Nanoparticles: Big potential or big threat?

11 July 2012, By Julie Deardorff

Zinc oxide would be the perfect sunscreen ingredient if the resulting product didn't look quite so silly. Thick, white and pasty, it was once seen mostly on lifeguards, surfers and others who needed serious sun protection.

But when the sunscreens are made with nanoparticles they turn clear - which makes them more user-friendly.

Improved sunscreens are just one of the many innovative uses of nanotechnology, which involves drastically shrinking and fundamentally changing the structure of chemical compounds. But products made with nanomaterials also raise largely unanswered safety questions - such as whether the particles that make them effective can be absorbed into the bloodstream and are toxic to living cells.

Less than two decades old, the nanotech industry is booming. Nanoparticles - measured in billionths of a meter - are already found in thousands of consumer products, including cosmetics, pharmaceuticals, antimicrobial infant toys, sports equipment, food packaging and electronics. In addition to producing transparent sunscreens, nanomaterials help make light and sturdy tennis rackets, clothes that don't stain and stink-free socks.

The particles can alter how products look or function because matter behaves differently at the nanoscale, taking on unique and mysterious chemical and physical properties. Materials made of nanoparticles may be more conductive, stronger or more chemically reactive than those containing larger-sized particles of the same compound.

"Everything old becomes new when miniaturized," said Chad Mirkin, director of the International Institute for Nanotechnology at Northwestern University. "This gives scientists a new playground, one focused on determining what those differences are and how they could be used to make things better."

But the development of applications for nanotechnology is rapidly outpacing what scientists know about safe use. The same unusual properties that make nanoscale materials attractive may also pose unexpected risks to human health and the environment, according to the scientific literature.

"We haven't characterized these materials very well yet in terms of what the potential impacts on living organisms could be," said Kathleen Eggleson, a research scientist in the Center for Nanoscience and Technology at the University of Notre Dame.

Scientists don't yet know how long nanoparticles remain in the human body or what they might do there. But research on animals has found that inhaled nanoparticles can reach all areas of the respiratory tract; because of their small size and shape, they can migrate quickly into cells and organs. The smaller particles may also pose risks to the heart and blood vessels, the central nervous system and the immune system, according to the Food and Drug Administration.

Animal studies have shown that some nanoscale materials can cross the protective blood-brain barrier, which could allow pharmaceuticals to deliver medicine directly to the brain to treat tumors or other conditions. But there's also evidence that some nanoparticles could cause damage through oxidative stress and other mechanisms if they got to the brain.

Still unknown is "how significant (potential damage) would be, how much nanomaterial would be needed to cause appreciable harm, and how well the body would be able to deal with the material and recover," said Andrew Maynard, director of the University of Michigan Risk Science Center.

Though nanomaterials have been used in consumer products for more than a decade, the FDA acknowledged for the first time in April that they differ from their bulk counterparts and have potential new risks that may require testing. In draft

guidelines on the safety of nanomaterials in cosmetic products, it advised companies to consult with the FDA to find out the best way to test their products.

Rather than adopting a one-size-fits-all approach, the FDA plans to assess nano-enabled products on a case-by-case basis, according to the guidelines. "There is nothing inherently good or bad about a nanomaterial," said Mirkin, who nevertheless thinks each class of material should be considered a new form of matter and properly reviewed for safety.

Several government reports have raised concerns over the lack of environmental, health and safety testing of nanomaterials that are expected to enter the market over the next decade. In 2009, developers generated $1 billion from the sale of nanomaterials; the market is expected to explode to $3 trillion by 2015, according to a report by the National Research Council.

Last year the Environmental Protection Agency found data gaps in six critical areas, including a review of human health and toxicological data. In a January report, the research council warned that "little progress has been made on the effects of ingested nanomaterials on human health."

Though federal funding earmarked for environmental health and safety research doubled between 2006 and 2010 - from $38 million to $90 million - it accounts for only a fraction of the billion-dollar federal budget for nanotechnology research and development, the Government Accountability Office said in a May report. The GAO also found serious problems with the way health and safety data were collected and reported.

Basic unanswered questions include which materials are harmful to humans or the environment, how exposure should be measured and what happens to nanoparticles once they enter a body of water or the soil. In some cases, nanomaterials have been linked to toxic effects but scientists don't know why the problems occur.

"People think the (nanomaterials) may be bad because they're in the size range of a virus; so they may go where viruses go, perhaps, triggering an immune response," said Nancy Monteiro-Riviere, a professor of investigative dermatology and toxicology at North Carolina State University. "Cells within the lymph nodes may pick it up and distribute it."

