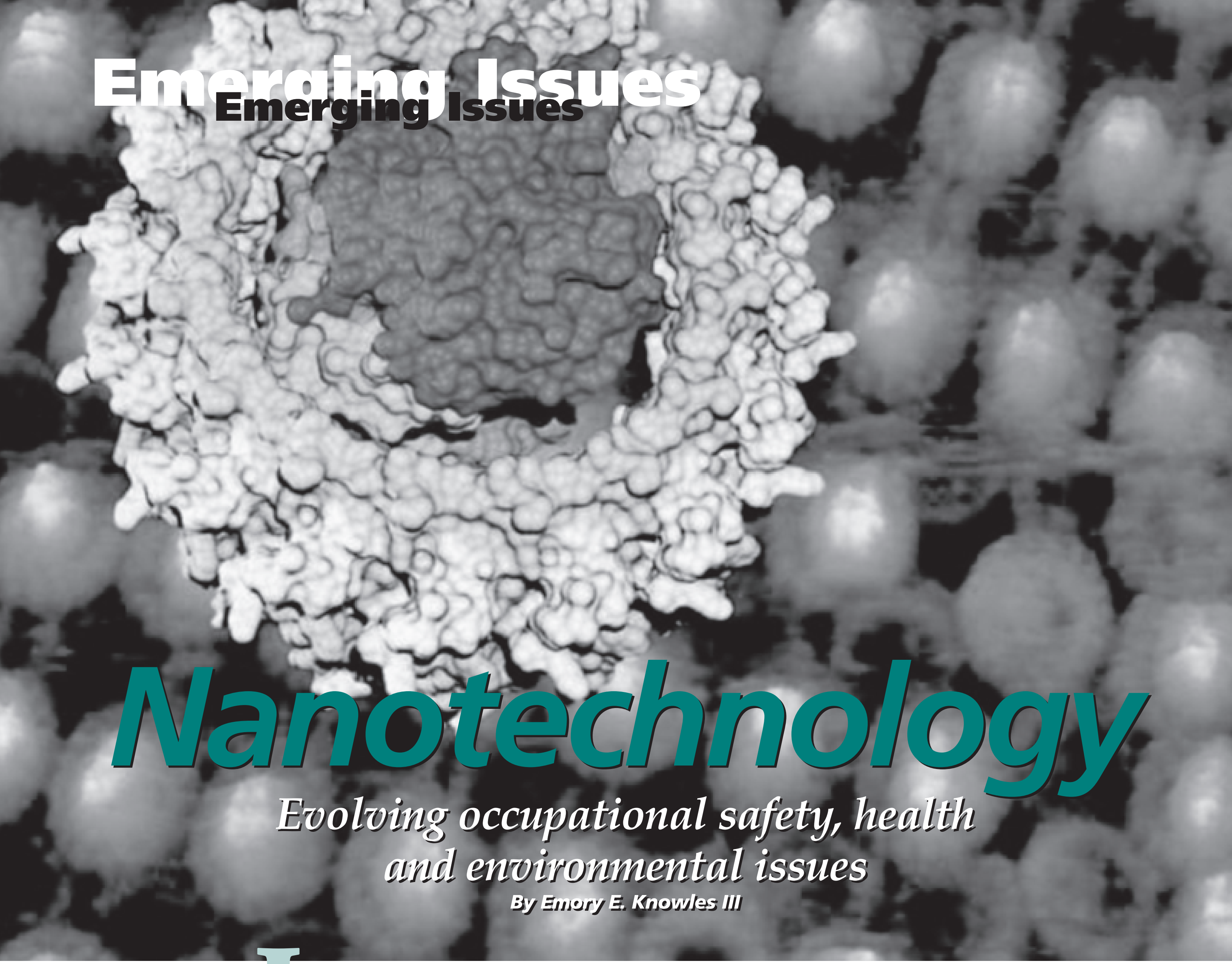
Emerging Issues



Nanotechnology

Evolving occupational safety, health and environmental issues

By Emory E. Knowles III

IMAGINE PRACTICALLY INVISIBLE nanomachines with the ability to digest organic and inorganic materials in order to create more nanomachines that do the same. Science or science fiction? The novel *Prey* introduced the world to nanobots—which consumed living creatures and used the breakdown products to create more nanobots (Crichton). But the concept of nanomachines is not purely science fiction. Some primitive nanomachines have been developed. Many types of nanoparticles and nanomaterials are being used in commercial products, and potential medical applications are being introduced at a rapid pace. If controlled, this technology has great promise. If not controlled, harm may be caused to human health and the environment.

