April 2003

Science & Technology REVIEW

National Nuclear Security Administration's
Lawrence Livermore National Laboratory

Aerosols and Our Changing Climate

Also in this issue:

- Tracking Neutrino Transformation
- Toward a Supercomputing Data Model
- Visualizing Secondary Hydrodynamic Instability

About the Cover

The puzzle of global climate change and the part human activity plays in it is far from solved. Beginning on p. 4 is a report on one part of the climate change picture that is being put together at Livermore—the effects of atmospheric aerosols resulting from human activity. Environmental researchers are using the Laboratory's advanced supercomputing capabilities to simulate the effect of aerosols on our planet's climate.

Cover design: Kitty Madison

About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy's National Nuclear Security Administration. At Livermore, we focus science and technology on assuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published 10 times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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April 2003

Lawrence Livermore National Laboratory

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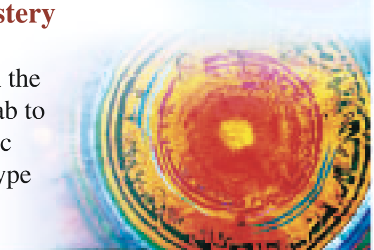

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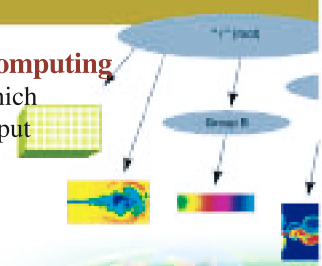

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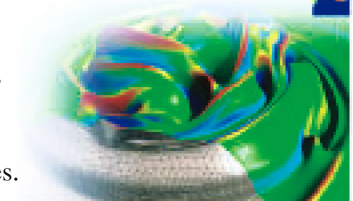

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HOPS heads off terrorism

Laboratory researchers have developed a new analysis tool to assist government agencies in preventing and mitigating terrorist attacks. The Homeland Operations Planning System, or HOPS, is a Web-based information system that models buildings, stadiums, convention centers, landmarks, and other potential terrorist targets.

HOPS can assist federal, state, and local agencies in making an inventory of high-value infrastructure such as key buildings, bridges, and convention halls; developing vulnerability assessments; and preparing emergency response plans. Using HOPS, security planners can examine overviews of a facility, including its location and proximity to hospitals, transportation systems, and fire stations. Interior views of facilities can provide information on the functioning of the building itself—for example, entrance and exit locations or power and water sources.

HOPS also contains an information inventory of more than 1,000 toxic substances and provides details about how the substances affect people, treatment methods, and cleanup. With HOPS and modeling technology from Livermore's National Atmospheric Release Advisory Center, government officials can access assessments of chemical, biological, or radiological attacks on laptop computers. The assessments, requested from anywhere nationwide about any U.S. location, can be displayed in less than 10 minutes on computer-generated maps.

Recently, HOPS assisted the Los Angeles Country Sheriff's Department in planning for the Democratic National Convention, supported the California National Guard's security efforts during the 2002 World Series, and was part of a California National Guard exercise in the San Francisco Bay Area in September 2002.

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Constructing an artificial retina

Lawrence Livermore's Center for Microtechnology is a key contributor to a Department of Energy project to construct an epiretinal prosthesis, or artificial retina. This device could restore vision to millions of people suffering from eye diseases such as retinitis pigmentosa and macular degeneration or who are legally blind because of loss of photoreceptor function.

This three-year project brings together Oak Ridge National Laboratory (the project lead) with Livermore, Argonne, Sandia, and Los Alamos national laboratories; North Carolina State University; the Doheny Eye Institute at the University of Southern California; and a private company, Second Sight LLC.

The project has called on Lawrence Livermore's Center for Microtechnology to develop a flexible microelectrode array that can conform to the curved shape of the retina without damaging delicate retinal tissue.

According to Peter Krulevitch, leader of the Livermore team developing the flexible array, the Center for Microtechnology was selected because of Livermore's pioneering use of poly(dimethylsiloxane), or PDMS, in fabricating hybrid integrated microsystems for biomedical applications. In particular, Livermore has worked on "metalization"—applying metals for electronics and electrodes to PDMS for implant devices. PDMS-based electronics are flexible, robust enough to withstand damage from the implant procedure, and compatible with human biology.

Says Krulevitch, "We've developed a technique for fabricating metal lines that can be stretched. This is really critical for a flexible device designed to conform to the shape of the retina."

Following up on successful tests with devices based on first-generation Livermore arrays, Livermore engineers are now working on a second-generation microelectrode array with smaller electrodes in greater numbers. They are developing techniques to integrate the electrodes with electronics chips and are also working on strengthening and stabilizing the array.

Krulevitch predicts additional applications for the flexible electrode array, including a cochlear implant for hearing, deep brain stimulation devices for treating diseases such as Parkinson's, and a spinal cord stimulation device for treating chronic pain.

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Aging effects on male fertility

A recent study by biomedical researchers at Livermore and the University of California at Berkeley concludes that healthy adult males become progressively less fertile as they age. Published in February in *Human Reproduction*, the study is one of the first to focus on men with no known fertility concerns. Its goal is to provide researchers and health professionals with a better sense of how aging affects semen quality in a healthy male population.

The researchers recruited 97 men between 22 and 80 years old, all employees or retirees of Lawrence Livermore who had not smoked within 6 months of the study and had no relevant health problems. They found that while age had affected semen volume, the more significant effect was on sperm motility, defined both as "liveliness" and as progressive motility, or the ability of sperm to move forward linearly. The researchers found that motility decreased by 0.7 percent per year.

"Simply put, sperm slow down with age," says Andrew Wyrobek, head of the Health Effects Genetics Division at Livermore and coauthor of the study. Gradually, beginning in men in their 20s, increasing numbers of sperm (3.1 percent per year) begin to swim around in circles and not move in a linear direction toward collision with the female egg.

The researchers found that unlike the female "biological clock," which shows a marked decline in fertility in a woman in her mid-30s, the male clock winds down gradually.

Commenting on the larger significance of this study, the authors said that the results mean that men as well as women need to consider fertility issues. Their study results indicate that men who wait until they are older to have children are risking difficulties conceiving.

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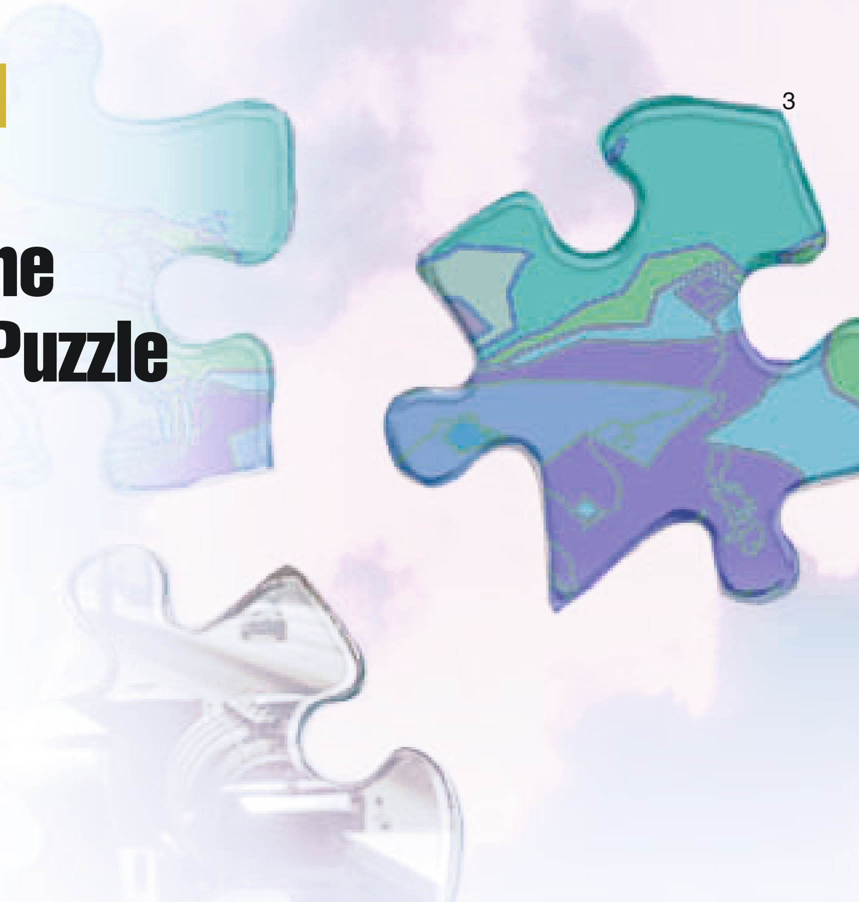
Aerosols and the Global Climate Puzzle



LAWRENCE Livermore has long been among the leaders in using the most powerful computers available to simulate the global changes in climate. As described in the article beginning on p. 4, a key factor in global climate change is aerosols, which are microscopic particles suspended in the clear sky and in clouds. Increasingly, scientists are studying aerosols to help explain our complex climate patterns. The most recent Livermore simulations show that rising concentrations of aerosols in the atmosphere may be cooling the planet and thus partially counteracting the effects from the steady accumulation of greenhouse gases.

The Laboratory's first aerosol simulations date back to the late 1980s, when researchers conducted studies of so-called nuclear winter. These studies simulated the climatic effects of large injections of smoke particles high into the atmosphere, which would likely follow a large-scale nuclear war.

