov](mailto:cooke.maryt@epa.gov).