But "there are so many different types of nanomaterials and shapes and sizes that every one has to be looked at as an individual particle," Monteiro-Riviere said. "You can't generalize."

In the case of sunscreen, nanoparticle toxicity depends on a variety of factors, including their size, structure, surface properties or coating and ability to aggregate or clump together, forming larger particles.

The main concern involves whether the particles can penetrate the skin barrier. "So far, they have not shown penetration," said Dr. Steven Q. Wang, director of dermatologic surgery and dermatology at Memorial Sloan-Kettering Cancer Center in New Jersey. "But we really don't know (what happens) if someone is burned, has eczema or a skin condition or the skin isn't intact." Though Wang thinks nano-sunscreens are safe for the majority of people, he said it's also unclear what the risks might be if a child were to lick a hand or arm and ingest the nano sunscreeen.

Exposing the nanomaterials used in sunscreens to the sun's ultraviolet rays also generates free radicals, which can damage cell membranes. In fact, the size and concentrations of nanoparticles that deliver the best sun protection factor and transparent appearance can also generate the most free radicals, according to a study by Amanda Barnard, an Australian researcher and theoretical physicist who specializes in predicting the real world behavior of nanoparticles.

As a protective measure, the nanoparticles are often coated with a shell that absorbs the free radicals, Wang said. But some remain uneasy about the potential toxicity of the coatings and whether the particles can penetrate cells. For a sunscreen to be listed on MightyNest.com, an online natural products marketplace, it must be mineral based, broad-spectrum and free of nanoparticles.

"Since it is not necessary for a sunscreen to have nanoparticles to be effective, we're playing it safe," said Mighty Nest co-founder Kristen Conn of Evanston, Ill., who said she's concerned about possible free radical production.

In April, in response to a petition demanding greater oversight of nanotechnology, the FDA ruled that topical use of nano zinc oxide and titanium dioxide sunscreens is safe. Citing Monteiro-Riviere's research, which the FDA called "the most definitive to date," the agency found "minimal evidence of the further penetration down to the capillary beds that would be necessary for systemic delivery to the organs, where it could have potentially deleterious effects."

Dr. Martha Howard, an integrative physician in Chicago, isn't yet convinced. The 70-year-old uses non-nano zinc sunscreens when she swims and hikes because they're extremely effective and "not enough is known about how long nanoparticles remain in the body and where they accumulate and the kinds of damage they can do," she said.

Though nano zinc and titanium are thought to be widely used in U.S. sunscreens, they are rarely labeled as such. If the product contains zinc oxide or titanium dioxide - known as physical sunscreens because they block the sun's rays - and appears white when applied, it is most likely a nano sunscreen. Terms such as "micronized and "ultra-fine" also could refer to nano-sized particles. (It's unclear which, if any, chemical sunscreens use nanoparticles.)

Proponents of nanotechnology say the potential benefits reach far beyond sunscreen. Controlling matter at the atomic scale is being hailed as the next "industrial revolution" because it could help solve everything from climate change and world hunger to energy shortages and biodiversity loss. In medicine, scientists envision microscopic robots that can swim around in the bloodstream, repairing cells and diagnosing diseases. Nanotechnology may also unleash powerful new therapeutic weapons for treating many of the worse forms of cancer, cardiovascular problems and neurodegenerative disease.

But as the field races forward, some are counseling a precautionary approach. Several advocacy groups, including the International Center for Technology Assessment, Friends of the Earth and the Natural Resources Defense Council, have called for a moratorium on the sale of "unsafe, untested and unregulated use" of nanomaterials.

The Environmental Working Group, an advocacy group that issues an annual list of sunscreen safety ratings, surprised some observers by calling nano sunscreens among the "safest and most effective" choices. But it doesn't endorse nanomaterials in general, and the group recommends that consumers avoid those found in cosmetics, which could be easily inhaled. "We remain deeply concerned about the overall safety and oversight of nanotechnology as well as impacts on workers and the environment," said David Andrews, a senior scientist at EWG.

Eggleson thinks it would be a mistake to place a moratorium on all things nano. "That would be putting the brakes on things we want and do need, but it rests on us to be good stewards of the technology we have," she said. "The human failings have been a greater problem than the technology itself."

More information: RESOURCES

The Project on Emerging Nanotechnologies, at nanotechproject.org, offers a database of more than 800 nanotech products, identified by the manufacturer, although the list is not comprehensive. Established in 2005, PEN is a partnership between the Woodrow Wilson International Center for Scholars and the Pew Charitable Trusts.

The federal government offers information through the website of the National Nanotechnology Initiative, a nanotechnology education, research and development program, at nano.gov.