Every day, different aerosols enter the atmosphere through natural processes, including dust storms and sea salt spray. Many other kinds, however, are produced by human activities such as the burning of fossil fuels and biomass. Understanding the geographic distribution of aerosols produced by human activities and their distribution within the atmosphere by particle size is crucial to understanding climate change.

The Department of Energy is interested in aerosols because of their effects on climate. Their influence on clouds is especially significant, which is why cloud–aerosol interplay is an important aspect of DOE-sponsored climate change research.

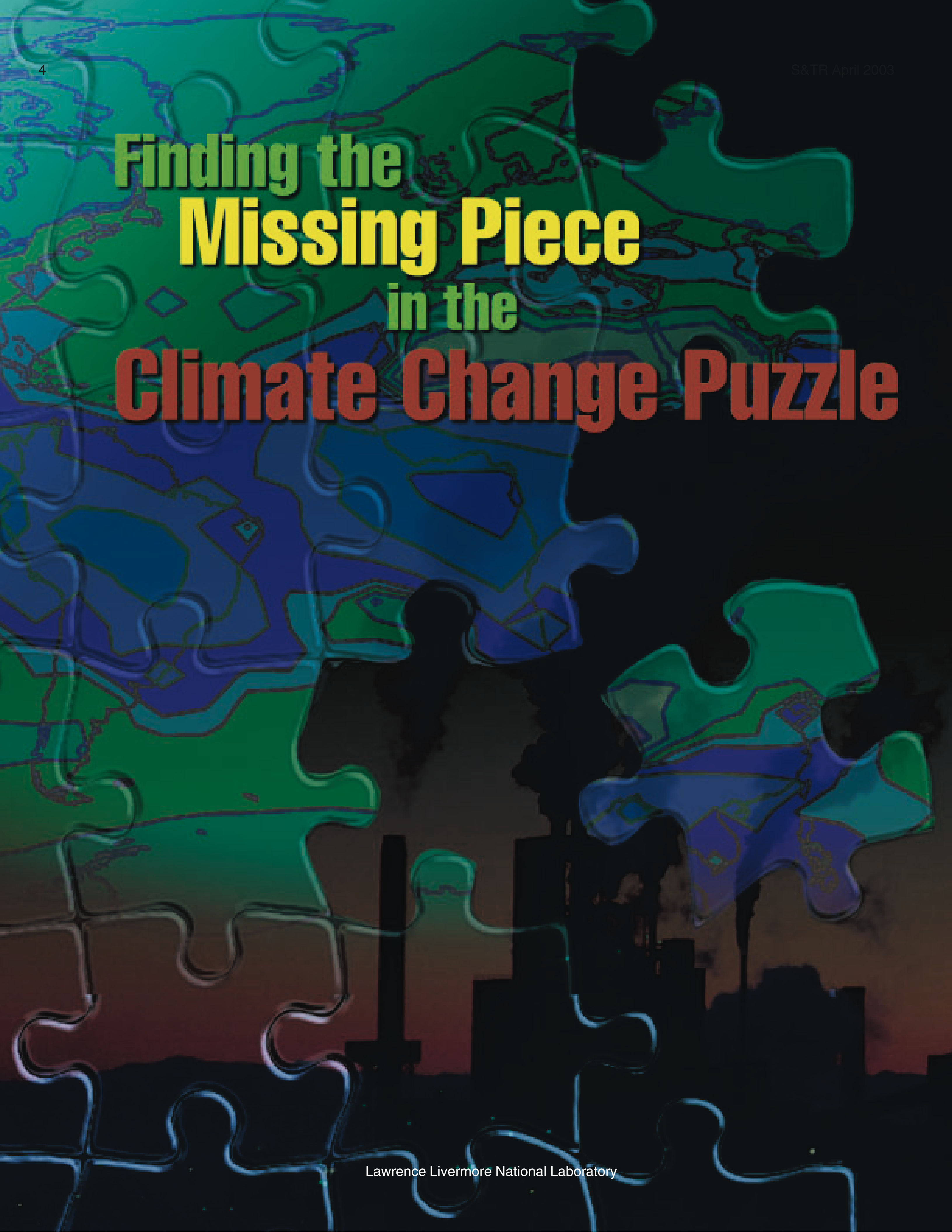
DOE also sponsors aerosol research because regulators must keep aerosols in mind when formulating energy policy. For example, regulators have placed restrictions on diesel emissions because they produce aerosols that, in high concentrations, can be harmful to people. In this respect, aerosols are important to air quality and human health. Aerosols composed of small particles, such as soot and sulfur dioxide, can lodge deep within our lungs and cause respiratory ailments.

Some forms of aerosols may also be involved in the carbon cycle and the ocean's ability to absorb carbon. The carbon cycle is the flow of carbon compounds between the biosphere, atmosphere, and oceans. When dust aerosols containing iron, for example, are deposited in the ocean, this iron can help accelerate natural oceanic processes that take up carbon from the atmosphere.

An important mission of the Energy and Environment Directorate is studying the link between energy production (and the fuels used in this production) and the resulting environmental consequences. Aerosols play an important role linking such diverse processes as energy production, air quality, atmospheric chemistry, climate change, human health, and possibly, the carbon cycle.

Simulating these processes, many of which are incompletely understood, and validating the simulation results require enormous amounts of data and the most powerful supercomputers. The Laboratory has long excelled in using supercomputers for understanding complex physical systems. Livermore's Energy and Environment Directorate is applying its modeling expertise and Lawrence Livermore's computing platforms to further understanding of aerosols and their relationship to energy, the environment, and human health.

■ C. K. Chou is associate director for Energy and Environment.



Finding the Missing Piece in the Climate Change Puzzle

Computer models reveal the significant effects of aerosols resulting from human activity.

ONE of the most controversial scientific issues is determining the causes of the gradual warming of Earth's atmosphere over the past century, especially the last 50 years. Lawrence Livermore scientists have been among the leaders in modeling global climate change to better understand the nature of the warming, to predict the probable climate in the coming decades, and to determine the role of anthropogenic (human) activity in climate change.

Until recently, the most important factor in global climate change appeared to be the steady accumulation of greenhouse gases, mainly produced by the burning of fossil fuels in cars, factories, and power plants. These greenhouse gases, such as carbon dioxide and methane, are known to trap sunlight and thereby warm the atmosphere.

Close observations of global temperature records over the past 50 years have shown less global warming than predicted by computer models that include only accumulations of greenhouse gases. The explanation for this apparent discrepancy is that increasing concentrations of anthropogenic aerosols in the atmosphere may be cooling the planet and so partially counteracting the effects from the greenhouse gases.

In the past 10 to 15 years, scientists have also begun to consider how aerosols, microscopic particles directly suspended in the atmosphere or trapped in clouds, may be changing the planet's climate. Beginning in the early 1990s, calculations showed that aerosols composed of sulfates (a form of sulfuric acid and a main component of air pollution) could be cooling the atmosphere by backscattering incoming solar radiation. The process works in much the same manner as volcanic eruptions, which spew many tons of sulfates into the higher atmosphere that eventually result in the cooling of Earth's climate. (See the box on pp. 10–11.)

Spotlight on Aerosols

In the past few years, intriguing data from ground stations and satellites, together with insight gained from computer models, have made aerosols a major focus of atmospheric research. "Ten years ago, the focus was on greenhouse gases. Now aerosols are getting the attention," says Livermore atmospheric scientist Catherine Chuang.

Chuang notes, however, that large variations in aerosol concentrations have made it difficult to confidently assess the magnitude of their effects on climate. Aerosol chemistry and physics, especially in clouds, are complex and not completely understood. Particles typically remain aloft in the troposphere (lower atmosphere) for a week or less, in contrast to greenhouse gases, which can persist for about a century.

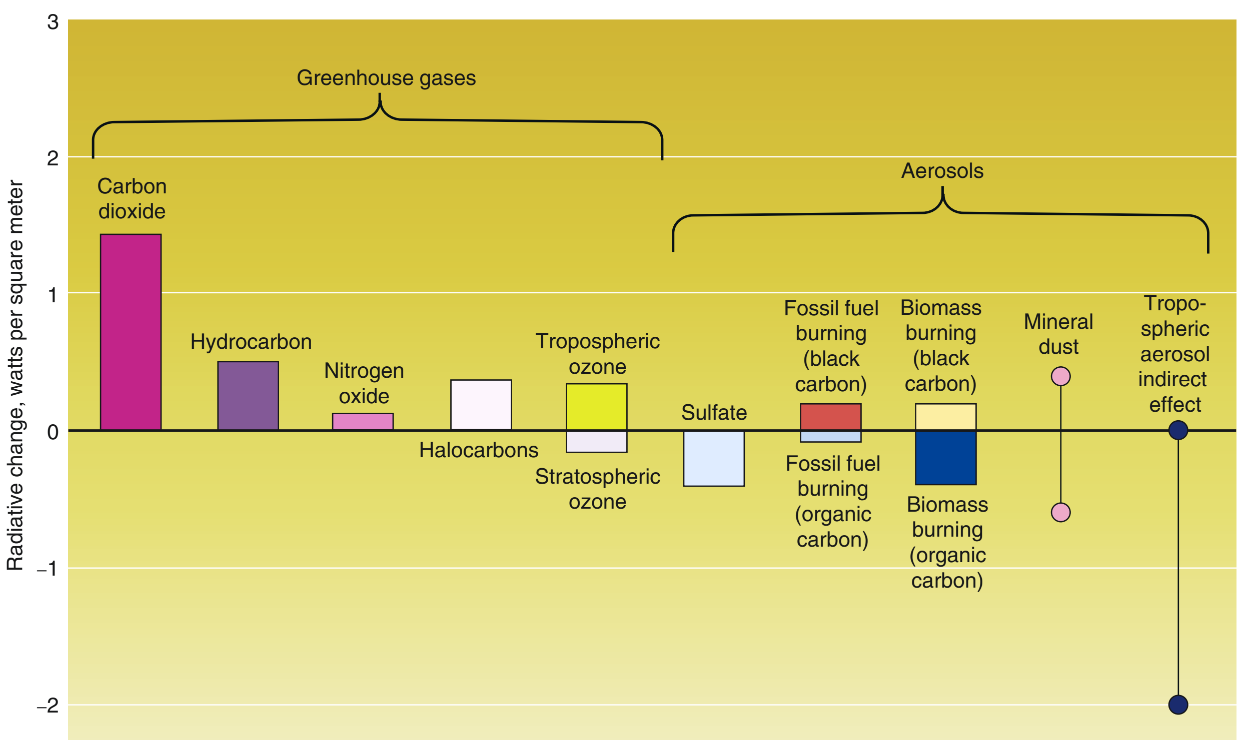
Because they are short-lived, aerosols do not mix homogeneously around the planet's atmosphere, and so concentrations differ greatly from one region to the next. What's more, aerosols come in a wide range of