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The Beginnings of Nano

What is the significance of the nanoscale? What do the terms nanometer, nanoscale, nanoscience and nanotechnology mean? The Royal Society and the Royal Academy of Engineering offer these definitions:

- **Nanometer (nm):** One thousand millionths of a meter. For example, a single human hair is about 80,000 nm wide; a red blood cell is 7,000 nm wide; and a water molecule is approximately 0.3 nm wide.
- **Nanoscale:** The size range from 100 nm down to 0.2 nm.
- **Nanoscience:** The study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties of materials can be quite different from those of larger scales.
- **Nanotechnology:** The design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanometer scale (The Royal Society and The Royal Academy).

Figure 1 illustrates the size of nanomaterials in comparison to some everyday objects.

During his 1959 presentation "There's Plenty of Room at the Bottom" before the American Physical Society, Feynman discussed "manipulating and controlling things on a small scale." He had identified the concept of nanotechnology. He speculated that people could manipulate "the very atoms, all the way down" (Feynman).

That vision has become reality and the possibility of developing nanomachines is very much alive— some primitive molecular nanomachines have been fabricated. Self-replicating machines have not been and are not likely to be created in the short term because of current technical and engineering limitations.

In the 1986 book *Engines of Creation: The Coming Era of Nanotechnology,* Drexler gave further life to the idea of being able to produce nanomachines for everything from machines that produce needed products to thinking machines and revolutionary medical applications. He also warned that replicating assemblers and thinking machines could pose great threats [Drexler(a)]. The possibilities have been further elaborated on in hundreds of articles—many widely available via the Internet (and not all peer-reviewed). Some of Drexler's general ideas have been further developed with a focus on business applications and opportunities presented by nanotechnology in *The Next Big Thing Is Really Small: How Nanotechnology Will Change the Future of Your Business* (Uldrich and Newberry).

Richard Smalley won the 1996 Nobel Prize in Chemistry for his discovery of fullerenes—spherical cages of 60 carbon atoms arranged as 20 hexagons and 12 pentagons like those seen on a soccer ball. Originally termed Buckminsterfullerene, they are now widely known as "buckyballs." Smalley's work is detailed in his Nobel speech published in *Reviews of Modern Physics* in 1997 (Smalley).

Thus began the major push by both businesses and scientists to explore and market the emerging field of nanotechnology. The field has now exploded, with expanding research activities, new businesses and new discoveries being publicized almost daily.

The advent of nanotechnology has brought with it concerns about its impact on safety, health and the environment. These concerns have been published in various articles and reports from organizations such as the ETC Group, the U.K. Group on Nanotechnology Applications (DTI), The Royal Society and The Royal Academy of Engineering, and NIOSH. On several occasions, NIOSH Administrator John Howard has discussed safety and health issues associated with nanotechnology and noted that issues such as engineering controls, PPE risk assessments, particle behavior, evaluation, measurement and toxicity need much more research (NIOSH).

Uses of Nanomaterials

Nanoparticles/nanomaterials are currently used in consumer products such as coatings for bowling balls and stain-resistant clothing (Hood). In addition, nanotechnology has been used to create clear sunscreens, integrated circuits, composites, fibers/textiles, sensors, and microdevices such as particle and gas detection systems. Having the capacity to enter a cell's nucleus, nanomaterials are being investigated for gene therapy and as drug delivery vehicles in medical applications.

Many articles tout both the beneficial and detrimental application of this technology. A quick Internet search returns myriad enticing headlines:

- "Nanosphere Product to Test for Heart Disease, Cancer, Alzheimer's."
- "Florida Professor Leads Drive for Nano-Enhanced Armor."
- "Electrical Detection of Single Viruses."
- "Carbon Nanotubes: Application of Buckytubes in Batteries, Capacitors and Fuel Cells."
- "Carbon Nanotubes (Buckytubes): Applications in Conductive Plastics, Adhesives and Connectors."
- "Nanoparticles Enable Speedy E.coli Detection."
- "Nanocomposites for Bone Replacement."
- "Tiny Antennas to Keep Tabs on U.S. Drugs."
- "Responsible Nanotechnology: Looking Beyond the Good News."
- "No Small Matter! Nanotech Particles Penetrate Living Cells and Accumulate in Animal Organs."

Implications of Use

The overarching concern is that nanoparticles/nanomaterials are being used in products or are being considered for other uses without a clear perspective on the SH&E impact of such uses. In the Swiss Reinsurance Co. report, "Nanotechnology: Small Matter, Many Unknowns," Hett discusses the quantum physics properties of matter at the nanometer scale. At the nanometer level, the laws of physics, biology and chemistry merge, and the behavior of these small particles changes—including their mobility in the environment, reactivity, toxicity and ability to enter the human body. The dramatic increase in surface area of such small particles is responsible for many of the changed properties and concerns with use of these materials (Hett).

