PROJECT UPDATE

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NYSERDA
New York State Energy Research and Development Authority

Clinical Studies of Exposure to Ultrafine Particles

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Keywords

- Airway inflammation
- Cardiac repolarization
- Leukocyte
- National Ambient Air Quality Standard (NAAQS)
- Ultrafine particle (UFP)

PROJECT FOCUS

Ambient ultrafine particles (UFPs) are important with regard to respiratory health for several reasons. They are biologically more reactive than larger particles and elicit effects at low mass concentrations. At the same ambient mass concentration, UFPs have a much higher concentration in terms of the number of particles and surface area than fine particles (see table). They also show a high deposition efficiency in the pulmonary region, since the probability of deposition by diffusion increases as particle size decreases. UFPs exhibit a higher propensity to rapidly reach the systemic circulation; they may therefore be linked to the cardiovascular effects attributed to the fine particle fraction.

The project initiated clinical studies of exposure to UFPs in healthy human subjects. The research team's hypothesis was that the increases in morbidity and mortality that are associated with ambient air pollution are related to the exacerbation of airway inflammation in susceptible individuals. In addition, they proposed that UFP exposure through ambient air alters pulmonary and vascular function, activation of circulating white blood cells (leukocytes), and the recovery of the heart from a beat (cardiac repolarization).

CONTEXT

In 1997, the U.S. Environmental Protection Agency (EPA) set a new mass-based National Ambient Air Quality Standard (NAAQS) for airborne particles smaller than 2.5 microns in diameter, called $PM_{2.5}$. Currently, the New York State Department of Environmental Conservation (NYS DEC) is conducting a three-year monitoring program to identify areas in New York State that may not meet the mass-based $PM_{2.5}$ NAAQS.

Airborne particulate matter (PM) is a broad class of materials of varying composition and sizes that are transported in the air as solid particles or liquid droplets. Airborne particles are emitted from a variety of natural processes and human activities, including fossil-fuel combustion, forest fires, wind erosion, agricultural practices, industrial manufacturing, and construction processes. The particles can be emitted directly into the atmosphere (primary particles) or formed in the atmosphere from precursor gases (e.g., sulfur dioxide, nitrogen oxides, ammonia, and volatile organic compounds). Ultrafine particles (UFPs) are extremely small particles, less than 0.1 micron in diameter. These particles are primarily generated from combustion processes, including stationary fossil-fueled electric-power generation, industrial processes, boilers, and car and truck engines.

While a variety of studies have shown a correlation between elevated concentrations of ambient particulate matter and adverse health effects, the exact mechanisms and chemical components responsible for the biological activity are not fully understood. Consequently, as EPA and the states proceed with the early phases of implementation of the mass-based PM NAAQS, numerous parallel research projects are underway to clarify which components in the PM mixture are responsible for the adverse health effects. Several hypotheses have been proposed, and various components and characteristics of PM have been targeted for exploration, including the UFP component of PM. This project explores the hypothesis that UFPs are a key culprit responsible for adverse health effects associated with fine particles. The results could have a significant impact on national regulatory control strategies and future ambient air quality standards.

Numbers and Surface Area of Particles Unit Density of Different Sizes at a Mass Concentration of 10µg/m³

Particle Diameter µm	Particle Number 1/cm³	Particle Surface Area µm²/cm³
0.02	2,400,000	3016
0.1	19,100	600
0.5	153	120
1.0	19	60
2.5	1.2	24

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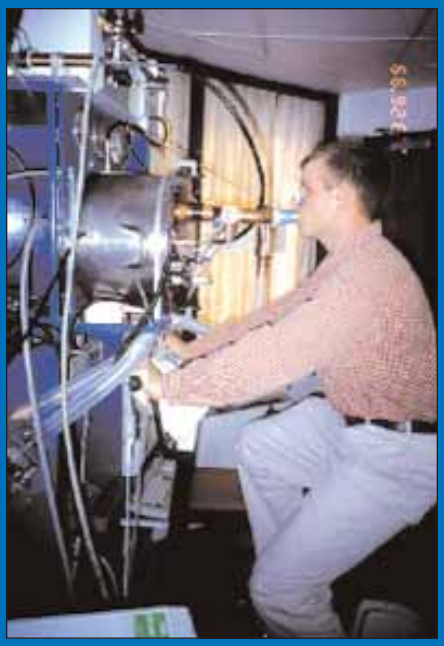

The ultrafine particle exposure system incorporated a bicycle to examine the effects of UFP exposure during exercise.