particle sizes, with particles smaller than a micrometer exerting comparatively greater climatic effects. As a result, says Chuang, one of the greatest uncertainties in climatic change is the role played by anthropogenic aerosols. To reduce these uncertainties, scientists are turning to sophisticated computer simulations in an attempt to gain insight into aerosols' climatic effects.

During the past few years, Chuang and colleagues including Joyce Penner (now at the University of Michigan), Keith Grant, Jane Dignon, Peter Connell, Daniel Bergman, and Douglas Rotman have used Livermore's TeraCluster2000 multiparallel supercomputer and the resources of the National Energy Research Scientific Computing Center at Lawrence Berkeley National Laboratory to model how anthropogenic aerosols affect global and regional climate. The researchers' simulations show in unprecedented detail how aerosols are partially offsetting the effect of global warming and changing the properties of clouds. In some industrial regions, the generation of aerosols from fossil fuel combustion and biomass (forest and grassland) burning may be as important to climate change as greenhouse gases. Also, climate changes caused by aerosols vary significantly by season and by region.

The research team belongs to the Atmospheric Chemistry and Aerosols Group, part of the Atmospheric Science Division of Livermore's Energy and Environment Directorate. The team's advanced simulations, whose findings have been corroborated by field measurements at different geographical locations, build on Livermore's expertise in aerosols, climate, chemistry, and supercomputer simulations. The research has received funding from the Department of Energy, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, and Laboratory Directed Research and Development. The work also contributes to fulfilling the goals of the federal government's National Aerosol Climate Interactions Program, an interagency effort created last year.

Chuang explains that aerosol concentrations from natural sources, such as volcanoes, sea spray, and desert dust storms, are believed to have remained generally steady over the past century. However, like greenhouse gases, anthropogenic aerosols have increased markedly since 1950. Based on satellite data, models, and information on urban and agricultural activities, scientists



Global climate change by greenhouse gases and aerosols since 1750. Factors above zero have a warming effect; those below zero have a cooling effect. A vertical line between two data points indicates scientific uncertainty regarding the estimated contribution of a particular factor.

believe anthropogenic aerosols currently contribute about half of the total submicrometer-size aerosols in the atmosphere. Most of the anthropogenic aerosols are sulfates and carbonaceous compounds produced by the burning of fossil fuels and biomass.

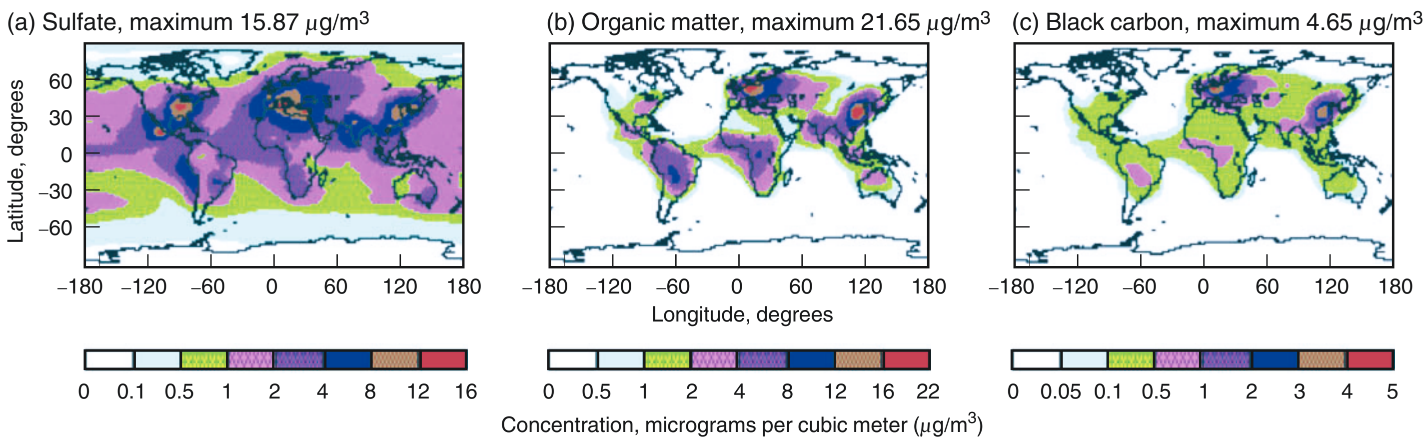
Solar Reflection Means Cooling

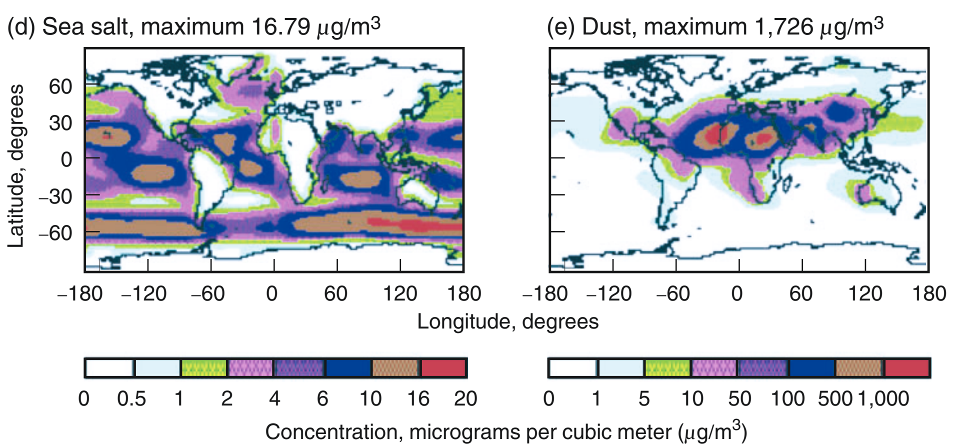
When directly suspended in the atmosphere, most aerosol particles exert a direct cooling effect on the global climate by scattering sunlight back into space. Aerosols also exert a significant indirect effect by serving as cloud condensation nuclei (CCN) for raindrops to form. Increases in CCN result in clouds with more but smaller droplets, thereby increasing the cloud's reflectivity of solar radiation, or albedo. Clouds with numerous small droplets tend to last longer and so prolong the cooling effect.

Complicating matters is the recently discovered influence of black carbon aerosols, such as soot (incompletely burned carbon), that absorb heat instead of reflecting it back into space. Black carbon aerosols are particularly prevalent over parts of Europe, eastern China, and India, where much coal is burned.

Beginning in the early 1990s, Chuang focused first on modeling the direct effects of anthropogenic sulfate aerosols because they were thought to be the most important compound involved in pollution over China, Europe, and the eastern coast of the United States. She then added the contribution from carbonaceous compounds because of their sizable emission from many industrialized regions of the Northern Hemisphere and tropical regions where agricultural burning is prevalent. The simulations also took into account the solar absorptive properties of black carbon, the first time this effect had been modeled.

The simulations showed that biomass aerosols suspended in the clear sky cool the climate by between 0.16 and 0.23 watts per square meter, while black carbon from fossil fuels heats the climate by between 0.16 and 0.20 watts per square meter. Also, sulfate aerosols cool the atmosphere by between 0.53 to 0.81 watts per square meter. The sum of the cooling effects ranges between 0.35 and 0.65 watts per square meter. (To place these figures in perspective, about 340 watts per square meter of





Aerosols vary greatly from region to region. These are predicted annual surface concentrations of aerosols (natural and anthropogenic) composed of (a) sulfate, (b) organic carbon (in terms of organic matter), (c) black carbon from soot, (d) sea salt, and (e) dust particles. The red areas indicate maximum concentrations of each type of aerosol.

solar radiation reaches Earth's atmosphere daily.)