Types of Nanomaterials

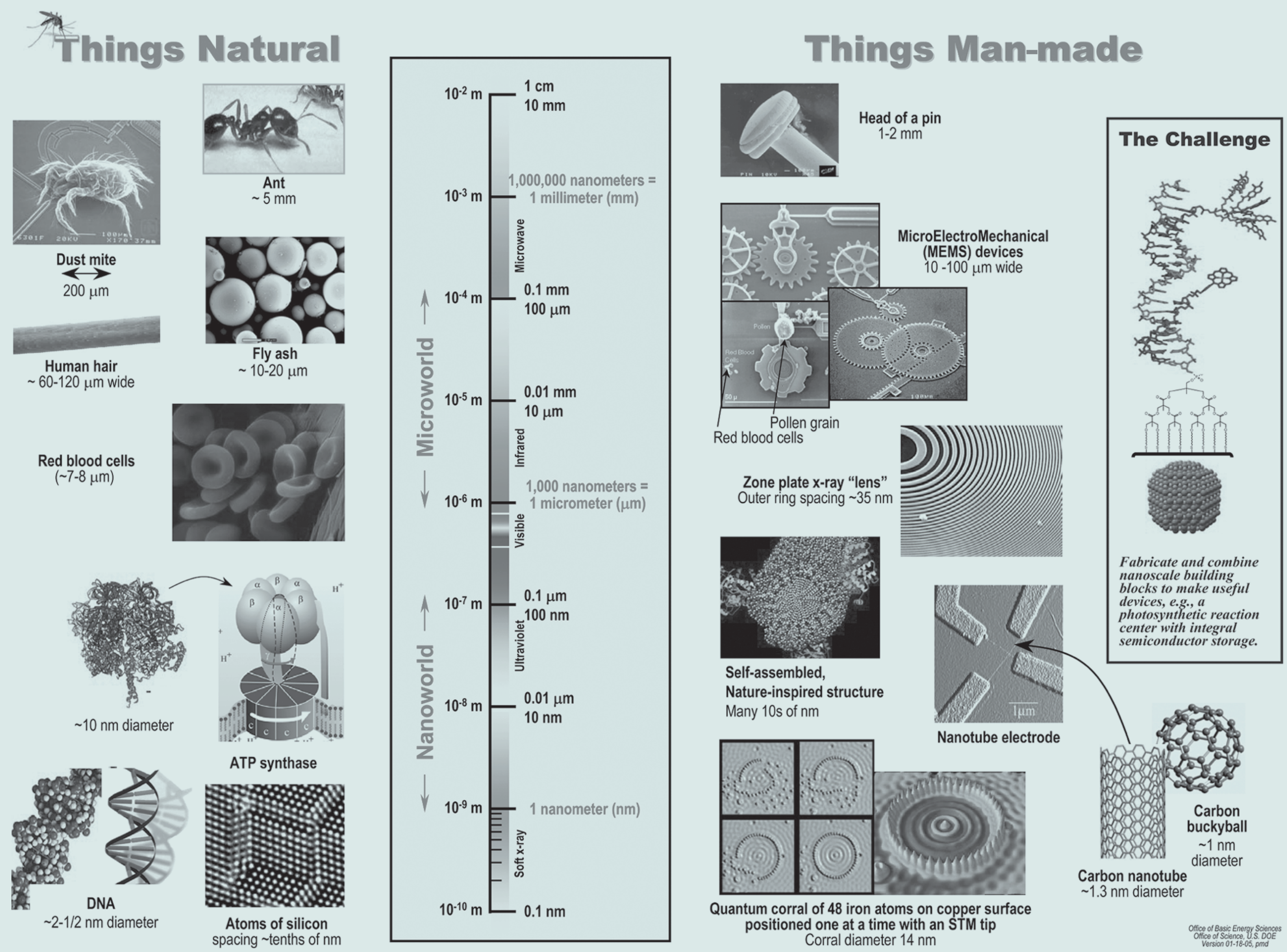
The Royal Society and The Royal Academy of Engineering offer these examples of the most common nanomaterials:

- Biopolymers. Complex molecules typically found in living cells, such as DNA; may be linked with inorganic compounds; possible uses include biocompatible sensors and simple motors.
- Buckyballs. Spherical arrangement of 20 hexagons and 12 pentagons of carbon; uses include miniature ball bearings, for drug delivery and in electronic circuits.
- Carbon nanotubes. Extended tubes of graphene sheets, either single-wall or multiwall; typically a few nanometers in diameter and several micrometers (10^{-6} m) to centimeters long; mechanically strong and flexible, these can conduct electricity; uses include reinforced composites, sensors, nanoelectronics and display devices.
- Dendrimers. Spherical polymeric molecules, the smallest of which is several nanometers in size; used in coatings and inks and may act as carrier molecules for applications in drug delivery systems; can trap metal ions and may have environmental applications.
- Inorganic nanotubes. Inorganic nanotubes and fullerene-like layered compounds; used for lubricating properties, resistance to shockwave impact, catalytic reactivity, and high capacity for lithium and hydrogen storage.

