

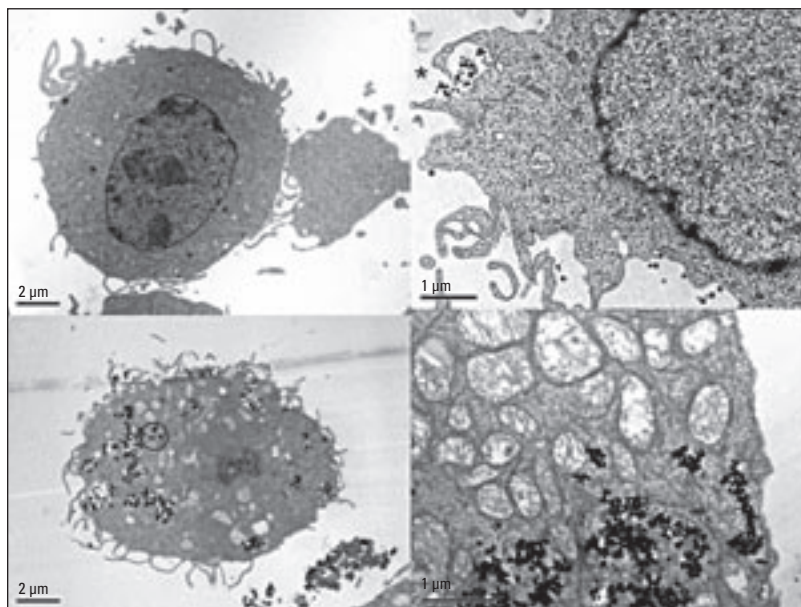
## Study links TiO<sub>2</sub> nanoparticles with potential for brain-cell damage

In a new study published in this issue of *ES&T* (pp 4346–4352), researchers report that titanium dioxide (TiO<sub>2</sub>) nanoparticles can trigger rapid and long-lasting defensive responses in mouse microglia, specialized cells that protect the brain from harmful external stimuli. The study—according to corresponding author Bellina Veronesi, a researcher at the U.S. EPA's National Health and Environmental Effects Research Laboratory—is the first to examine the potential neurotoxicity of nanoscale TiO<sub>2</sub>, which is widely used in consumer products like sunscreen and cosmetics.

The authors followed a protocol for nanotoxicity testing that they hope other researchers will adopt in order to facilitate comparison across studies. “You carefully characterize the particles,” Veronesi explains, “and you begin with a very simple in vitro model. Then you move up the ladder” to more complicated systems and in vivo experiments.

Evidence is mounting that relatively nontoxic materials, like TiO<sub>2</sub>, become increasingly harmful at smaller sizes. Although they have yet to study the phenomenon in humans, toxicologists have begun to explore how nanomaterials spur the generation of biologically active molecules, known as reactive oxygen species (ROS), that can damage cells by inducing oxidative stress. Certain physical and chemical properties—including size, surface area, and surface charge—interact to determine how likely nanomaterials are to cause oxidative stress in biological systems.

But these same properties can be dramatically altered in solution,



Mouse microglia are shown engulfing a cluster of TiO<sub>2</sub> nanoparticles. Scientists at EPA and elsewhere are studying the potential neurotoxicity of nanoscale TiO<sub>2</sub> by monitoring the defensive reactions of microglia.

explains Greg Lowry, a professor of environmental engineering at Carnegie Mellon University and a coauthor of the paper. Nanoparticles may cluster and form larger aggregates, for example, changing their effective size and surface area. “When you put these metal nanoparticles in water, they don’t behave well,” says Lowry, “and you have to understand that response.”

After characterizing solutions of commercially available TiO<sub>2</sub> nanoparticles—Degussa’s Aeroxide P25, used as a thermal stabilizer and in catalysis applications—Veronesi and her colleagues exposed cultured microglia to the particles at concentrations ranging from 2.5 to 120 ppm. Microglia respond to stimuli by engulfing them, in a process known as phagocytosis, and releasing chemicals in an “oxi-

dativ burst” designed to eliminate the offending stimuli. By monitoring a chemical signature of ROS formation over the course of 2 h, the researchers found that TiO<sub>2</sub> nanoparticles provoked a rapid and prolonged release of ROS by the microglia.

Although the microglia generate ROS as a defensive mechanism, a prolonged release can actually be harmful to the brain. “When [microglia] release ROS to the [brain] environment, they can damage surrounding cells,” explains Veronesi. A similar mechanism has been implicated as the cause of neuronal damage in certain neurodegenerative diseases, including Parkinson’s and Alzheimer’s.

The authors’ next step is to determine whether neurons are harmed by the ROS triggered by

nanoscale TiO<sub>2</sub>. According to Veronesi, a pilot study has shown that dopaminergic neurons exposed to TiO<sub>2</sub> initiate cellular processes that can ultimately progress to cell death by apoptosis or necrosis, although she stresses that the findings are still preliminary.