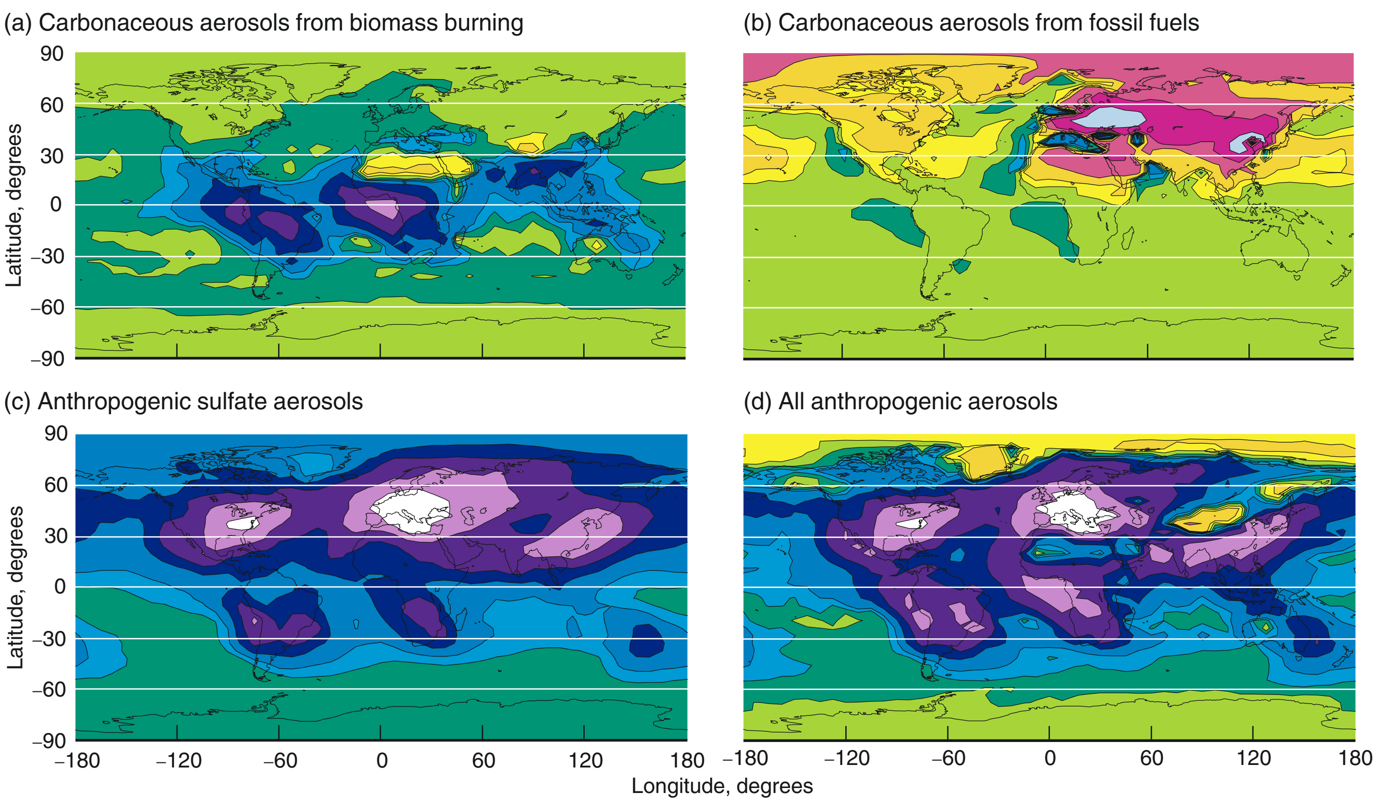
Chuang's research then moved to the vastly more complex task of modeling the indirect effects of anthropogenic sulfate and carbonaceous aerosols through their interaction with clouds. These simulations indicated that the indirect effects of aerosols are greater than the direct effects. The simulations also showed that aerosols can mask the warming effects of greenhouse gases, at least in regions with high pollution levels.

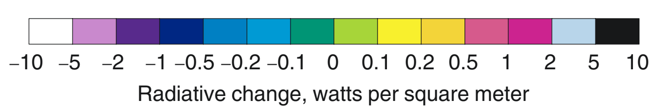
Aerosol–Cloud Interactions

The simulations estimated that aerosols acting as CCN cool Earth by about 1.85 watts per square meter, with 0.30 watts per square meter associated with anthropogenic sulfate, 1.16 watts per square meter associated with carbonaceous aerosols from biomass burning, and 0.52 watts per square meter associated with carbonaceous aerosols from fossil fuel combustion. While concentrations of anthropogenic carbonaceous aerosols are about equal in the Northern and Southern hemispheres, aerosols of anthropogenic sulfates are more prominent in the Northern Hemisphere.

Also, the simulations showed that concentrations of aerosols vary with the seasons. The global average of indirect effects by anthropogenic aerosols is greatest in April through June, a period when biomass of savanna and forested areas is burned in the topics. The indirect cooling effect is highest in May, with 2.4 watts per square meter.

Chuang also addressed how black carbon absorption affects solar energy in clouds. She found that including this absorption does not decrease the overall cooling effect by more than 0.07 watts per square meter on a global scale, but that locally, it can decrease the cooling effect by as much as 0.7 watts per square meter in regions that have significant black carbon emissions. The model shows that if the effect of black carbon absorption in clouds is not included, the indirect cooling effect by carbonaceous aerosols may be overestimated by up to

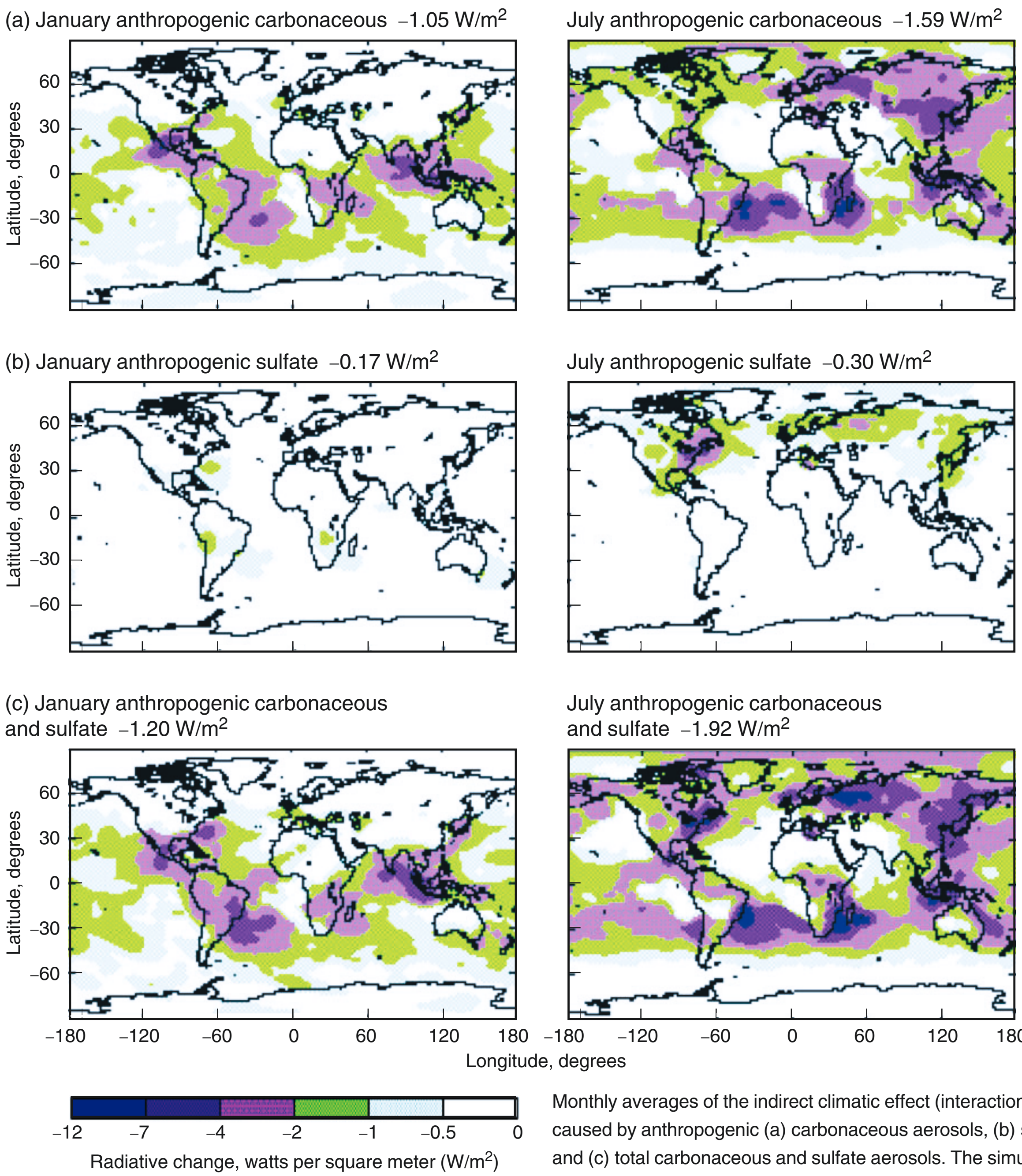




Simulations show the direct (that is, without interactions with clouds) climate effects of (a) carbonaceous aerosols from biomass burning, (b) carbonaceous aerosols from fossil fuel burning, (c) anthropogenic sulfate aerosols, and (d) all anthropogenic sources. Note that both the fossil fuel and biomass burning release sulfur dioxide, which later oxidates to sulfate.

25 percent in regions where black carbon emissions are significant.

The Livermore assessments were based on a three-dimensional general circulation model called Community Climate Model-1 (CCM-1), which was developed by the National Center for Atmospheric Research in Boulder, Colorado. General circulation models predict global changes that result from changing concentration of gases by dividing the global atmosphere into tens of thousands of boxes and using the equations describing motion, energy, and mass to predict the changes in climate. Chuang linked CCM-1 to GRANTOUR, a three-dimensional global chemistry code for the



Monthly averages of the indirect climatic effect (interactions with clouds) caused by anthropogenic (a) carbonaceous aerosols, (b) sulfate aerosols, and (c) total carbonaceous and sulfate aerosols. The simulations show the wide variation between January and July.

troposphere, which was first developed at Livermore in the late 1980s to simulate the concentration and distribution of aerosols and their gaseous precursors.