Abstract: *Many types of nanoparticles and nanomaterials are being used in commercial products, and potential medical applications are being introduced at a rapid pace. If controlled, this technology has great promise. If not controlled, harm may be caused to human health and the environment. This article discusses types and uses of nanomaterials, and explores potential safety, health and environmental issues, as well as societal implications of these materials.*

Figure 1

The Scale of Things: Nanometers & More



Source: Dept. of Energy's Office of Basic Energy Science.

•Nanoparticles. Particles of less than 100 nm in diameter, found widely in the natural world as products of photochemical and volcanic activity, created in plants and algae, and from products of combustion, food cooking and diesel exhaust; also manufactured particles such as metal oxides (titanium dioxide, zinc oxide); used in cosmetics, textiles, paints, targeted drug delivery systems and sunscreens.

•Nanowires. Ultrafine wires or linear arrays of dots, formed by self-assembly; typically made of silicon, gallium nitride, indium phosphide; uses for semiconductor applications and high-density data storage.

•Quantum dots. Extremely small (as small as 2 nm in diameter) nanoparticles of semiconductors whose small size imparts quantum effects that imparts optical properties which can be finely tuned; used in composites, solar cells and fluorescent biological labels.

•Thin films, layers and surfaces. Typically one-dimensional nanomaterials such as thin films; used in the integrated circuit industry.

Those interested in technical aspects of molecular manufacturing, scaling of systems, quantum theory and mechanics, positional uncertainty, synthesis, structures and components, and molecular assembly and engineering should see *Nanosystems: Molecular Machinery, Manufacturing and Computation* [Drexler(b)].

Potential Health Issues

Swiss Reinsurance reported that several spray products may contain nanoparticles, including disinfectant or air freshener sprays, dyes, paints, and sprays for impregnating clothing and other porous materials (Hett). Because of the large surface area and small size of nanoparticles, nanotubes, buckyballs and quantum dots, it would be expected that inhalation could be a primary exposure route.

According to Donaldson, et al, as particles become smaller, their likelihood of causing harm to the lung increases. Tests on animals have found that these particles can overload macrophages and lead to tissue inflammation or more potentially serious consequences such as granulomas. This may be due to the fact that deep in the lung they may bind to proteins causing unexpected consequences. These nanoparticle-protein complexes may be more mobile and may gain access to sites in the body that larger particles cannot reach, or the nanoparticles could cause functional changes in the proteins due to the particles' large surface area (Donaldson, et al).

Inhaled particulates may be captured in the mucociliary escalator of the lungs or penetrate to the bronchioles and alveoli. The respiratory system is lined with epithelial cells that have hairlike structures termed cilia. Cilia move mucus up from the depths of the lungs, which is termed the mucociliary escalator. It is in the deeper region of the lungs that particles may also be phagocytized by alveolar macrophages. Phagocytosis is a process whereby a cell envelops and normally digests foreign particles. Particles in the alveoli (the air sacs deep within the lung) may enter the bloodstream. In the Swiss Reinsurance report, it is speculated that if equal quantities of nanoparticles—or larger particles of the same substance—are inhaled, the smaller particles may cause a reaction in the lung tissue that is many times stronger (Hett).

Furthermore, the macrophages may become overloaded with nanoparticles, which may cause inflammation of the surrounding tissue. Free radicals may also be formed due to the large surface area of the nanoparticles, depending on their reactivity, and these free radicals could impact the immediate area or be transported to other areas of the body. The Swiss Reinsurance report provides more detail on these mechanisms of harm (Hett). It is known that titanium dioxide and zinc oxide nanoparticles used in sunscreens can cause free radicals in skin cells and possibly damage DNA (Dunford, et al).

The report "Nanoparticles: An Occupational Hygiene Review" suggests that nanoparticles which have been phagocytized by macrophages may be introduced via the mucociliary escalator into the digestive tract where the potential for transfer to other body organs exists. It is known that nanoparticles can penetrate epithelial cells. The report also states that little is known about health effects of nanoparticles in the liver and kidneys or transfer across the placenta (Aitken, et al).

