Breathing less easily with ultrafine particles

On a cold January morning in 2008, a white van patrolled the streets of a neighborhood that sits just outside of Boston, several hundred meters (m) from two major freeways. Inside the van, researchers from Tufts University and their colleagues took a first spin around the neighborhood in the mobile laboratory built by Aerodyne Research, Inc. That day, they-collected gigabytes of data on the levels of a suite of pollutants that came from the traffic emissions raining down around them: CO, NO, NO_2, black carbon, PAHs, and three kinds of particulate matter, from coarse particles to fine particles larger than 2.5 micrometers ($PM_{2.5}$) down to ultrafine particles at 10–100 nanometers in diameter.

That morning, the researchers found that one cubic centimeter of Somerville's air held about 120,000 ultrafine particles, as reported by one of the lead investigators, Doug Brugge of Tufts. The team wants to explore the connection between exposure to these ultrafine particles and human health.

Ultrafine particles' contributions to human-health problems have attracted increasing attention from environmental scientists, as indicated by some of the research published in this issue of *ES&T* and elsewhere. Research communities that are working to answer these questions—in public health, environmental monitoring, medicine, and more—are moving toward the idea that such tiny particulate matter could be as important as the larger particles that are already regulated. But much remains to be discovered about these ulftrafine particles and exactly how they might cause damage.

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Drivers stuck in traffic have more to worry about than accidents ahead. Ultrafine particles, among other components of vehicle emissions, could be damaging their health.

Background levels

Like some manufactured and naturally occurring nanoparticles, ultrafine particles can be difficult to measure, impossible to detect in biological tissues in real time unless they are labeled, and tricky to track behaviorally because of their tendency to clump or change in other ways once they are released into the atmosphere. Such tiny particles also have large surface-to-volume ratios, which gives them extra area for surface chemical reactions, as well as the ability to act as vehicles for transporting other contaminants. They also change quite rapidly, from the first few seconds after they exit a tailpipe, for example, to minutes and hours later as they undergo chemical transformations in their airborne travels.

First examined for their possible health impacts in the 1990s by Günter Oberdörster of the University of Rochester and others, nanosized ultrafine particles did not set off alarm bells until researchers and policy makers turned their attention to the growing market for manufactured nanoparticles. "Since then, this has become a very important field," Oberdörster says, with indications that nanosized particles can damage animals' respiratory tracts and cardiovascular and central nervous systems. Once inside the body, ultrafine particles might also be able to travel to other organs in unexpected ways. Oberdörster points to one forgotten pathway: through the nose to the olfactory system, then to the central nervous system, and finally to the brain. (This route was found in the 1940s in studies of viruses in monkeys.)

Engineered nanoparticles get more attention than ultrafine particles, Oberdörster comments, particularly for industrial and medical purposes such as drug delivery. This focus, taken together with the difficulty of measuring these particles in real environments, means that the bulk of the data on both manufactured nanoparticles and ultrafines comes from in vitro studies or from animals exposed to well-characterized nanoparticles in known quantities.

"It's easy enough to put lots of material on those cells, [and] even the most benign material causes harm if you put in enough," Oberdörster says. The question is how to extrapolate those lab results "to real-world implications."

Traffic ahead

The best place to go for real-world data seems to be the open road. Any driver heading down the freeway breathes in a range of particles from the vehicles ahead. The mix includes metals, PAHs attached to particles, unburned oil droplets, and other components that have as-yet-unknown impacts when taken in altogether. But the key constituents that impact human health have been thought to be particles at around $PM_{2.5}$.

Regulations in the U.S. and Europe started with coarse particulate matter, PM_{10}, and expanded

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to $PM_{2.5}$ as epidemiological studies connected those fine particles to mortality. Coarse PM_{10} sticks in the upper reaches of the lung, as does $PM_{2.5}$, where their role in asthma and impact on the cardiovascular system have been well-documented. But $PM_{2.5}$ and smaller particles can get deeper into the lungs and into the alveoli—and eventually across the thinner membranes into the bloodstream, where they might cause clots or other damage.

About 150 epidemiological studies made the connection between $PM_{2.5}$ particles and death, says Robert Devlin, a researcher at the U.S. EPA Research Triangle Park. "Almost one million people a year die because of particulate matter exposure," according to the World Health Organization, he adds. "I don't think anyone disputes that fine particles are killing people. I don't think anyone doubts ultrafine particles have effects. The question is, how do they compare with other particles?" For example, although coarse particles may exacerbate asthma, they may not be as hazardous as fine particles; but, all three size classes could cause cardiovascular damage or lead to heart attacks. Devlin says new studies are needed to take into account both large-scale exposure and epidemiology in real-world situations.

That's the goal of the Tufts study currently in progress. The team will measure concentrations from the highway itself to the neighborhoods in Somerville 400 m away (with control sites 1000 m away) and try to identify when and where people are most exposed to different particles. The researchers expect to have their first whole-neighborhood human-health surveys completed later this year, and they hope to see health outcomes correlated with specific particle exposures.