"Both GRANTOUR and CCM-1 were developed more than a decade ago," notes Chuang. "They lack advanced physics and modeling techniques that prevent us from exploring in greater detail the interrelationship between aerosols, clouds, and climate variation. We believe this interrelationship is the leading source of uncertainty in predicting future climate change."

New Era of Modeling

The research team's goal is to move to what Chuang describes as a "new era of modeling" that will link the most advanced atmospheric chemistry and climate codes. To that end, last year Chuang and her colleagues added improvements to Livermore's integrated, massively parallel atmospheric chemical transport (IMPACT) code so that it better represents aerosol chemistry and runs faster on multiparallel supercomputers. IMPACT, which was previously applied by Livermore researchers to global ozone calculations, includes both the stratosphere and troposphere and uses databases of monthly averaged emissions compiled by scientists and government agencies worldwide to treat global chemistry processes.

Aerosols: A Short Primer

Aerosols are concentrations of exceedingly minute particles suspended in the atmosphere. Aerosol particles range in size from 0.01 micrometer (millionth of a meter) to several tens of micrometers in diameter. Particles generated by pollution tend to be less than a millimeter in diameter.

The particles enter the atmosphere from many different natural and anthropogenic (human activity–related) sources. For example, nature generates sulfate aerosols from volcanoes, salt aerosols from sea spray, dust aerosols from desert areas, and carbonaceous aerosols formed from volatile organic compounds emitted by plants.

A growing fraction of aerosols are byproducts of human activities, as seen in the ubiquitous hazes that persist in the industrialized regions of the world. Anthropogenic aerosols include sulfuric acid, soot and smoke from the burning of fossil fuels in factories, vehicles, power plants, cookstoves, and fireplaces. The burning of forests and grasslands to clear them for farming is another source of carbonaceous aerosols. (Although dust is typically considered a natural source of aerosols, human activities such as farming or erosion caused by changing land use also kick large amounts of dust into the atmosphere.)

Aerosols have a significant effect on climate. Whereas greenhouse gases trap the Sun's heat, thereby warming Earth's atmosphere and surface, aerosols mainly reflect solar radiation, a phenomenon called the aerosol direct effect. By reducing the amount of solar energy reaching the Earth's surface, aerosols serve as agents of climate cooling.

Aerosols also cool the climate indirectly, by changing the properties of clouds, which cool Earth by reflecting solar radiation back to space. (Of the daily average of about 340 watts per square meter of solar radiation that reaches the atmosphere, clouds reflect about 45 watts per square meter.) Although commonly thought of as pristine sources of water, clouds could not form without aerosol particles (natural or anthropogenic) acting as cloud condensation nuclei, which are sites on which water droplets can condense.

Reflecting Sunlight, Modifying Rainfall

Higher concentrations of aerosols in the atmosphere lead to the formation of clouds with water content spread over many more particles. Clouds with smaller, more numerous droplets have a larger surface area and therefore reflect up to 30 percent more sunlight, a phenomenon called aerosols' first indirect effect. What's more, the smaller water droplets in the cloud fall more slowly, thereby prolonging the lifespan of the cloud and strengthening its cooling effect. This second indirect effect is believed to be changing rainfall patterns in populated regions worldwide.

Complicating the scientific understanding of aerosols' climatic effects are recent satellite observations revealing that aerosols of black carbon from biomass and fossil fuel burning can absorb sunlight in the atmosphere, thereby increasing the warming effect of greenhouse gases. Satellite observations have also revealed that the absorption of heat by soot can evaporate cloud droplets and thus reduce the presence of clouds. This phenomenon, called the aerosol semidirect effect, is particularly prevalent over heavily polluted areas.

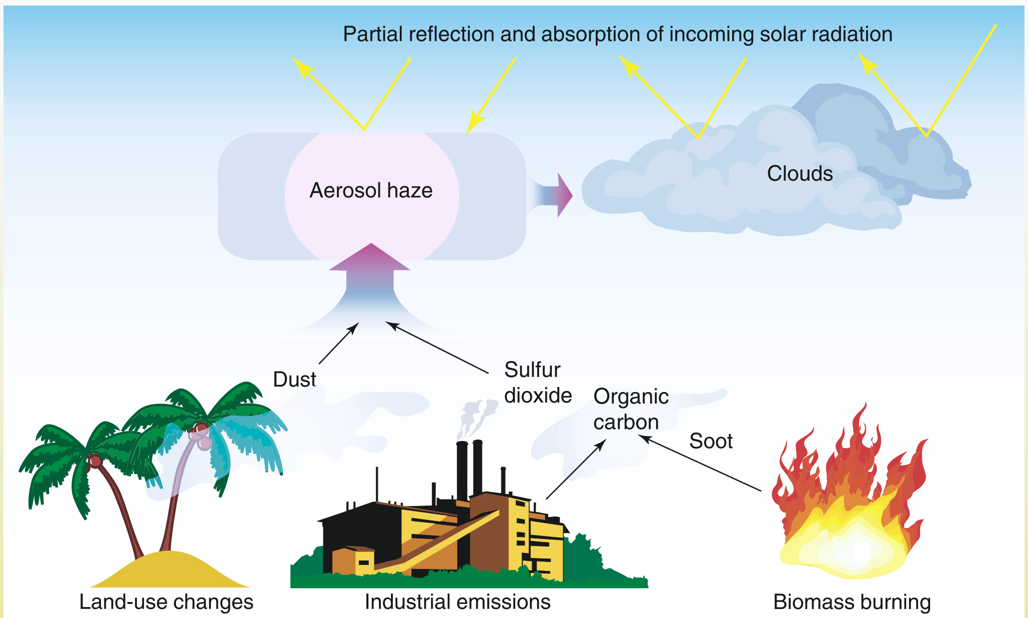
Taken together, all of the direct and indirect effects of aerosols are believed to increase Earth's albedo (percentage of sunlight reflected), thereby cooling the surface and offsetting the warming effects of greenhouse gases by 25 to 50 percent globally (and even much more in some areas).

However, aerosols' climatic effects cannot be simply compared to those of greenhouse gases because they are distributed in time and space far differently. For example, greenhouse gases are well mixed in the atmosphere and have a lifetime of up to 100 years. In contrast, aerosols suspended in the troposphere (lower atmosphere) last only about a week before they are removed by winds and rain. (The exception is the injection of sulfates into the stratosphere, or upper atmosphere, where they can remain for a few years. The global cooling observed following large volcanic eruptions, such as

With the recent revisions, IMPACT can simulate the complicated reactions involving sulfate aerosols that are formed from sulfur dioxide generated by power plants and biomass burning. The code can also account for other sources of sulfates, including the production of dimethylsulfide by plankton, sulfur dioxide by volcanoes, and hydrogen sulfide by soils, forests, and crops. The new version of IMPACT also predicts the concentrations of black carbon and other carbonaceous compounds, dust, and sea salt as well as their seasonal variations.

To better represent the ever-changing size distribution of aerosol particles, Chuang is adapting an aerosol microphysics module developed at Brookhaven National Laboratory. The module simulates aerosol dynamics through complicated nucleation, growth, and transport processes by tracking the lower order moments of an aerosol size distribution in space and time.

Chuang plans to link IMPACT and the new microphysics module with the Community Climate Model-3, or CCM-3, the fourth-generation model developed by the National Center for Atmospheric Research. This climate model allows more realistic and higher resolution simulations of aerosol effects on regional climate. For example, it can show how aerosols are transported to different regions by strong winds and removed by rainfall.



Clouds could not form without aerosol particles (natural or anthropogenic) acting as cloud condensation nuclei or sites on which water droplets can condense. Anthropogenic emissions increase aerosol concentrations and result in clouds with smaller and more numerous droplets. These clouds have a larger albedo (percentage of reflected sunlight) and a longer lifetime, and thus they reflect more sunlight back into space.

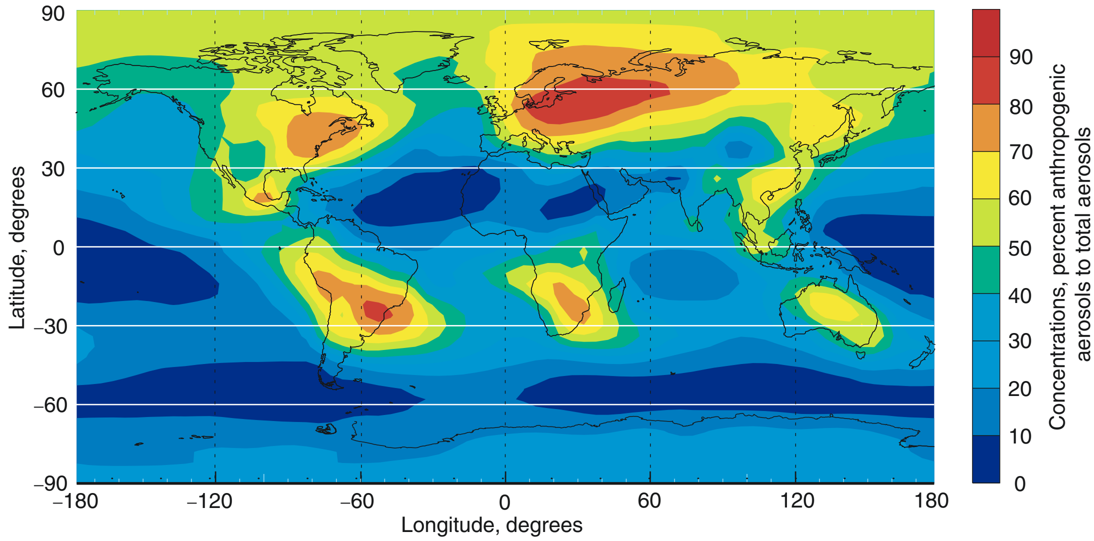
that of Mount Pinatubo in the Philippines in 1991, provides dramatic evidence for the climatic influence of aerosols.)