Since carbon is the backbone of most nanoparticles, the effects of carbon on living tissue are relevant. Driscoll, et al note that chronic inhalation of carbon black can produce carcinomas in rat lungs. These researchers observed genotoxic effects (mutations) on alveolar epithelial cells and observed significant inflammation and epithelial hyperplasia, which they hypothesized was due to cell-derived oxidants and increased cell proliferation (Driscoll, et al).

Lam, et al and Warheit, et al employed a comparative toxicological approach and intratracheal instillation route of exposure to determine the effects of single-wall carbon nanotubes (SWCNT) in mice and rats. Lam, et al demonstrated that three different types of SWCNTs in mice induced dose-dependent lung lesions. These were characterized by granulomas. Carbon black-laden macrophages were observed in alveolar spaces. Macrophages filled with SCWNT were observed in centrilobular locations. In these areas, epithelioid granulomas were observed. The conclusion was that under their test conditions and on an equal weight basis, SWCNTs could be more toxic than quartz (Lam, et al). Dreher postulated that the Lam, et al data suggested that extrapolation of the OSHA permissible exposure limit for graphite may not be protective for exposure to SWCNTs due to their unique physicochemical properties and pulmonary toxicity (Dreher).

Warheit, et al examined the ability of particles to induce pulmonary inflammation and alter lung cell proliferation in rats. They noted that pulmonary granulomatous lesions appear to occur as a result of the lung's immune response to removal of foreign substances that are not easily degraded (Warheit, et al).

Oberdorster, et al noted that ultrafine carbon-13 particles were deposited in the olfactory bulb of rats throughout a seven-day post-exposure period following a six-hour inhalation exposure to ultrafine carbon-13 particles. The brain cerebrum and cerebellum also showed significant increase of particle deposition on two post-exposure days. They postulated that translocation of the inhaled ultrafine particles could occur via two mechanisms: 1) across the blood/brain barrier after translocation into the blood circulation from deposits anywhere in the respiratory tract and 2) specific for the olfactory bulb, via the olfactory nerve from deposits on the nasal olfactory mucosa. Significant amounts of ultrafines also accumulated in the liver (Oberdorster, et al).

In another study, E. Oberdorster exposed juvenile largemouth bass to a form of uncoated water-soluble buckyballs and demonstrated significant evidence of oxidative stress in the brains and gills of the fish exposed for 48 hours in aquarium tanks. She postulated a selective transport mechanism from the olfactory nerve into the olfactory bulb for redox-active, lipophilic fullerenes, which in turn caused the oxidative damage in the brains of the fish [E. Orberdorster(a)]. This research also demonstrated that buckyballs at a concentration of 800 parts per billion would kill 50 percent of a test population of daphnia (water fleas) over a 48-hour period [E. Oberdorster(b)].

Reports indicate that direct penetration of the skin has been observed for particles with a diameter of 1,000 nm, which is much larger than nanoparticles (Aitken, et al). Thus, one may postulate that it may be easier for nanoparticles to penetrate the skin. Exposure via the digestive route is possible but has not been demonstrated.

Some have speculated that carbon nanotubes, similar in size to asbestos fibers, may have health effects similar to asbestos. Huczko, et al demonstrated in guinea pigs that carbon nanotubes did not induce any abnormalities of pulmonary function or measurable inflammation (Huczko, et al). Oberdorster noted that chronic inhalation of fibrous and nonfibrous particles by rats at high concentrations results in lung tumor formation if the particles are poorly soluble in the lung. Even rather benign nonfibrous particles such as titanium dioxide produce this result (G. Oberdorster).

Bottini, et al indicated that although preliminary studies suggest nanotubes and fullerenes are not associated with any asbestos-like health risks, they note that many researchers highlight the need to assess possible risks of such structures before they become ubiquitous in every aspect of life (Bottini, et al).

Because these initial studies illustrated biological effects in various animals, it is possible that similar effects could occur in humans and this will become clearer as researchers begin to study workers who have been exposed to nanomaterials. At this time, air-sampling methodologies have not been fully validated, and the appropriate engineering and administrative controls have not been fully investigated.

Therefore, the conservative SH&E professional is strongly encouraged to perform detailed risk assessments and use a hierarchy of engineering controls and PPE to minimize risk to workers. At the time of this publication, cartridge-type respirators and N-95/N-100 dust masks have not been validated as protective PPE. In the absence of such validation, the only acceptable respiratory protective equipment would be a full-facepiece positive-pressure, pressure-demand self-contained breathing apparatus (SCBA) or positive-pressure, pressure-demand full-facepiece airline respirator with a backup air supply.

SCBAs and airline respirators are cumbersome to use, and their use requires compliance with rigorous OSHA standards that address medical examinations, training, cleaning and sanitation, and maintenance. Therefore, to minimize worker exposure, use of adequate local exhaust ventilation with a dust collector is recommended.

