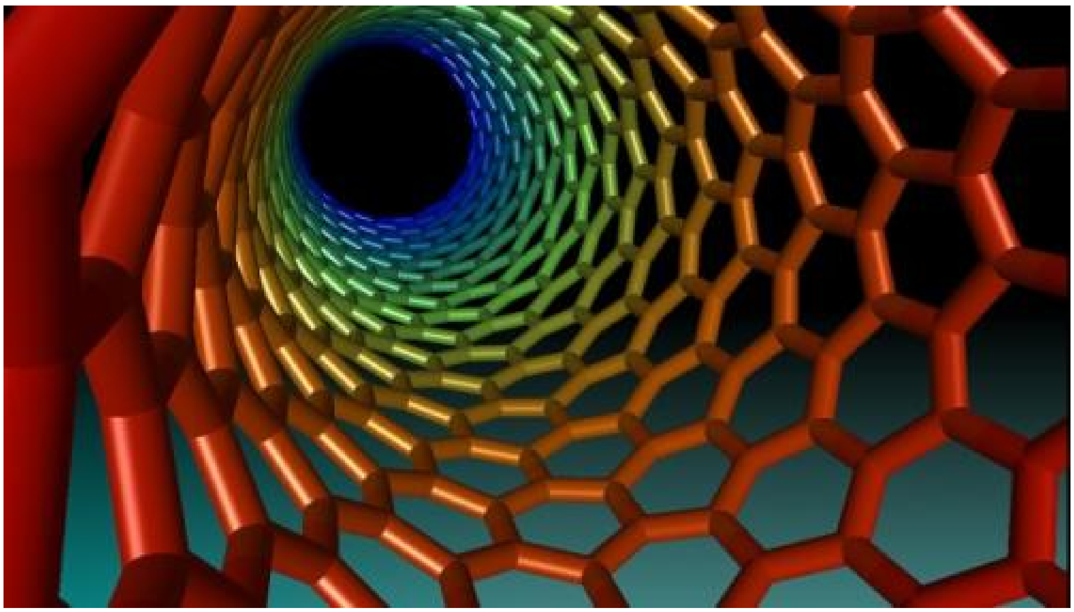
The promise and peril of nanotechnology

March 26 2014, by Renee Cho, Earth Institute, Columbia University



Computer-rendered view inside a carbon nanotube. Credit: Geoff Hutchison

Scientists at Northwestern University have found a way to detect metastatic breast cancer by arranging strands of DNA into spherical shapes and using them to cover a tiny particle of gold, creating a "nano-flare" that lights up only when it finds breast cancer cells. At MIT, researchers are trying to boost the photosynthetic capacity of plants by embedding tiny tubes of carbon called nanotubes into chloroplasts. They hope to eventually develop plants with the ability to monitor environmental pollution, pesticides, fungal infections, or exposure to bacterial toxins. These are just two instances of ongoing research in nanotechnology, one of the fastest growing areas of science, engineering and industry that is used in more and more consumer products each day.

Nanotechnology encompasses the production and manipulation of materials on a tiny scale – measured in billionths of a meter, or nanometers. It sometimes involves layers of material just a single atom thick – about 0.2 nanometers. By comparison, a human hair is 80,000 nanometers; a DNA molecule is 2–2.5 nm.

Nanoparticles do exist in nature—in dust, forest fires, volcanoes, metals, etc. But nanotechnology generally involves engineered materials (which can include natural nanoparticles) with at least one dimension measuring 100 nm or less. At the nanoscale, the classic laws of physics no longer apply, resulting in material taking on different optical, electrical or magnetic properties than it would have in a bulkier form. This is partly because material at the nanoscale has a relatively larger surface area vis à vis its volume than the same material in bulk form.

It is because nanomaterials have these altered properties that they are so useful. They can have increased capacity to conduct or resist electricity, excellent color purity, enhanced heat storage or transference ability, extra absorbability, or antibiotic properties. At the nanoscale, copper, normally opaque, becomes transparent; stable aluminum turns combustible; and gold, usually solid, becomes a liquid. Nano silver, an antibacterial, is used in bandages, socks and food packaging. Zinc oxide nanoparticles are found in sunscreen and cosmetics. Nano titanium dioxide is used in medicine capsules, nutritional supplements, food additives, skin creams, and toothpaste; and in foods like coconut and yogurt as a whitener.