Also, many anthropogenic aerosols are localized and occur near or downwind from their sources, such as power plants, factories, and large urban populations. As a result, most aerosols are found in the Northern Hemisphere, where most industrialized nations are located.

Instrument Data, Models Aid Understanding

To accurately study aerosol distribution and composition requires continuous observations from instruments located on satellites and aircraft as well as ground-based field stations. Data from these instruments, combined with numerical models that mimic the formation of aerosols and their interactions with clouds, have led to a much greater understanding of how and to what degree aerosols influence climate. Lawrence Livermore scientists have been among the leaders in developing these models.

Aerosol research marked a turning point in January 2002, when more than 50 leading American atmospheric scientists (including Livermore's Catherine Chuang), together with representatives from federal agencies, met to explore ways to achieve breakthroughs in understanding and modeling aerosols' role in climate change. The meeting led to the formation of a national Aerosol Climate Interactions Program supported by several federal agencies. The program's goals are to more accurately measure the sources, distribution, and properties of aerosols and their influence on climate; to more completely model the processes that govern aerosols' distributions and climatic effects; and to better quantify the relative importance of aerosols and greenhouse gases in global warming, including the effects on regional climates.



This simulation, using IMPACT, shows the percentage of concentrations (averaged on an annual basis) from all anthropogenic sources of aerosols.

Chuang notes that CCM-3 is typically used by research centers at 300-kilometer resolution. Such coarse resolution limits the code's usefulness because it does not adequately represent topographic features that strongly influence surface temperature and precipitation. Much finer resolutions are required to examine regional climate change and the transport of aerosols through the atmosphere. Chuang notes that a Livermore team headed by Philip Duffy has simulated the effects of increased greenhouse gases by using CCM-3 at 50-kilometer resolution to obtain the finest resolution of global warming performed to date. (See *S&TR*, July/August 2002, pp. 4–12.)

Putting Everything Together

With all the modeling elements in place, Livermore atmospheric scientists will be able to simulate early next year the global and regional climate changes caused by both aerosols and major greenhouse gases. "With more complete chemistry and physics in our models, we hope to have more accurate answers about how human activities are affecting our climate," Chuang says.

Ultimately, she says, realistic climate models—augmented by other data—provide the only viable approach for determining how aerosols are changing the planet's climate and for assessing the effects of future emissions. "Models are the only tools for making predictions about climate change so that we can help policymakers arrive at the most informed decisions for responding to changes in the environment."

She notes that at first glance, it might seem that aerosols are a positive element because they tend to counter the effects of global warming. However, purposely allowing a greater buildup of aerosols to offset global warming would lead to greater health and ecological damage. Aerosols that affect climate are associated with air pollution and acid rain, lower visibility, and decreased agricultural production.

The results from the advanced Livermore simulations will surely help society as it decides to manage air pollution, global warming, changing rainfall patterns, and the unavoidable effects on human health and society.

—*Arnie Heller*

Key Words: aerosols, biomass, black carbon, cloud condensation nuclei (CCN), Community Climate Model (CCM), dimethylsulfide, global warming, GRANTOUR, IMPACT, National Center for Atmospheric Research, soot, sulfate.

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An Elusive Transformation

The Mystery of Oscillating Neutrinos

An experiment to determine whether one type of neutrino spontaneously transforms into another type will improve understanding of particle physics and the forces that guide the universe.

NEUTRINOS are enigmas in the world of particle physics. Cosmically created in stars and supernovas, produced by cosmic rays colliding with the Earth's upper atmosphere, and unleashed in nuclear reactors and in the detonation of nuclear weapons, neutrinos are one of the most pervasive forms of matter in the universe. They are also elusive and difficult to detect. Unlike other particles in the pantheon of particle physics, neutrinos almost never interact with other forms of matter. These chargeless, seemingly massless particles stream through space, planets, and solid walls, leaving nary a trace.

Even as scientists invent ways to measure the occasional rare interaction as a means of studying neutrinos, the mystery surrounding these elusive particles intensifies. For instance, scientists now know that three types of neutrinos exist—the electron neutrino, the muon neutrino, and the tau neutrino, which are related, respectively, to the common electron and the less common muon and tau particles. The fusion process—the process that powers our Sun—produces electron neutrinos, and scientists have calculated how many electron neutrinos should arrive on Earth. But more than two decades of experiments have found less than half the predicted number. The same conundrum appears with the neutrinos produced by cosmic rays. Theory says that twice as many muon neutrinos should exist at ground level as electron neutrinos because of the interaction of cosmic rays with the upper atmosphere. But experiments find muon and electron neutrinos in about equal measure.

So where are the missing neutrinos?

Neutrinos, they are very small.
They have no charge and have no mass
And do not interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids down a drafty hall
Or photons through a sheet of glass.
They snub the most exquisite gas,
Ignore the most substantial wall, . . .

—From John Updike's "Cosmic Gall," which originally appeared in **The New Yorker** *and was published in* **Telephone Poles and Other Poems** *(Knopf: 1960, 1988).*

In the late 1950s, physicists first suggested that neutrinos might be able to transform from one type to another. If true, this transformation would explain the "missing" particles. Even more importantly, these oscillations would prove that neutrinos are not massless—as originally theorized in the 1930s by physicist Wolfgang Pauli and declaimed in 1960 by writer John Updike—but "weigh" something after all, albeit very little. (See the box below.) If the electron neutrino has a mass, it would be less than one-hundred-thousandth that of the electron.

If these subatomic particles do indeed have mass—and more and more evidence seems to point in that direction—that fact will have vast implications for understanding cosmology and for the prevailing physics theory that describes the elementary particles and forces of the universe.

Since measuring neutrino mass directly is beyond present-day technology, scientists must use indirect methods, such as determining whether neutrino oscillations occur. A team from Lawrence Livermore—including physicists Peter Barnes, Douglas Wright, and Edward Hartouni—are part of an international collaboration of 200 scientists from 26 institutions taking part in an experiment centered at the Fermi National Accelerator Laboratory (Fermilab) to look for neutrino oscillations and begin to understand their particulars. Results from the Main Injector Neutrino Oscillation Search (MINOS) will help illumine the nature of neutrinos and, ultimately, the universe.

MINOS to Shed Light on Mystery

The job of detecting neutrino oscillations is a daunting one. The neutrinos must travel far enough (that is, travel a long enough time at nearly light speed) for a significant portion of them to change into a different neutrino type. The beam of neutrinos must also be intense enough to produce measurable interactions at the detector, because the neutrino beam, like a flashlight beam, will fan out over distance, going from about 30 centimeters wide about 1 kilometer from the source to nearly 1 kilometer wide at a detector over 700 kilometers away. Finally, out of 5 trillion neutrinos a year passing through the detector, only about 9,000 will interact and produce a measurable signal.

The MINOS experiment will use a beam of neutrinos generated at Fermilab,

Pursuing Neutrinos

Neutrinos—those mysterious bits with almost no mass at all—are central to the continuing quest to understand the fundamental structure of matter and the nature of the universe. Researchers have been pursuing and wooing them for over 60 years. In 1930, physicist Wolfgang Pauli postulated a new particle to explain the physics dilemma involving certain radioactive decays in which a neutron transforms into a proton and electron and some energy and angular momentum seem to vanish. Pauli proposed that a particle, later dubbed the neutrino, would carry the missing energy and momentum. To fit the bill, the neutrino had to be a neutral, uncharged particle, have practically no mass, and have almost no interactions with matter. In other words, it would be almost impossible to observe.

More than 20 years later, physicists Frederick Reines and Clyde Cowan used the nuclear reactor at the Department of Energy's Savannah River Plant in South Carolina to find the first direct evidence of Pauli's elusive neutrino. Then in 1957, physicist Bruno Pontecorvo theorized that if different species of neutrinos existed, they might be able to "oscillate," or transform, into each other. In 1962, Brookhaven National Laboratory and Columbia University conducted the first accelerator neutrino experiment, demonstrating the existence of two species: the electron neutrino and the muon neutrino. Just as this mystery was laid to rest, another arose: Electron neutrinos were detected from the Sun for the first time—but in far fewer numbers than predicted by solar models. Other experiments found a deficit of muon neutrinos from the interactions of cosmic rays with atoms in the upper atmosphere. The question became: Where are the missing neutrinos?

If neutrinos have mass, then according to physics theory, they could oscillate, which could explain a great deal—including the missing neutrinos. It could also account for some fraction of dark matter, the 90 percent of the mass of the universe that cannot be seen.

Meanwhile, in 1975, an experiment at the Stanford Linear Accelerator Center provided strong evidence of a third species—the tau neutrino. In 1995, Los Alamos scientists reported results that hinted at the existence of neutrino oscillations, in which muon neutrinos seemed to be oscillating into electron neutrinos. In 1998, physicists from the Super-Kamiokande experiment in Japan presented new data on the deficit in muon neutrinos that should be produced in Earth's atmosphere by cosmic rays. Japanese scientists also found a difference in the type of neutrinos that arrived at their detector from directly overhead compared with those that had passed through an extra 13,000 kilometers of Earth's subsurface to enter the detector underneath. These differences suggested that the distance traveled was a factor in the makeup of neutrinos—an indication that neutrinos oscillate and, therefore, have mass.