"I think they set the stage for future work," agrees Lisa Opanashuk, a professor of environmental medicine at the University of Rochester. "The most important aspect [of this research] is the particle characterization." Opanashuk notes that "ROS analysis is a good step to look at potential reactivity at the cellular level." But she adds that researchers should also look for signs that nanoparticles are acti-

vating antioxidant defense systems or leading to inflammation.

Wolfgang Kreyling of the GSF Institute for Inhalation Biology (Germany), who has extensively studied the translocation of nanoparticles in the body, notes that certain nanomaterials have been found to cross the blood-brain barrier and persist in the brain.

Although Kreyling has not determined whether TiO<sub>2</sub> nanoparticles reach the brain, he has already seen that they can spread from the lungs to other organs. He cautions that the concentrations used in Veronesi's research may be higher than actual exposures, but researchers cannot know for sure.

—LIZZ THRALL

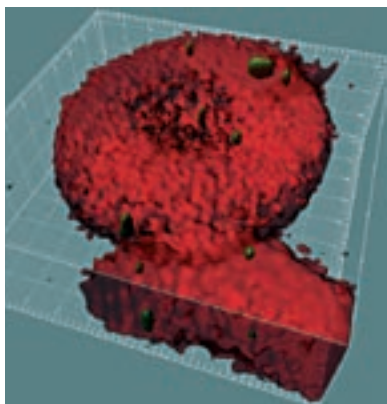
## Are red blood cells defenseless against smaller nanoparticles?

A study published in this issue of *ES&T* (pp 4353–4359) shows that many different types of <100-nm-diam particles can penetrate human red blood cells. The research adds to the growing body of evidence that nanoparticles do not

behave like other fine particles.

In the past 20 years, epidemiologists have linked many of the harmful effects of air pollution—including respiratory and cardiac problems—to the presence of fine particles, those with diameters of 0.2–2.5 μm. A growing body of evidence, however, suggests that nanoparticles—commonly defined as having 1 or more dimensions <100 nm—may be able to reach places that larger particles cannot. As a result, nanoparticles may prove more toxic than the same materials in bulk quantities.

Although previous studies have shown that nanoparticles can penetrate various cell types, corresponding author Barbara Rothen-Rutishauser, a researcher in Peter Gehr's lab at the University of Bern (Switzerland), and her colleagues set out to determine whether red blood cells take up particles of different composition (polystyrene, gold, and titanium



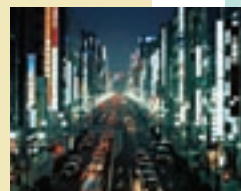
BARBARA ROTHEN-RUTISHAUSER

Researchers at the University of Bern (Switzerland) have found that nanoparticles of different composition and surface charge can penetrate human red blood cells. Negatively charged nanoparticles are shown in green.

## News Briefs

### Ozone, traffic, and developing countries

In a model that analyzed automobile emissions, local air pollution, and photochemical smog, researchers showed that countries in the Northern Hemisphere generally increase their radiative forcing because of high ozone emissions during summertime driving. Radiative forcing denotes the amount of heat absorbed by the planet's



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surface and is expressed in W/m<sup>2</sup>. In the *Journal of Geophysical Research* (2006, doi 10.1029/2005JD006407), the team reported that Northern Hemisphere emissions will increase radiative forcing by 0.05 W/m<sup>2</sup> by 2050. Using projected changes for South Asia, Africa, and elsewhere, and assuming that U.S. driving habits remain dominant, they found that emissions worldwide would spike summertime radiative forcing by 0.27 W/m<sup>2</sup> by 2050.

### Solar power cuts pollution

Over their 30-year life spans, photovoltaic panels with an area of 10 m<sup>2</sup> can spare the planet ≤40 t of CO<sub>2</sub>. That is how much pollution would be generated by burning fossil fuels to get the same amount of electricity. The findings were released this May in a report by an international consortium of solar-energy producers. Additionally, photovoltaic systems can pay back the energy required for their production, installation, and dismantling in 19–56 months. Even better, solar panels deliver 8–18× that amount over their lifetimes. Researchers based their conclusions on a worldwide survey of existing studies on solar products and compared solar performance in the 26 countries.

dioxide) and surface charge (positive, neutral, and negative).

Using laser scanning microscopy and transmission electron microscopy to visualize the particles, researchers observed how nanoparticles of all material types and surface charges interact with the cells. Many nanoparticles tend to cluster together in solution, and Rothen-Rutishauser found that even these aggregates, as long as the diameters are <100 nm, could also enter the cells.

Rothen-Rutishauser and her colleagues report the interaction of nanoparticles with only the relatively simple red blood cells, which lack a nucleus and other organelles. Paul Borm, the director of the Center for Expertise in Life Sciences at Zuyd University (The Netherlands), cautions that the findings cannot necessarily be generalized to in vivo systems. Whole blood contains several different phagocytic cells that recognize antigens and engulf them, in a process known as phagocytosis. “The question is really whether this is an artificial situation,” says Borm. “In whole blood, there are plenty of phago-

cytic cells available to recognize the particles and ‘eat’ them.”