In addition, MSDS from some manufacturers provide excellent guidance; however, some manufacturers use the same MSDS as the parent compound, despite the fact that nanoparticles exhibit quantum effects that are distinct from the parent material (e.g., graphite). Therefore, one should consult with CIHs, CSPs, P.E.s and medical authorities who have experience with particulates. The bottom line is that the exposure potential needs to be assessed as do key factors such as the amount of material involved, its form, the degree of containment and the duration of use.

Potential Safety Issues

Manufacture of nanoparticles requires that risk analyses be performed to assess the hazards of processing equipment, gases, solvents, cooling systems, electrical shock hazards, electrical arc hazards, intense light hazards, including UV hazards in some instances, vacuum hazards, etc. At this point, information is limited regarding how particles/fiberlike nanomaterials behave in air, water or soil, or their ability to accumulate in food chains (Ahwahnee Technology). Manufacturers should be contacted to obtain all relevant information regarding the safe installation and use of processing equipment and chemical suppliers should be contacted relative to MSDS information.

Because of the quantum properties of nanoparticles and especially the large surface area effect, it is suspected that nanomaterials could be potential catalysts for reactions which would otherwise proceed slowly (HSE). National Institute of Environmental Health Sciences has also stated that generally the smaller the particles, the more reactive and toxic are their effects (NIEHS).

Under certain conditions, nanoparticles may pose a fire or explosion hazard. An increasing range of materials (e.g., carbon black, metals, carbon, borides, carbides, sulfides) may be able to produce explosive dust clouds. Explosive issues related to nanoparticles/nanomaterials have not been addressed adequately despite the large body of knowledge on the explosion characteristics of micron-scale particles. Use of wet slurries or encapsulation of particulates may decrease hazards (Pritchard).

Ajayan, et al described an interesting photoeffect in which single-wall nanotubes can be ignited by a camera flash at several centimeters from a sample. Ignition did not occur for multiwall carbon nanotubes, graphite powder, fluffy carbon soot or C_{60} (Ajayan, et al). The most recent edition of the *National Fire Protection Assn. (NFPA) Handbook* and other NFPA references should be consulted before beginning any work with nanoparticles/nanomaterials.

Potential Environmental Issues

Based on the information presented, it is clear that nanoparticles may impact living organisms in their natural environment. It is also possible that microorganisms in soil or water could bioaccumulate nanoparticles within their cells. Potential impacts could be persistence, bioaccumulation and toxicity. Currently, the exact fate of nanoparticles in the environment is unknown. Until such effects are clearly understood, some are recommending that the use of free (i.e., not fixed in a matrix) manufactured nanoparticles in environmental applications such as remediation be prohibited until appropriate research has been performed and it can be demonstrated that the potential benefits outweigh the potential risks (The Royal Society and The Royal Academy of Engineering).

In addition, regulation of nanoparticles has not been resolved. Colvin reported that consumer exposure to nanoparticles in products such as sunscreens and cosmetics presents another potential exposure route. She also commented that it is impossible to assess the quantities and types of nanoparticles in such products since this information is often protected from public disclosure by trade secret regulations. Furthermore, the U.S. Food and Drug Administration (FDA) ruled in 1999 that the micronized Titania in sunscreens was not a new ingredient, thus providing little incentive for studies on particle additives (Colvin).

It is possible that the Toxic Substance Control Act (TSCA) could be applied to regulate nanoparticles/nanomaterials. Wardak's paper on this subject states that at the very least one must consider further research to determine health and environmental effects of nanoparticles/nanomaterials. He noted that EPA's Office of Research and Development has requested studies on the environmental effects of nanotechnology (Wardak). EPA has since issued a draft white paper on the topic of nanotechnology; it can be found at www.epa.gov/osa/nanotech.htm. NIOSH has also initiated a series of studies to support the National Nanotechnology Initiative (NIOSH).

Societal Implications

The potential societal implications of nanotechnology are enormous, promising exponential advances in manufacturing, technology, communication, medicine and military applications. However, most people have not heard of nanotechnology. The results of an opinion poll published by The Royal Society on March 15, 2004, reported that only 29 percent of the public claim to have heard of nanotechnology, while only 19 percent were able to give some definition of nanotechnology (The Royal Society).

Research has provided an awareness that some nanoparticles enter cells and may damage tissue and that nanoparticles may pose both safety and environmental hazards. As a result, several key questions must to be addressed: What will be the long-term health impact? What safety and industrial hygiene measures are needed to ensure safe processes and equipment and proper control of potential exposures? These questions become significant when one considers that there are currently more than 2 million workers exposed to nanometer-diameter particles in the U.S. (Parsons).