Nanotechnology involves the creation of nanostructures like carbon-based graphene (a sheet of carbon atoms 1 atom thick) or carbon nanotubes (a tube of carbon atoms), which are excellent conductors of electricity; as well as the use of nanoparticles that are combined with other materials to optimize certain characteristics.

Scientists working in nanotechnology usually use molecules as building blocks. As an example, they may make something partly out of silicon, combined with an organic molecule and some nano widgets to produce a multifaceted nanostructure unlike anything found in nature, explained James Yardley, managing director of Columbia University's Nanoscale Science and Engineering Center. The choice of materials often depends on the area of research. Electronics researchers, for instance, often work with silicon or carbon; biotechnology researchers work with larger organic molecules; and materials researchers might utilize iron, steel or chromium.

Columbia's Nanoscale Science and Engineering Center, one of the first nanoscale science and engineering centers established by the National Nanotechnology Initiative, focuses its research on electronics. Scientists here, pioneers in research on graphene (the strongest material known to man per unit weight), are figuring out how to use it to replace silicon, essential in semiconductors and many electronic products. They are using it to develop applications for solar cells, touchscreens and sensors. The center is also working with carbon nanotubes, which are enabling the development of new electronic devices; and building photovoltaic devices on the nanoscale to make them much more efficient.

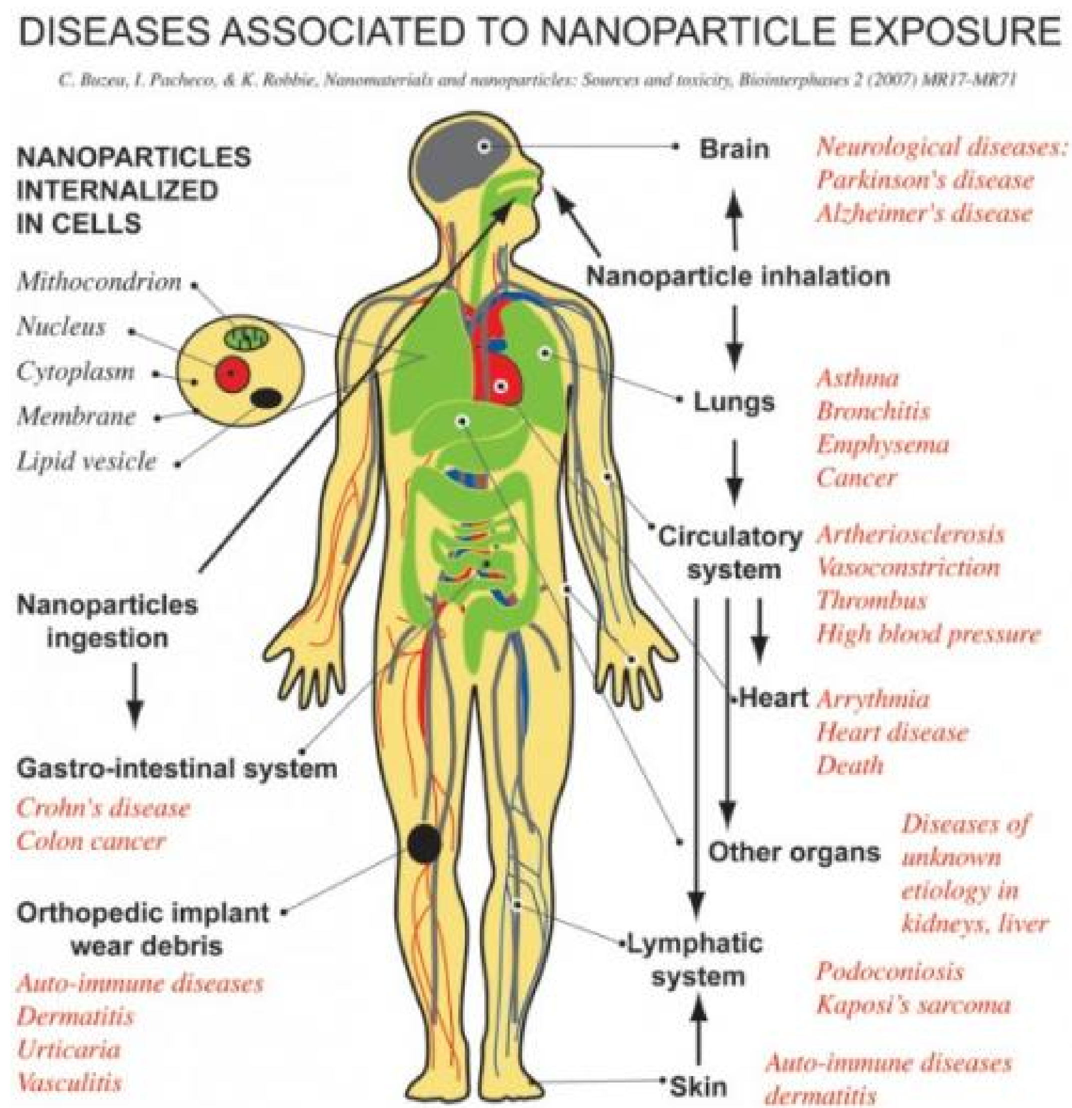
Every day, scientists are coming up with new applications for nanotechnology. An international nano research center has created a nanofiber mesh that can remove toxins from the blood, which could eliminate the need for dialysis for kidney failure patients. Swiss researchers recently succeeded in producing uniform antimony nanocrystals, which can store a large number of lithium and sodium ions, and could one day be used to produce high-energy-density batteries.