But researchers are concerned that nanoparticles may evade the body’s defenses—possibly by penetrating the membranes of nonphagocytic cells before they can be recognized and engulfed by phagocytes. “There are so many routes into the body,” explains Vicki Stone, a professor of toxicology at Napier University (U.K.), “that I think it’s conceivable that nanoparticles might come into contact with red blood cells.”

Various nanoparticles are known to cross the lung epithelium and the blood–brain barrier, and some penetrate cell membranes and lodge in mitochondria. According to Ken Donaldson, a professor of respiratory toxicology at the University of Edinburgh (U.K.), nanoparticles might interfere with cell functions. “This idea that nanoparticles can get places that other particles can’t get has become a driver for research.”

Another difficulty in extrapolating from in vitro studies to biological systems is determining how the nanoparticle surface is modi-

fied, says John Balbus, the health program director at Environmental Defense, a nonprofit environmental group that is monitoring implications of nanotechnology. “This is a big research need,” Balbus explains, “to see how these alterations affect cellular uptake quantitatively.”

Rothen-Rutishauser and her colleagues are expanding their research to more biologically relevant systems, including a cell-culture model of the respiratory tract. They have also begun to quantify the uptake of fluorescently labeled particles and to look at how the process unfolds in real time—a technique that may shed more light on the mechanism by which nanoparticles enter nonphagocytic cells.

As the field of nanotoxicology progresses, Rothen-Rutishauser explains, researchers will depend upon accurate and reliable imaging techniques to study particles in biological systems. “Nanoparticles are very difficult to find in cells because they are so small,” she says. “So you need advanced techniques to really show them.”

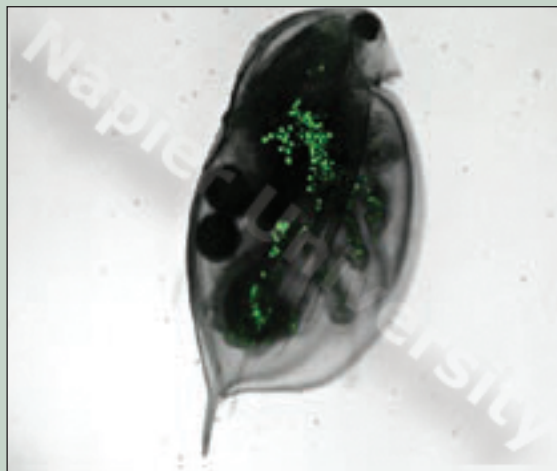
—LIZZ THRALL

## Still life with nanoparticles

For the first time, researchers have captured an image of nanoparticles inside a whole, live organism. Nanoparticles have been photographed previously in cells in vitro, but this image, which was presented at the Society of Environmental Toxicology and Chemistry Europe meeting in May by Teresa Fernandes of Napier University (U.K.), captures the tiny particles inside a daphnid or water flea (*Daphnia magna*).

Fernandes and her team started with immature (neonates) and adult daphnids swimming in an environment containing nanoparticles of titanium dioxide and carbon black. Both the immature and adult water fleas ingested the particles immediately. Graduate student Philipp Rosenkranz captured images of the carboxylated, fluorescently tagged particles in an adult’s gut as well as in its fatty-lipid storage droplets. A neonate, <1 d old, also ingested the particles, as documented in images that the team plans to publish later this year.

The researchers expected the particles to be readily seen in the adult animal’s gut, but they wanted to determine whether the daphnid would excrete them immediately or store them elsewhere internally. “Within an hour of ingestion, one of the photographs indicated that the



TERESA FERNANDES, COPYRIGHT NAPIER UNIVERSITY (U.K.)

nanoparticles had been translocated to other parts of the body,” Fernandes says. “They’re going to use those storage deposits eventually,” she says, “however, this requires further work to determine the relevance to nanoparticle safety.” —NAOMI LUBICK

## Bacteria may break down popular flame retardant to produce toxics

Research published in this issue of *ES&T* (pp 4429–4434) documents that microbes can break down the large molecules of the widely used Deca PBDE (polybrominated diphenyl ether) flame retardant. The paper raises concerns about the Deca flame retardant's safety by showing that various anaerobic bacteria can work in concert to dehalogenate the Deca compound to produce the smaller PBDE compounds that have been banned in the EU and discontinued in the U.S.



STEPHEN ZINDER

**Bacteria such as the *Dehalococcoides* shown here may be able to work in concert with other bacteria to attack the Deca PBDE flame retardant and produce small toxic PBDEs.**

The paper is the first to identify species of bacteria capable of breaking down the main constituent of the Deca flame retardant formulation, Deca-BDE. The study builds on previous research showing that the Deca flame retardant could be transformed during anaerobic sewage treatment.

The Deca mixture is found in electronic products such as computers and televisions, and it is the only PBDE formulation currently in use. Because of the Deca-BDE molecule's large size, it is considered relatively inert, but the smaller PBDE compounds, or congeners, that have been banned and discontinued are persistent and bioaccumulative. The levels of these compounds have been rising throughout the world, especially in North America, and their neurotoxic effects are similar to those of PCBs, which they resemble chemically.