In April 2002, the Sudbury Neutrino Observatory in Canada announced results conclusively showing that solar neutrinos (electron neutrinos) oscillate before reaching Earth, thus solving the problem of missing solar neutrinos raised nearly 25 years ago.

In December 2002, KamLAND, an underground neutrino detector in central Japan, produced results indicating that antineutrinos emanating from nearby nuclear reactors were "disappearing." Because antineutrinos are the antimatter counterpart to neutrinos, these results confirm earlier studies suggesting that neutrinos oscillate and have mass.

With MINOS, the Main Injector Neutrino Oscillation Search, the story continues to unfold.

40 miles west of Chicago, one of the few facilities able to generate a beam intense enough for the experiment. Fermilab is constructing a new particle beamline to direct a nearly pure beam of muon neutrinos at a detector deep in a former iron mine in Soudan, Minnesota, 735 kilometers away. "Fermilab will tune the beam to an energy spectrum of 0.5 to 8 gigaelectronvolts," says Barnes, "which, according to calculations, is the energy range that allows the most neutrino oscillations for the distance the beam needs to travel to the 'far' detector."

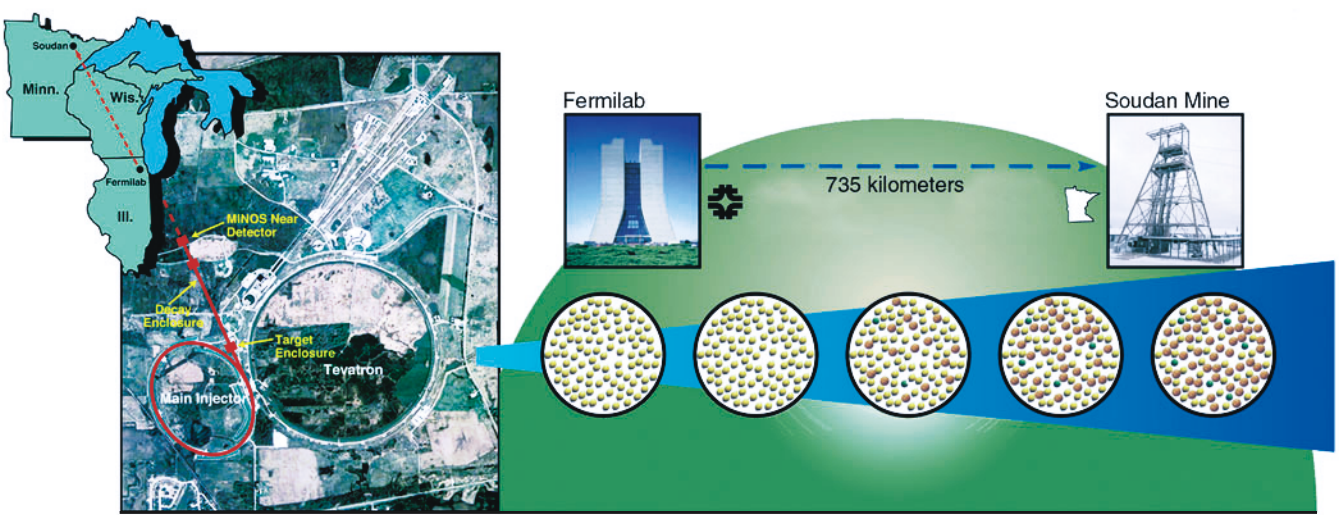
Before reaching Soudan, though, the neutrino beam will zoom through a smaller "near" detector a mere 1 kilometer from the beam source. This detector will measure how many muon neutrinos are at each energy. During the next 2 milliseconds, the beam will flash beneath northern Illinois and Wisconsin—2 milliseconds during which some of the muon neutrinos are expected to oscillate into tau neutrinos. The beam will then encounter the far detector, 800 meters deep in the Soudan mine. Some of the remaining muon neutrinos—about one in a million—will interact with the detector. "We won't be able to identify the tau neutrinos," explains Barnes, "but we will see a decrease in the number of muon neutrinos, and we'll be able to measure how many remain at each energy. The decrease will tell us that some of the muon neutrinos in the beam have changed into another type. The oscillations will help confirm that neutrinos have mass."

Physicists hope to uncover other details about the nature of neutrino oscillations as well. For instance, they hope to discover the oscillation probability of the beam—that is, the fraction of a beam that can change from one type to another at a given energy—by measuring the fraction of oscillations at each energy. In addition, they hope to determine the oscillation length, which is the distance a beam of neutrinos of a particular energy must travel to transform from one neutrino type to another and back again.

Down in the Mine

The experiment itself is impressive enough—but putting it all together presents another set of challenges no less daunting. A key issue is how to design the steel planes of the detectors. Each plane is 8 meters in diameter and weighs 10,000 kilograms, and 450 of them must be transported 800 meters underground. Plus the only access and egress underground is a mine shaft 2 meters across.

Several designs were put forth by different collaborators, including making the plate in one long, coiled strip—like an old-fashioned watch spring—that could be uncoiled and snaked downhole. Because much of the Laboratory's research has coupled physics and engineering, Livermore's Douglas Wright, a physicist with engineering training and experience, was selected to lead the steel design work for the MINOS collaboration. By 1995, Livermore engineers Marcus Libkind and Johanna Swan came up with the selected solution: make the planes from plates of steel—2 meters across, 8 meters long and 1.25 centimeters thick—that could be lowered down the mine shaft and assembled underground. This concept was fully developed at Livermore by engineer Tony Ladran (now with Lawrence Berkeley National Laboratory). The crucial feature of the design is that each plane is composed of



A beam of muon neutrinos will travel 735 kilometers in 2 milliseconds, from a linear accelerator in Chicago, Illinois, to a detector in Soudan, Minnesota. In that brief interim, some of the muon neutrinos will oscillate, or change, into tau neutrinos. This oscillating will be further proof that neutrinos have mass.

two layers of steel formed by strips laid at right angles. The two layers are joined by welds through precut holes in the steel. The technique results in a monolithic plane that is exceedingly flat and magnetically similar to a solid plane.

Even this solution presented challenges. The long, wide, thin plates were the steel equivalent of strips of paper. Unfortunately, unlike paper, which can bend but keep its structural integrity, steel doesn't have as much yield strength, and excessive bending causes it to tear. Also, once assembled, the steel planes could not be simply mounted on the floor with all the weight on the bottom edge. In addition, the edges all around the detectors had to be kept free for optical and electrical cables to snake in and out.

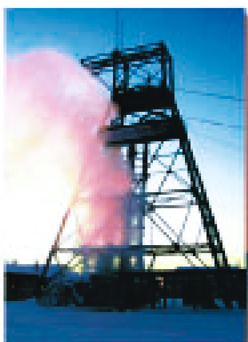
But how can 450 such planes be supported so they don't buckle under their own weight? The answer lies in a filing cabinet, says Barnes. "We decided to suspend them like hanging file folders, using two metal ears on each plane that rest on metal rails." For each plane, 9,000 kilograms of steel plate and 900 kilograms of plastic scintillator strips are supported on two 5- by 10-centimeter areas, one under each ear, resting on 10-centimeter-wide rails.

By July 2003, the entire detector system will be assembled in the mine. Fermilab is using the same design on a smaller scale for the near detector, and the MINOS experiment is expected to be up and running in early 2005.

Bring on the Beam

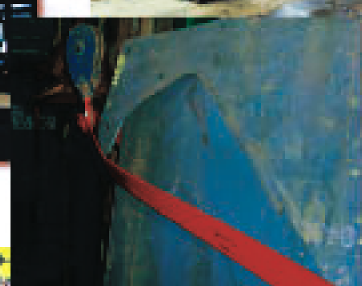
Livermore is also a key participant in another MINOS-related effort to look at exactly what happens in creating the neutrino beam—or indeed, any beam of particles. The answers will have important ramifications for Livermore's basic science and stockpile stewardship missions.

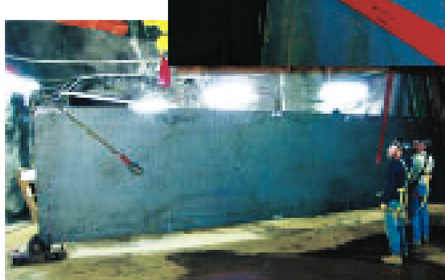
To produce neutrinos for MINOS, a 120-gigaelectronvolt proton beam will slam into a graphite target, producing pions and other particles as well. Because



Head frame of the Soudan Mine shaft.

Steel plates 2 by 8 meters are lowered down the mine shaft.





Livermore engineers and physicists worked together to come up with a design that would allow sections of the 450 detector planes to be lowered into the mine and assembled underground. All equipment must be broken down to fit into the 2 meter by 2 meter shaft and then reassembled underground.

Scintillator modules are welded to the steel planes.

A dozen steel plates ready for assembly.

Two layers of steel plates (four plates per layer) are welded together on a detector frame.

pions—precursors to muon neutrinos—are charged particles, they can be focused with magnetic fields and directed into a vacuum pipe of sufficient length to give them time to decay into neutrinos. (See the box at the right.)