Roco provides a broader view of the impact of investments in nanotechnology. He reports that the U.S. National Nanotechnology Initiative annual investment in research with educational and societal implications would be about $30 million [with $23 million earmarked for National Science Foundation (NSF) awards] and environmental nanoscale research will be about $50 million (with $30 million to NSF and $6 million to EPA). According to Roco, 35 countries have initiated nanotechnology initiatives, and worldwide investments have increased more than sixfold—from $430 million to $3 billion—between 1997 and 2003. He further states that the annual global impact of products where nanotechnology will play a key role will exceed $1 trillion by 2015 (Roco).

National and international scientific groups and other organizations recognize the dramatic benefits that nanotechnology applications offer, yet most of these organizations recommend caution or a moratorium on use of nanomaterials in products. The summary report of the 3rd EC/NSF Workshop on Nanotechnology discusses the impact of nanotechnology on better lighting, catalyst applications, biotechnology and biomedical engineering, while also discussing "the revenge of unintended consequences" such as harmful effects on organisms, potential misuse to invade privacy, and autonomous operation and self-replication. The report concludes, "Nanotechnology is a new frontier with few sheriffs"(EC/NSF).

ETC Group, an environmental activist organization, has called for a global moratorium until more is known about the health and environmental hazards of the nanoparticles and nanomaterials. According to this organization, "Researchers should come together immediately to propose the 'best practices' possible for laboratory workers within the internationally recognized concept of the precautionary principle" [ETC Group(b)].

The precautionary principle simply states that if there is the potential for harm to human health or the environment, precautionary measures should be implemented. The annex to the ETC report contains a discussion of the toxicity of nanoparticles. It states that there is enough evidence that nanoparticles can pose a health hazard and that "human exposure in general, and particularly in the workplace, should be minimized on a precautionary basis" [ETC Group(a)]. ETC further observes, "Full hazard assessments should be performed to establish the safety of species of particle before manufacturing is licensed. We are dealing with a potentially hazardous process."

Given the potential applications of nanotechnology and the current uncertainties relative to safety, health and the environment, employers will consider SH&E professionals to be the subject-matter experts when it comes to defining the engineering and administrative controls needed to protect workers and businesses.

In considering the societal and even the ethical impact of nanotechnology, scientists, governments and industry need to prepare to address concerns that may become significant issues to the public. Mnyusiwalla, et al call for the issues of equity (as it relates to developing countries), privacy, security, environment and metaphysical questions concerning human/machine interactions to be addressed (Mnyusiwalla, et al). Add to that worker safety and health, and the equation becomes quite complex.

Looking to the Future

The future for nanotechnology appears to be bright. In *Future Technologies, Today's Choices: Nanotechnology, Artificial Intelligence and Robotics,* Arnall discusses nanotechnology as an enabling technology that will likely have broad and unanticipated impacts on society. Potentially wondrous materials and applications—from self-assembling monolayer materials to nanotube-based materials 50 to 100 times stronger than steel—are envisioned. Arnall also posits that as the range of tool and fabrication techniques begins to mature, the field is set to become commonplace in the coming decades (Arnall).

Currently, the U.S. has no specific law or regulations on nanotechnology. However, many existing

Test Your Nano IQ

1) The prefix "nano" comes from a Greek word meaning _______.

a) billion b) dwarf
c) invisible d) infinite

Answer: b). *From the Greek word nanos or the Latin word nanus. A nanometer is one billionth of a meter.*

2) If a nanometer were as big as the width of a pinhead, about how long would a meter be?

a) as long as the pin shaft
b) as long as a ladder
c) as long as a blue whale
d) as long as a trip between Washington, DC, and Atlanta

Answer: d). *A pinhead is about a millimeter wide. If a nanometer were as wide as a pinhead, then a meter would have to be a billion times bigger or a billion millimeters. One billion millimeters is equal to about 1,000 kilometers (or about 620 miles). The distance (traveling by road) between Washington, DC, and Atlanta is 632 miles.*

3) How many hydrogen atoms lined up "shoulder to shoulder" would fit in a one nanometer space?

a) less than one b) 10
c) 1,000 d) 1 billion

Answer: b). *A hydrogen atom is about one-tenth of a nanometer wide.*

4) Which of the following products contain nanoscale manufactured parts or materials?

a) sunscreen
b) khaki pants
c) tennis balls
d) devices that read computer hard drives
e) all of the above

Answer: e). *Nanoscale particles are used in some sunscreens to block ultraviolet light. Certain brands of khaki pants are made with a nanowhiskers surface that resists stains. Premium tennis balls can be sealed with nanoparticles designed to double the balls' lifetime. Some computer hard drives have read heads (the stylus that reads magnetic bits) made with thin films only 1.5 nanometers thick.*