In the new paper, Lisa Alvarez-Cohen and her colleagues at the

University of California, Berkeley, describe research they conducted with bacteria known to be able to dehalogenate large molecules containing chlorine. *Sulfurospirillum multivorans* are able to break down TCE (trichloroethylene), and the different species of *Dehalococcoides* used in the experiments can attack both chlorinated ethenes and dioxins. The new study firmly establishes that the *Dehalococcoides* bacteria can use brominated compounds as electron acceptors, says Lorenz Adrian, who is with the Technical University of Berlin's Institute for Biotechnology and who first showed that the bacteria could attack dioxins.

Alvarez-Cohen's team documented the *S. multivorans* bacteria's ability to decompose the Deca-BDE molecules into smaller PBDE compounds containing 8 and 9 bromine atoms.

The *Dehalococcoides* bacteria cannot attack the large Deca-BDE molecules, but they could dehalogenate PBDE compounds containing 8 bromines to produce PBDE compounds with 6, 5, and 4 bromines. The breakdown products included BDE-99, which contains 5 bromines and is often found to bioaccumulate in people and animals. Although these tests took place in a laboratory, Alvarez-Cohen says that "it is highly likely that we'll see this kind of sequential transformation in the environment."

Other researchers agree. The research raises the question of whether "continued production and use of the Deca may lead to ongoing exposure of wildlife and people to the lower brominated congeners for which we have toxicity concerns," adds Linda Birnbaum, director of the experimental toxicology division at the U.S. EPA's National Health and Environmental Effects Research Laboratory.

Andreas Gerecke, a project leader in the analytical chemistry de-

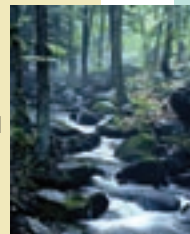
## News Briefs

### Nanotechnology-based consumer products

More than 200 consumer products—ranging from cosmetics, to laptop computers, to stain-resistant clothing—now contain nanoscale materials, according to the first publicly available inventory. Compiled by the Woodrow Wilson International Center for Scholars, the analysis found that most of the items were targeted at health and fitness consumers—products such as antiaging creams and sunscreens. Other items found to contain nanoparticles were computers and electronics, home and garden wares, food and beverages, and automotive appliances. U.S. companies manufacture the most nanotechnology-based products, followed by companies in Asia and Europe. Scientists with the Royal Society and the Royal Academy of Engineering (U.K.) called on industry to reveal safety tests of consumer goods containing free nanoparticles. The report is available at [www.nanotechproject.org/44/consumer-nanotechnology](http://www.nanotechproject.org/44/consumer-nanotechnology).

### U.S. streams faring poorly

Only 28% of U.S. stream miles are in good condition, finds the U.S. EPA in its first-ever national assessment. Some 42% were rated as poor and 25% as fair. Those in the eastern mountains fare worst, while western streams remain the healthiest. Between 2000 and 2004, researchers collected samples from ~1400 sites for the survey called the Wadeable Streams Assessment. Riparian disturbance; excess sediments; and nutrients, such as nitrogen and phosphorus, were the most widespread stressors observed in each of the three major regions. The stream survey is the second in a series of reports evaluating U.S. waters. Next, the agency plans to survey the nation's lakes, large rivers, and wetlands.



JUPITERIMAGES

partment of Switzerland's National Materials Science & Technology Laboratory (EMPA), was the first scientist to report that Deca-BDE was being broken down in sewage treatment plants. He says that "it is likely that Deca[-BDE] undergoes microbially mediated reductive debromination in the anaerobic environment." However, he points out that the rates documented in the paper are quite slow.

Alvarez-Cohen acknowledges that this is true but says that she is currently involved in studies with additional bacteria showing

"much [more rapid] rates of degradation." However, scientists from the Bromine Science and Environmental Forum, an industry group, point out that "no degradation was found without TCE being added as a fuel, along with other substrates. Since TCE is not normally present in the environment at high concentrations (it oxidizes to another substance), the environmental relevance of this study is questionable; i.e., the conditions under which degradation was forced to occur are not likely to be found in the environment."

Even so, scientists interviewed for this article agree that the paper's findings are significant. Deca-BDE is also "detected at elevated levels in sewage sludge [and] biosolids, which can be home to multiple strains of bacteria," points out Heather Stapleton, an assistant professor of environmental sciences and policy at Duke University. "Considering that land application of biosolids and soil amendment is an increasing practice, [this new paper's findings warrant] further investigation." —KELLYN BETTS

## Capturing "real-world" aircraft emissions

The days of watching a black plume of smoke burst out as commercial aircraft take off are long gone. Still, public fears about toxic air pollution being sprayed across nearby communities remain. While studies focusing on NO<sub>x</sub> have measured and quantified emissions at high altitude, very few studies have looked at emissions from operating airplanes on the ground.