Project Status

- Initiated 1999
- Project ongoing

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Public Service Commission — NYSERDA

Since 1975, the New York State Energy Research and Development Authority (NYSERDA) has developed and implemented innovative products and processes to enhance the State's energy efficiency, economic growth, and environmental protection. One of NYSERDA's key efforts, the Environmental Monitoring, Evaluation, and Protection (EMEP) Program, supports energy-related environmental research. The EMEP Program is funded by a System Benefits Charge (SBC) collected by the State's investor-owned utilities. NYSERDA administers the SBC program under an agreement with the Public Service Commission.

METHODOLOGY

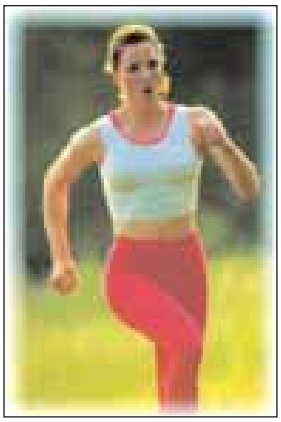
Researchers developed a UFP exposure system and a clinical protocol incorporating measurements of particle deposition that were used in two studies on UFP inhalation. Each involved 12 subjects with healthy, normal lung function. In the first study, subjects at rest were exposed to 10 micrograms per cubic meter (μg/m³) UFP and filtered air for two hours. In the second, each subject underwent three exposures of air, 10 μg/m³, and 25 μg/ m³ of carbon UFPs for two hours, with intermittent exercise on a bicycle ergometer.

In the exposures, ultrafine carbon particles were generated and diluted with filtered air, breathed by the subjects through a mouthpiece, then passed though one-way rebreathing valves. Exhaled particles and excess aerosol were removed through the exhaust system. Different exposure factors were monitored in real time through the mouthpiece exposure system. Particle mass concentrations, number concentrations, size distributions, and system losses were determined. UFP deposition in the study subjects was measured by calculating the number of particles going in through the mouthpiece and the number coming out.

RECENT FINDINGS

The studies show that UFP inhalation by healthy subjects has a number of cardiovascular, rather than pulmonary, effects to which women may be more susceptible. These may be persistent or delayed, lasting for at least 21 hours after exposure. The project found:

- A statistically significant decrease in blood oxygen saturation in females after exposure to 25 μg/m³ UFPs.
- No significant physiological changes in response to breathing 10 μg/m³ UFPs at rest. Also, no evidence for airway inflammation or irritant effects or an early immune system response at 10 μg/m3 or 25 μg/m³ with intermittent exercise.
- Signs of alterations in cardiac repolarization (QT interval). The change observed during exercise was more pronounced with UFP exposure than with pure air, and remained in effect for several hours after UFP exposure, but not after pure air exposure. While the changes are small, they could affect heart function in people with severe cardiac disease.
- A high pulmonary deposition rate that increased with exercise. As expected, the smallest particles had the highest deposition rate. No gender difference was found in terms of deposition.
- A number of effects on circulating leukocytes, such as a reduction in the percentage of blood monocytes in females that was greatest 21 hours after exposure.
- Effects consistent with changes in blood vessel walls and how leukocytes move through the blood vessels.



Credit: Atlanta Urogynecology Associates ©2000-2002

Responses to UFP inhalation were seen only during exercise, with women being more responsive than men.

PROJECT IMPLICATIONS

While the particles generated for these studies from elemental carbon are relatively inert compared to UFPs in ambient air, this research suggests that exposure to even these relatively benign particles at very low mass concentrations during exercise has subclinical effects on blood flow to the lungs, circulating leukocytes, and cardiac repolarization in healthy subjects (particularly females). If these findings are confirmed, they will provide convincing support for current hypotheses about the health threats posed by UFPs. The project team is presently conducting a new study that aims both to confirm previous findings and to assess the effects of 50 μg/m³ UFP exposures with intermittent exercise.

The adverse health effects of UFPs raise the question of whether mass-based NAAQS are adequately protective of human health. While current $PM_{2.5}$ standards address mass concentrations of particulate matter in ambient air, a small mass concentration of particulate matter can mean very high number concentrations of UFPs. The results of further assessments of the cardiovascular and pulmonary effects of UFPs may necessitate reconsideration of the regulatory regime for $PM_{2.5}$.