In the future, nanotechnology is expected to make communication and information technologies faster and cheaper, and create super-hard materials. In medicine, nanomaterials will be used as tiny sensors to detect disease or as chips to monitor bodily processes, for implants, and as drug delivery systems that can target specific cells. Nanomaterials will be able to filter pollutants from the environment or remove them from waste effluents. Nanotechnology will benefit space exploration by making lighter-weight vehicles and smaller robotic systems possible. Nano detectors of chemical and biological agents will improve national security. Some scientists predict that one day, they will be able to create programmable nanomatter whose properties can be controlled or altered.

"Nanoscience is one example of a real frontier in basic science that really has the potential to revolutionize so many aspects of every day existence," said Michael Purdy, executive vice president for research at Columbia University. "In a few decades, we will see some major revolutions, and it's really physics that have provided these new breakthroughs." He is particularly excited about the new materials research, which offers the possibility of developing super conducting materials and increasingly efficient solar panels.

Today, there are already more than 1,600 products on the market that incorporate nanomaterials: curling irons, refrigerators, car wax, projection screens, inks, iPhones, laptop computers, towels, house paint, clothing, sunglasses, toothbrushes, pacifiers, laundry detergent, plush toys, tennis rackets, throat spray, food containers…and many more.

In the U.S., manufacturers are responsible for ensuring that their products meet all legal and safety requirements, including products involving nanotechnology. There are no specific regulations for nanotechnology, nor any labeling requirements for products that contain nanomaterials.



But do we know enough about this new technology to understand what the potential unintended impacts on human health and the environment could be? As nanomaterials become more widespread, the public and those who work with them will be increasingly exposed to them. Since 2001, the federal government has invested almost $20 billion in nanotechnology research through the National Nanotechnology Initiative, but only $750 million on studying the environmental and health impacts and safety of nanotechnology.

While nanostructures are usually embedded in larger entities and remain quite stable, nanoparticles, because of their size, can be inhaled, ingestedand absorbed through the skin and eyes.

They can enter cells, nerves, ovaries, lymph nodes and muscles and cross the blood-brain barrier. They may accumulate in the lungs, liver or brain. Some nanoparticles could affect the immune system and the ability of cells to deal with pathogens.

Researchers have found that when rats inhaled manganese oxide nanomaterials inhaled daily by factory welders, the nanoparticles settled in their brain and lungs, triggering signs of inflammation and cellular stress. When tested on hairless mice, titanium dioxide nanoparticles, commonly used to block sun rays without the white pastiness, induced skin aging. After mixing nano titanium dioxide into the drinking water of mice for two years, scientists discovered the mice had significant DNA and chromosomal damage. Carbon nanotubes introduced into the stomachs of mice behaved like asbestos, causing inflammation and lesions.

It is inevitable that engineered nanoparticles will gradually be released into the environment through leakage from the production and transport of products, usage, and waste materials. They will enter the air, soil and water. Nano silver, which is antibiotic, could find its way from landfills, wastewater treatment plants and industrial plants into ecosystems where it could be toxic to aquatic and terrestrial creatures.