In research described in a paper published in this issue of *ES&T* (pp 4406–4413), corresponding author Scott Herndon from Aerodyne Research, Inc., and colleagues used a mobile laboratory parked near the airport fence at Boston's Logan Airport. As the plumes floated downwind across the lab's instruments, they gathered data that result in "real-world" hydrocarbon emissions from airplanes. These measurements show that such emissions may be much higher when planes are left idling on an airport tarmac than previously believed, Herndon says.

The results of this experiment will help local air-quality planners estimate airport emissions, according to researchers work-

ing on similar studies. "We have a national crisis, in effect, in that a large number of our airports are landlocked and very much need to expand," says Phil Whitefield, a researcher at the Center of Excellence for Aerospace Particulate Research at the University of Mis-

Aviation Organization (ICAO) to revise the engine certification standards, says co-author Richard Miake-Lye of Aerodyne. ICAO, which sets engine certification standards followed by aircraft engine manufacturers, last published standards for smoke and hydrocarbons, CO, and NO<sub>x</sub> in 1981. These standards were developed with data from stationary engines rather

than planes operating at an airport.

The study took advantage of the Aerodyne Mobile Laboratory, a package-delivery-sized truck recently used in a project to characterize fine particulate matter in Mexico City. The lab sat for a few hours near the fence at busy Logan Airport for one day in May 2003. Herndon, John Jayne of Aerodyne, and 3 graduate students intercepted >45 plumes from

specific commercial aircraft. The ambient air was continuously analyzed through a sample port, located near the roof on the front of the truck, and delivered to various instruments on board.

The plumes were captured <2 min after being emitted. Two rapid and sensitive analytical methods were used to perform analyses: proton transfer reaction mass spectrometry and infrared differ-



Data were gathered from instruments inside this mobile lab parked near the fence at Boston's Logan Airport.

RICHARD MIAKE-LYE, AERODYNE RESEARCH, INC.

souri. Airport expansions must be approved, and regulators will look for an environmental impact statement that estimates the impact of new emissions. "You can't put a big bag around the airport, but we can use our emission indices and the operational aspects of the airplanes and get a very good estimate," Herndon says.

The data may also lead collaborators at the International Civil

ential absorption spectroscopy. They measured the plumes while the planes were idling, taxiing, taking off, and landing, and when the pilots started the engines.

The researchers found that hydrocarbon emissions from an idling plane engine may be greater than the emissions in the ICAO databank, by as much as 40–90%. The discrepancy can be accounted for by how the ICAO data were gathered: Engines studied for ICAO were idling at 7% of thrust. Most of the planes observed in this study had idling thrust levels <7%; in other words, the engines studied were running at lower power levels, the researchers say. “This is

really suggesting that we should think about how we model the hydrocarbon emission from idling aircraft,” Herndon says.

Many researchers contacted for this story complained that over several years, media reports have blamed airports for spreading harmful emissions to the nearby community. This paper will allow for improved toxicological analysis, by targeting the packet of air that is being dispersed into the community, says Wayne Miller of the University of California, Riverside. “I’ve read about people talking about airlines being primary sources of air toxics. And if this is really the case, then you need

current data to make those assessments,” Miller adds. Setting up indoor chambers that simulate natural dilution and temperature change is time-consuming and expensive; this approach is quicker and cheaper, Miller adds.

Herndon says that their paper is just the beginning of a flood of new data on aircraft emissions, much of it scheduled for publication in the next 6 months. “So in fact, the database of well-identified toxics that are traced to specific engine models is huge now,” Herndon says. What’s next? “The ground-service vehicles are now a big unknown,” he adds.

—CATHERINE M. COONEY

## Large carbon sequestration project planned to enhance oil recovery

Energy companies Statoil and Shell are planning to build a gas-fired power station in Norway and channel the CO<sub>2</sub> emissions into offshore oil fields to enhance oil recovery. The partners claim it would be the biggest scheme of its type in the world.

Under the plan announced in March, CO<sub>2</sub> would be captured from an 860-MW gas-fired power plant to be built at Statoil’s Tjeldbergodden (Norway) methanol complex. CO<sub>2</sub> emissions from the plant—2–2.5 million t-CO<sub>2</sub>/yr—would be piped to Shell’s Draugen oil field and to Statoil’s Heidrun oil field, both off the coast of Norway, and then injected into subsea reservoirs to force oil to the surface. (The operators currently use water for this purpose.)

The companies say that this operation would increase energy production in Norway while lowering the country’s CO<sub>2</sub> emissions. However, they also admit that their plan is technologically and commercially challenging and depends on substantial government funding and involvement. They estimate the project will cost

\$1.19–1.49 billion. If they secure all the necessary funding and approvals, construction of the power plant could start in 2010, with the first CO<sub>2</sub> being delivered as early as 2011.

Although Norwegian Environment Minister Helen Bjoernoy has praised the plan, she has not yet committed any funding. “This is a good example of industry responding constructively to political signals,” she said in a statement. “The Norwegian government has made it clear that carbon capture is a prerequisite for any new concessions to build gas-fired power stations.”