"It's important to do," Brugge says. "Putting the two together is really at the center of what makes this a potentially valuable project."

DOUG BRUGGE

Researchers at Tufts will be driving a mobile lab, like the one in this van built by Aerodyne Research, into neighborhoods outside Boston to track emissions from traffic-heavy roads. The team will conduct surveys to see how people might be exposed in their daily lives to different vehicles' emissions and will look for correlations with health effects.

Location, location, location

"Ultrafine particles are more related to being in a specific transport environment," comments Mark Nieuwenhuijsen of the Centre de Recerca en Epidemiologia Ambiental (Spain). He and his coauthors tracked pedestrians on London streets; in their paper in this *ES&T* issue, they report that people are exposed to high levels of CO and ultrafines on busier roads, with exposure dropping off on the quieter streets nearby.

Previous studies have shown that the concentration of ultrafines drops off dramatically near the 200-m mark (though $PM_{2.5}$ might travel farther). "In a car, [a driver] gets quite a bit of exposure to this. On the pavement, exposure is going to be quite a bit less," Nieuwenhuijsen says. Exposure studies must account for a variety of factors: for example, traffic changes according to time of day, which leads to different emissions levels in the morning than at night. Meteorological conditions on a nice, windy day may carry air pollution away quickly, but quiet windless mornings mean that emissions stick around. Temperature, relative humidity, wind speed: all of these factors "are highly correlated, and it is hard to analyze the independent effects" in some studies, Nieuwenhuijsen says.

Those variables also may differ depending on the urban areas studied, Nieuwenhuijsen and others suggest, and that might explain some of the differences reported in the literature for Los Angeles, for example, versus smaller urban areas on the East Coast.

Andre Nel of the University of California Los Angeles says that particulate matter "gets really complex on a physical-chemistry level. Once particles are emitted, they change size; the numbers change with proximity to [the] freeway; the numbers change during the day; and chemical composition changes [during] travel through the atmosphere," as the particles move from, say, Los Angeles to Riverside, which is about 50 miles away.

But a more important consideration may be where the particles end up in an animal or cell, or which animal or person they end up in. "The way you are breathing and the shape of your lungs" could make a difference to exposure levels, says Jakob Löndahl of Lund University (Sweden), who led a team of researchers reporting in this *ES&T* issue on the uptake in the lungs of emissions from traffic and wood combustion. "Some people get a much higher dose than others; it could be a factor of two in difference, which could partly explain why some people are more vulnerable than others." Although Löndahl is among the researchers who suspect that ultrafines stay in the lungs, he says that some recent studies indicate transport to other organs.

Measuring up to expectations

Scientists have yet to come to consensus on how ultrafine particles create health problems. They still need to determine which characteristic to monitor: is it the number (or concentration) of particles, their surface area, or their mass? Researchers seem to tilt toward numbers and surface area, because these give a better idea of the chemical reactions that could occur or the metals or other constituents that might be present on a calculated surface area. In general, the particles are so small that their mass is almost impossible to measure.

"It really depends on which endpoint we're looking at, if number, concentration, or surface area is the best predictor" of human-health outcomes, says Junfeng (Jim) Zhang of Rutgers University. "It's too early to say what's the best thing to do." Zhang, who coauthored research in this issue examining $PM_{2.5}$ and oxidative DNA damage in people, also was on a team reporting to the Health Effects Institute on real-world diesel exposures and people with asthma. In that study, more than 80% of the emissions samples were composed of ultrafines. Zhang suggests that differences in damaging activity may exist even among different size classes of ultrafine particles: a few nanometers versus a few tens of nanometers might make the difference.

One likely metric for harm seems to be oxidative stress. Nel's team has been developing a "test-in-a-tube" for oxidative properties of particulate matter. They want to find a fast way to put an air sample in a test vessel and find out which metals, particles, and other constituents there could damage a cell's activity, and how that might translate to whole organisms.

New endpoints

Taking these considerations from observation to regulation could lead to solutions that range from local to global in their scope. Nieuwenhuijsen suggests cities might plan separate biking and walking paths or create canyon-like traffic corridors that generate wind to carry away pollution. Devlin says that EPA and others are working to evaluate a new generation of engines and filters, which are expected to be on the market by 2010, to see how clean they will be with respect to particle emissions.

Devlin adds that other sources, such as power-plant and ship emissions, also will have to be considered under any regulatory scheme. Nel suggests that using a CO_2 standard to regulate fossil fuel combustion could control much of the source of ultrafine particles.

In the meantime, getting to the answers on how ultrafines impact human health could be as complex as the particulate emissions themselves. The behavior of these nanoparticles in cells, animals, and the atmosphere, and the chemical reactions on their surfaces, remain to be parsed.

—NAOMI LUBICK