5) What is a nanonewton?

a) a new kind of cookie
b) a miniature pop singer
c) the approximate amount of force required to break a single chemical bond between two atoms
d) a tiny lizard

Answer: c). *The newton (named after physics great Isaac Newton) is the internationally accepted unit for measuring force. One newton is about equal to the force needed to hold a dollar's worth of nickels or (fittingly) the force required to hold a good-sized apple against the force of Earth's gravity. A nanonewton is a billionth of a newton.*

6) What is a qubit?

a) unit of measure used in ancient Egypt
b) a cover for the tip of the stick used in billiards
c) a unit of information that takes advantage of the laws of quantum mechanics
d) a pair of atoms used to store digital information

Answer: c). *In the everyday macroscopic world, objects obey classical physics laws—e.g., objects can be only in one place at a time. In the nanoscale world of atoms, objects follow a different set of laws, the laws of quantum mechanics. In the world of quantum mechanics, one atom* ***can*** *be in two places at once and two atoms can be "entangled" even though they are apart.*

7) What is a flying qubit?

a) a prehistoric bird
b) a muon
c) a photon used to transport quantum information
d) a gluon

Answer: c). *A photon is a unit of electromagnetic radiation such as light or X-rays. Photons are quantum units of energy that fly through air. When used in quantum information processing, photons are "flying qubits." Photons can carry quantum information because they can be oriented with one of two different spins, up or down, or a blend of these two states.*

8) What is a "self-assembled monolayer"?

a) atoms or molecules that spontaneously form uniform single layers
b) a type of clothing that gets thicker in response to colder temperatures
c) optical device that puts itself together
d) a fuzzy logic circuit

Answer: a). *Self-assembled monolayers are made of atoms or molecules that attach to specific surfaces in very predictable, uniform ways. For example, alkyl thiol molecules self-assemble on gold surfaces into a single molecular layer. Alkyl thiol molecules act like a ball and chain. One end of the molecule (the ball) attaches firmly to gold surfaces while the hydrocarbon "chain" floats above it. At the end of the chain, a variety of different chemical groups or "locks" can be attached. As a result, these surfaces may make good surfaces for chemical or biological sensors.*

9) What is spintronics?

a) using the spins of electrons to carry information
b) electronics made of textiles
c) a rock group
d) a type of dance music

Answer: a). *Electrons, like photons, have one of two different spins, up or down. When a device uses the flow of electrons to operate, we call it an electronic device. When a device uses the pattern of electron spins to operate, it is a "spintronic" device.*

Source: National Science and Technology Council. Nanotechnology: Shaping the World, Atom by Atom. *December 1999.*

standards could apply, such as those addressing hazard communication and TSCA. Of course, when one examines processes and manufacturing, many other standards may apply as well.

Scientists, manufacturers and the government recognize that controls need to be defined for nanotechnology. In 2004, ANSI formed the Nanotechnology Standards Panel, which will be the coordinating body for the development of standards in the area of nanotechnology (ANSI). Also in 2004, American Society for Testing and Materials (ASTM International) held an organizational meeting for an international ASTM activity on nanotechnology. ASTM established six standards development subcommittees to address terminology and nomenclature, characterization, environmental, occupational health and safety, international law and intellectual property, liaison and international characterization, standards of care and product stewardship (ASTM).

Conclusion

The future is now. SH&E professionals must be on the front lines to ensure that workers and employers have a safe, healthy and environmentally friendly workplace. Given the many potential applications of nanotechnology and the current uncertainties relative to safety, health and the environment, the one certainty is that employers will consider these occupational professionals to be the subject-matter experts when it comes to defining the engineering and administrative controls needed to protect workers and businesses. Therefore, SH&E professionals must begin to research the available literature, attend related conferences, and continue to apply the fundamental principles of risk assessment, hazard control, safety engineering, industrial hygiene, and environmental protection and engineering in a manner that is both ethical and consistent with the practice of their professions. ■

ASSE Resources on Nanotechnology

Nanotechnology: Environmental Implications & Solutions
By Louis Theodore, Ph.D., and Robert G. Kunz, Ph.D.

Nanoparticles have had a major impact in many industries including semiconductors, chemical engineering, ceramics, coatings, polymers, and purification of pharmaceuticals and enzymes. This book reviews both future and soon-to-be realized applications and examines both legal and technical aspects of environmental controls. Current pollution control technologies designed to meet EPA regulations for air, water and soil deposition are assessed in terms of their ability to control the release of nanoparticles. Principles of both health risk assessment and hazard risk assessment, including emergency planning are also discussed. To learn more about this resource, visit www.asse.org. Additional links and related information can be found at www.asse.org/nanocallsupport.

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