The Statoil–Shell partnership comes at a time of heated political debate in Norway over whether to build gas-fired power plants. At present, the country generates almost all its electricity at hydro-power plants, but little further expansion is possible. However, Norway is one of the world’s largest consumers of electricity and, with demand still growing, the government is looking for other energy sources that will find favor with its environmentally conscious popu-

lation. Gas-fueled power linked to carbon sequestration is one such solution. Currently, Norway has no traditional gas-fired power plants.

Some environmental groups, such as the Bellona Foundation, support this approach and have welcomed the Statoil proposal. Diana Wallis, a member of the Bellona Foundation and of the European Parliament, says that CO<sub>2</sub> capture and storage offer great opportunities to reduce emissions.

However, Truls Gulowsen of Greenpeace Norway points out that the overall balance of carbon emissions from the scheme will be higher because more oil will be produced and burned. Greenpeace is skeptical about CO<sub>2</sub> capture projects in general. “We believe money is better spent unleashing the energy-efficiency potential, supporting renewable energy solutions, and implementing low-energy solutions,” Gulowsen says.

Meanwhile, in the U.S., the Department of Energy released a series of reports in February claiming that the development of new CO<sub>2</sub> capture and sequestration for enhanced oil recovery could more than quadruple U.S. domestic oil production. About 30 million t of CO<sub>2</sub> is already used to boost oil recovery from onshore oil fields in Texas every year. —MARIA BURKE

## Mercury model at the top of its game?

A team working for the Port Authority of New York and New Jersey has built a state-of-the-art model that can forecast the behavior of methylmercury in an estuary and will aid in decisions about dredging to keep ship channels open. By making interactive links between complex physical and biological processes, the model can map when and where mercury can be transformed to toxic methylmercury.

The exact mechanisms behind mercury methylation—the microbial transformation of different forms of mercury into methylmercury—are unknown, but the basics were hammered out more than a decade ago: Sulfate-reducing microbes can take up inorganic mercury and transform it in the process. A model first presented in 1991, by Cindy Gilmour of the Academy of Natural Sciences's Estuarine Research Center and Elizabeth Henry of Harvard University, estimates the bulk microbial response according to sulfate or sulfide concentrations, which enhance and limit methylation, respectively.

Using that work as a guide allowed researchers from HydroQual, Inc., a consulting company, to estimate how much methylmercury is produced in different scenarios. The resulting model is the first to link methylation to physical characteristics such as sedimentation rates and hydrodynamics. The researchers also point out that another key improvement on past models is the mechanistic links to eutrophication in the system, which affects microbial processes.

The HydroQual team's new model incorporates well-established

models of currents, salinity, sediment deposition, and other factors from previous work as part of the long-term Contamination Assessment Reduction Program (CARP). The Port Authority and others expect to use the model to make management decisions about mercury as well as vari-

the magnitudes, though not quite the seasonal fluctuations, of the observed mercury methylation rates. In particular, the model reproduced a "hot spot" at the southern tip of Manhattan Island.

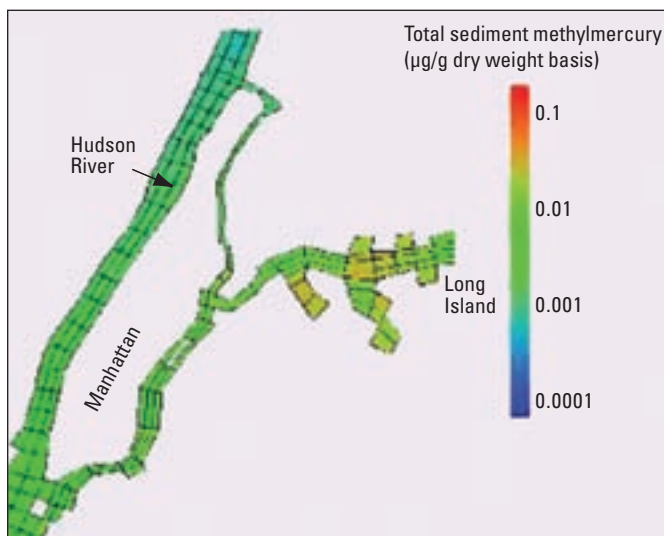
"Getting close was certainly very encouraging," says Redman, but "seasonality is the difficult thing."

The team's data set, though immense, lacks multiyear measurements that would help to pin down that variability, and extrapolating from centimeter-scale sediments to kilometer-sized model cells introduces more uncertainty. In addition to these factors, methylation rates are not dependent solely on sulfate reduction rates; this means that the team must "fill in the pieces as best we can," he says.

"Building a site-specific mercury transport and fate model is quite complex," says the U.S. EPA's Bob Ambrose, who notes that a complete model must carefully consider watershed inputs as well as wetland dynam-

ics. "Hydrodynamics are probably the best known component of the model," he continues. "Dispersion and mixing are less well characterized in these kinds of models, but still better [known] than the complex chemistry" of mercury, including methylation kinetics.