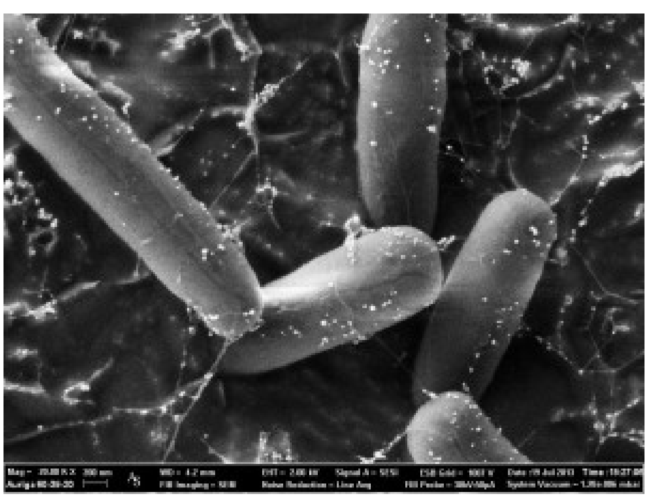
The Center for the Environmental Implications of Nanotechnology, another center established by the National Nanotechnology Initiative, studies the behavior of nanomaterials and their potential biological, environmental and ecological impacts.

Over five years, the center exposed plants and microbes to nano silver and found that even when given a low dose, the plants and microbes produced about a third less biomass, which indicates stress.

Because of their relatively large surface area, engineered nanoparticles are highly reactive. According to the National Nanotechnology Initiative, nanomaterials released into the environment may be transformed by environmental conditions such as temperature and salinity, the nature of a habitat, and the presence of other contaminants. The transformed nanomaterials may in turn alter atmospheric, soil, or water chemistry. And these transformations may change the form of the nanomaterials to which humans and ecosystems are exposed.

Benajamin Bostick, an environmental chemist and associate research professor at Lamont Doherty Earth Observatory, is studying how certain nanoparticles transform in the environment in order to understand if they are good or bad, how they move in the environment and their toxicity.

"Nanoparticles aren't necessarily safe or dangerous," he said, "You have to know what their constituents are." Their toxicity is influenced by their size, chemical composition, shape, surface structure, surface charge, solubility, how they aggregate and the presence of other chemicals.



E-coli dotted with silver nanoparticles. Credit: ZEISS Microscopy

A multitude of factors need to be taken into consideration when assessing the safety and impacts of nanoparticles, and they need to be studied in complex realistic environments over time to accurately predict their effects. For the next five years, the Center for the Environmental Implications of Nanotechnology will look at how nanomaterials are transferred between organisms, how they bioaccumulate in food webs, the interaction between nanoparticles and environmental contaminants, and the impact of low-dose and long-term exposure to nanoparticles on ecosystems.

"Part of the purpose of the research going on at the center is to help the community define what rules will assure a high degree of safety…the scientists work closely with the EPA, and OSHA, and the whole set of agencies," said Yardley.

Nanomaterials are currently covered under various acts under the U.S. Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), and the Occupational Safety and Health Administration (OSHA), but the agencies are beginning to look specifically at the risks posed by nanotechnology.

Bostick cautioned against painting all nanoparticles with a broad brush.

"We do need to think about the nanoparticles that are dangerous and figure out how to use them safely or find alternatives. But we shouldn't group all nanoparticles into one category so the safe ones can't be used. We need to distinguish between them," he said.

The EPA is currently assessing the health and safety impacts of certain nanomaterials: carbon nanotubes, cerium oxide, titanium dioxide, nano silver, iron and micronized copper. In April 2012, the FDA issued two draft guidance documents on the use of nanotechnology in foods and cosmetics. Companies using nanoparticles in food additives or packaging were advised to consult with the FDA and demonstrate that their products are safe before selling them. Cosmetics companies using nanotechnology were urged to do additional safety testing. No final guidance has been issued as yet.

Berkeley, Calif., is the first and only city in the United States regulating nanotechnology. It requires manufacturers and handlers of nanoparticles to disclose toxicological, environmental and safety information to the city's Toxics Management Division.

While Yardley has faith in our existing regulatory system and how it works, he acknowledged, "There must be changes in our regulatory definitions of materials and categories…these things have not only chemical composition, but they do have a size and shape, and surface functionalization, and all those things determine the toxicity in nanoscale materials. … For sure, the nature of our regulations will have to change, and they'll have to consider these functions. And we will have to worry about cradle-to-grave effects."

Meanwhile, consumers who want to avoid products containing nanomaterials or nanoparticles should avoid textiles, dietary supplements and cosmetics labeled "nano," "ultrafine," "micronized" or "antimicrobial." Steer clear of biosolid fertilizers, sometimes called "organic" fertilizers, as they often contain nano silver. USDA organic certified products do not contain nanomaterials, but "organic" or "all natural" cosmetics may.

Provided by Earth Institute, Columbia University