Modeler Joel Baker at the University of Maryland's Center for Ecosystems Studies is part of a team hired to review the model by the Hudson River Foundation (which oversees HydroQual's work for the Port Authority). He calls the CARP-based model "perhaps the highest-resolution contaminant model for an estuary that I've ever seen." The HydroQual model is expected to be published by the end of this year, once the review process wraps up. —NAOMI LUBICK



**The rainbow colors in the snapshot shown here represent different levels of total methylmercury in sediments in the waters surrounding Manhattan and the mouth of Long Island Sound, according to an advanced model that maps the potential for producing methylmercury in sediments in the Hudson River estuary.**

ous other contaminants, including PCBs and PAHs, in the Hudson River estuary. The model breaks down the estuary into a network of 32,000 cells of different sizes, mapping out >63 different chemicals over 66,729 km<sup>2</sup> of an ever-changing ecosystem.

At the European meeting of the Society of Environmental Toxicology and Chemistry in May, Aaron Redman of HydroQual presented mercury projections from the model. To field-check the model, the team used measurements taken at different points in the Hudson River (which divides New York and New Jersey) and the estuary where the river meets the Atlantic Ocean, including the inland bay of Long Island Sound. The projections over a little more than a year matched

## Mis-lead

At water conferences across the U.S., scientists and engineers are talking about lessons learned from the record levels of lead in Washington, D.C., drinking water that caused panic in the city in 2004. Government agencies describe the lack of harm from the incident; this has prompted many water and public-health professionals to argue that the D.C. experience shows that lead in drinking water is not a health threat. As a result, some experts now question the need for complex and costly technologies to control corrosion and keep lead levels low.

But are the water experts being misled? An extensive 2-year investigation by Virginia Polytechnic and State University corrosion engineer Marc Edwards, who initially identified the severity of the D.C. problem, and further *ES&T* reporting reveal that the federal and local agencies charged with overseeing the D.C. water system used flawed science to try to quiet public concerns.

In January 2004, D.C. residents learned from a *Washington Post* story that hazardous levels of lead had been present in their drinking water for several years. The problem was caused by a switch from free chlorine to chloramine disinfectant in order to meet new U.S. EPA regulations. D.C. officials pointed to old lead service lines, which bring water to homes, as the source of the lead.

On March 31, 2004, D.C. Department of Health (DOH) interim chief medical officer Daniel Lucey told the *Washington Post*, "We are not seeing any widespread lead toxicity attributable to the water in D.C." Lucey's comments were prompted by a preliminary CDC study that concluded blood lead levels had not risen appreciably as a result of D.C.'s tainted water, even in homes where concentrations were unusually high:  $\geq 300$  ppb. Meanwhile, sampling data from local schools and day-care

facilities suggested that drinking-water lead concentrations in these places were not extraordinarily high. On the basis of these findings, many accepted the statements of agency experts, that the "D.C. lead crisis" was much ado about nothing and that "drinking water is at most a minor source of lead for children" (*The Washington Post*, May 9, 2004, p B1).



CHRISTOPHER STROCK

**Not just lead pipes: Particles of lead solder in drinking water can cause elevated blood lead.**

But a careful investigation of the D.C. studies gives a different picture. The crucial assumption that the lead service lines were the only major source of the toxic metal, along with the surveys for lead in blood and in drinking water at D.C. schools and apartments, is deeply flawed and misleading, say experts familiar with the work.

The change in disinfectant did cause mineral scales inside D.C. lead service lines to dissolve, says corrosion expert Michael Schock with EPA's Office of Research and Development. However, the more-corrosive water also eroded lead solder, which sent particles down the pipes, and leached the metal from brass plumbing in homes. He points out that brass faucet bodies and necks, shutoff valves, water meters, and other plumbing components usually contain lead, even if the brass is labeled lead-free. That is because Congress defined in the 1996 Safe Drinking Water Act Amendments that "lead-free" plumbing pipes and components could have up to 8% lead.

However, misconceptions from the D.C. lead crisis persist, even as other water utilities switch from

chlorine to chloramines disinfection to comply with EPA's Stage 2 Disinfectants and Disinfection By-products Rule.

Early on, officials in D.C. decided to focus on lead service pipes as the only significant source of contamination. Through numerous Freedom of Information Act requests, Edwards has pieced together a partial chronology of the discussions that focused attention on the lead service lines. Despite repeated requests, officials at DOH and D.C. Water and Sewer Authority (WASA), the capital's water provider, declined to speak to *ES&T* for this article.

From the start, some at DOH expressed the hope that the data supported a focus only on lead service lines, because this would limit the problem. Of the ~123,000 residences in D.C., only ~23,000 have lead service lines.

WASA mailed an information letter on the lead crisis, which emphasized the problem of lead service lines, briefly mentioned solder, and ignored brass plumbing components. But within the agencies involved, a very different discussion was taking place.

On February 12, EPA Region 3 environmental scientist Lisa Donahue emailed agency colleagues: "We continue to miss a 'teachable moment' by maintaining the emphasis on the service lines as a perceived sole source of lead contamination. The first draw [sic] samples that put WASA into this situation came from plumbing containing brass faucets, fixtures, and valves. Until the water has been tested below 15 ppb, shouldn't those high risk populations be particularly cautious? If the water is corrosive, the brass will leach lead."

Donahue's viewpoint was never accepted. And throughout the crisis, DOH focused its public-health intervention efforts almost exclusively on those homes with lead service lines.

On April 29, DOH and WASA released the results of sampling for lead in D.C. public schools. Only

4% of the 1976 water samples tested from 130 schools had lead levels >20 ppb, the action level specified by the 1988 Lead Contamination Control Act, which covers drinking water in schools and day-care centers.

Experts say that these results were surprisingly low and had the effect of reassuring people. But there are strong reasons to think that the sampling strategy was flawed. For instance, a neighboring utility that used the same water source as D.C., but which has extremely good lead-corrosion control, did not have a single home sample above the EPA action limit. Yet 23.5% of the water taps in schools served by this utility were >20 ppb, says Edwards.

The school sampling was ordered by EPA Region 3 administrator Donald Welsh, who added that "Sampling must follow EPA protocol." The agency's protocol for sampling schools calls for first-draw samples to be taken after the water has been in contact with pipes for 8–12 h. But a very different protocol was followed in D.C. schools. The day before sampling, staff members were directed to remove the aerators and flush all of the drinking-water lines in the entire building from top to bottom. After letting the water sit overnight, they were directed to slowly fill sample bottles.

Edwards has followed the standard EPA protocol and the modified one used in D.C. schools to sample for lead in buildings that do not have lead service lines. The modified approach decreases lead levels in faucets with aerators by 2–3× the values from the EPA protocol; in some situations the decrease is as much as 200×. Edwards and his students have been unable to get permission to collect samples in D.C. schools using the standard EPA protocol.

The same modified protocol was eventually used by WASA to assess problems with lead in D.C. apartments—and found relatively low levels of lead. This observation was used to justify WASA and DOH's exclusive focus on homes

with lead service lines.

A growing number of studies quantitatively assess the effect of low-level exposure to lead, says John Rosen, a pediatrician and national expert on lead poisoning at Montefiore Medical Center. Last year, a study by Bruce Lanphear at Cincinnati Children's Hospital Medical Center and colleagues associated a drop of ~4 IQ points with a blood lead increase from 2.4 to 10 µg of lead/dL of blood (*Environ. Health Perspect.* **2005**, *113*, 894–899). This study is consistent with other reports, say experts.

In the midst of the lead crisis, EPA's Office of Water asked the agency's National Center for Environmental Assessment (NCEA) to evaluate the effects of lead in drinking water on children's blood lead levels with the agency's Integrated Exposure Uptake Biokinetic Model for Lead in Children. In March 2004, NCEA delivered its assessment: The blood lead levels of infants up to 1 year in age who drink formula made with tap water "are sensitive to drinking water lead concentrations." The model predicted that infants' blood lead levels would increase to ~6 µg/dL for a water lead concentration of 50 ppb, to 11 µg/dL for 100 ppb, and to a dangerous 20.8 µg/dL for a concentration of 200 ppb.

However, Tee Guidotti, health adviser to WASA and director of occupational medicine and toxicology at George Washington University, and officials at WASA and DOH have frequently noted in presentations that when CDC measured blood lead levels in the residents of ~98 homes with drinking-water lead >300 ppb, the study did not find elevated blood lead levels.

But Mary Jean Brown, head of CDC's lead poisoning prevention branch and the principal author of the study, doesn't agree. She tells *ES&T* that up to a year separates collection of the water and the blood samples. "This study does not say that 300 ppb lead in drinking water is safe," says Brown.

As Edwards points out, many of those tested by CDC had been noti-

fied that their water contained lead at >20× the EPA action limit months before their blood was drawn. It is likely that many began drinking bottled water or using water filters. Since the half-life for lead in the blood is about a month, this was more than enough time for blood lead levels to drop, he adds.

When asked by *ES&T*, Guidotti agrees that the CDC study is not conclusive. "This was an ecological study, and ecological studies are weak at proving associations," he admits. "All of D.C. was intensely aware of the lead problem—not just through newspaper reports but through public meetings and announcements in churches. People rapidly started using filters or bottled water," he says. "It is a major misinterpretation of the data to say that this study shows that 300 ppb in drinking water is not associated with an increase in blood lead levels."

Brown tells *ES&T* that she intends to look into the issue of the study's interpretation and seek ways to clarify its significance. "If misinterpretation is widespread, we'll have to do something, because that's not what this study is saying."

"At a minimum, it seems easy to understand how otherwise responsible public-health officials believed that the takeaway lesson of Washington, D.C., is that more than 300 ppb lead in drinking water did not significantly elevate blood lead or otherwise harm the public," says Edwards. "It may take years to correct this mistaken belief," he adds.

Neither Edwards nor any of the experts contacted for this story claim that drinking water is the major source of lead for children nationally. Public-health experts are much more concerned about chips and dust from leaded paint, says Brown. But Edwards has assembled enough evidence to indicate that lead in water can sometimes be a key source of elevated lead in children's blood. And that may be the real lesson of the D.C. water crisis.

—REBECCA RENNER