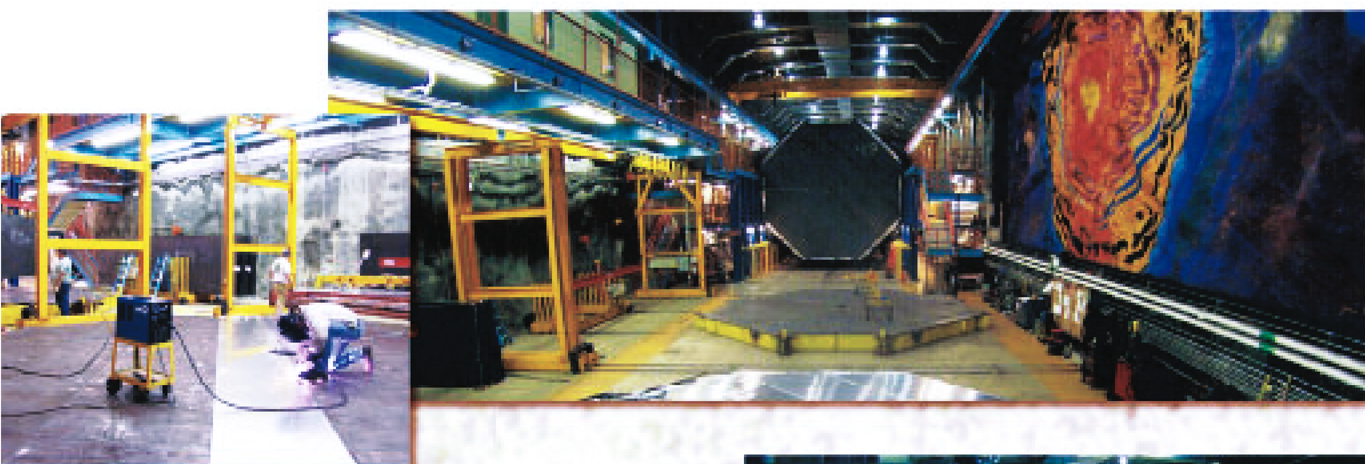
"The focusing properties of pions are well understood," says Barnes. "Propagation in the decay pipe is also well understood. What isn't well characterized is the nature of the stuff produced at the target by the proton beam. How many of what particles? And at what angles do they leave the target and at what energies? We need to characterize these details better. In addition, we know that the muon neutrino

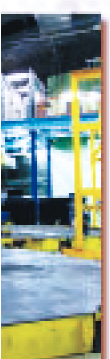
Recipe for a Neutrino Beam

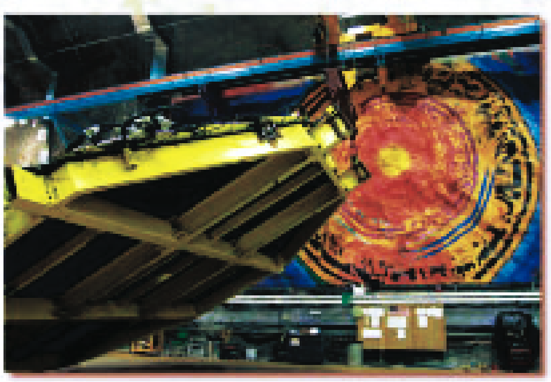
1. Take a beam of 120-gigaelectronvolt protons.
2. Aim the beam on a graphite target, where the protons can interact with the carbon atoms.
3. Take the beam produced from this interaction (which will contain mostly pions and kaons), and use magnets to focus the positively charged particles.
4. Direct these positively charged particles down a decay pipe. The pions will decay into muons and muon neutrinos. The kaons will also decay into muons and muon neutrinos and sometimes into electrons and electron neutrinos as well.
5. Send the subsequent beam through 229 meters of rock and steel to remove unwanted particles and muons.

Result: A beam of muon neutrinos, with a few scattered electron neutrinos.

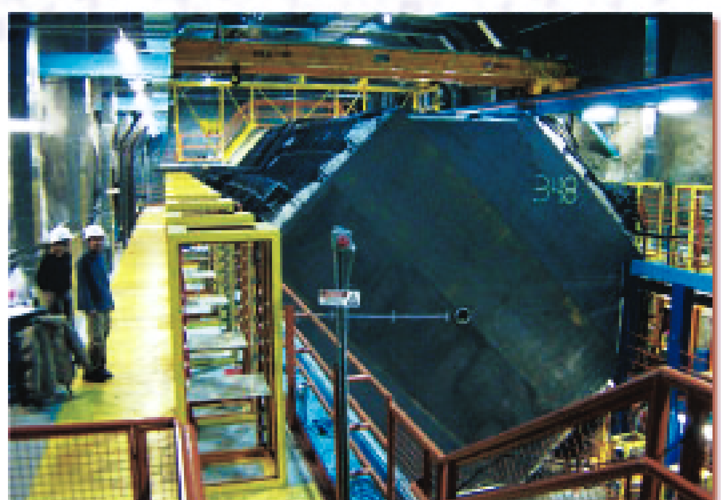
A CAUTION TO THE COOK: Neutrinos, being neutral, cannot be steered, so be sure your focusing system and decay pipe are pointing in the direction of the desired beam. For the Main Injector Neutrino Oscillation Search (MINOS) experiment, point the pipe 3 degrees down and north-northwest toward Minnesota.







Each assembled 8-meter-diameter detector plane is raised into place to join the array of 450 planes that comprise the MINOS detector.



The MINOS detector with 348 of its 450 detector planes in place.

beam produced in the decay pipe is not pure—it contains some electron neutrinos. We need to know more about these particles as well."

Because the beam will be only 30 centimeters in diameter at the MINOS near detector, the entire beam will pass through it. But only a small fraction of the beam ends up aimed at the far detector, explains Barnes. "Since the beam spreads out to a diameter of 1 kilometer at the far detector, we won't be measuring the whole beam. We need to know the angular distribution of the particles produced at the target and their energy spectrum. This information will help us understand the differences between the whole beam seen by the near detector and the subset seen by the far detector."

The lack of information about the particle production of the proton beam is the largest systematic uncertainty in the MINOS system. Details of particle production also turn out to be important for other efforts where particle beams interact with targets, such as future accelerator concepts like muon colliders and Livermore's stockpile stewardship work with proton radiography. (See the box below.)

To better understand the details of particle production, Livermore is leading the Main Injector Particle Production (MIPP) experiment in collaboration with Fermilab and a group of 10 universities, colleges, and institutes of technology. In preparing for MINOS, MIPP will examine what happens when 120-gigaelectronvolt protons hit graphite targets. Beams of protons, kaons, and pions at energies from 5 to 100 gigaelectronvolts will also be generated to examine particle production on target materials as diverse as hydrogen and lead. The experiment, which takes place at Fermilab, is just getting under way. MIPP begins this summer and will continue until MINOS comes on line.

Bringing in the Next Generation

In addition to providing results of interest to basic science and stockpile stewardship efforts, the MIPP and MINOS experiments are introducing postdoctoral fellows and others just entering the field of high-energy nuclear and particle physics to some of the work being done at Livermore. Barnes explains, "Most of the particle and high-energy nuclear physics experiments take a long time to plan and execute. One set of postdoctoral fellows works on the early part of the experiments—setting up the systems, doing early calculations, and so on—and then, years down the road when they've moved on, another set comes in

Proton Radiography

In addition to supplying information critical to the Main Injector Neutrino Oscillation Search (MINOS) experiment and other basic physics experiments, results from the Main Injector Particle Production (MIPP) experiment will contribute to Livermore's stockpile stewardship efforts. For seven years, Livermore has been exploring whether beams of high-energy protons could be used to create three-dimensional images or movies, much the way that x rays are used to create medical computed tomography scans. (See *S&TR*, November 2000, pp. 12–18.)

Such proton radiographic systems could be used in stockpile stewardship to image deep inside dynamic systems and obtain information about materials too dense for x rays to penetrate. One of the roadblocks to using proton beams is the tendency for protons to scatter at small angles off other particles, leading to blurry images. In 1995, researchers at Los Alamos National Laboratory came up with the idea of using a magnetic lens to refocus the charged protons, much as an optical lens refocuses a blurry image.

Such focusing techniques can be effective but present another problem. Just as MINOS physicists need to understand the scattering processes in detail, so physicists need to understand the scattering processes of proton radiography in detail. The beam that reaches the film also contains other particles produced as the beam passes through the target material. "We need to better understand these other particles," says physicist Peter Barnes. "Some of them reach the radiographic film and add their own signal. Not only do they blur the image, but their added signal also lightens the image, making the imaged materials appear to be less dense than they really are."

Because sharpness and density of image are critical to interpreting what is happening inside these complex systems, stockpile stewards need to know what the secondary particles are and how they affect the final image. MIPP will provide a more complete picture of the particles produced, including their energy spectrum and angular distribution.

and gathers and interprets the data. But for MIPP, we started work a year ago and now we're almost ready to take data. It's a three-year project, from building the system, to taking data, to producing a paper. It has a much shorter cycle than most experiments, allowing someone in a postdoctoral position to be involved in the project from start to finish." Through MIPP, a new generation of researchers is introduced to the Laboratory.

"The work on neutrino oscillations and proton radiography is a good example of how the Laboratory integrates basic science research with its missions," says Barnes. "Ultimately, the answers gained about neutrino oscillations through MINOS will connect to the early history of the universe. With MIPP, we're supporting that search for answers as well as supporting the Laboratory's stockpile stewardship work. It's a perfect example of what high-energy physics at the Laboratory can achieve."

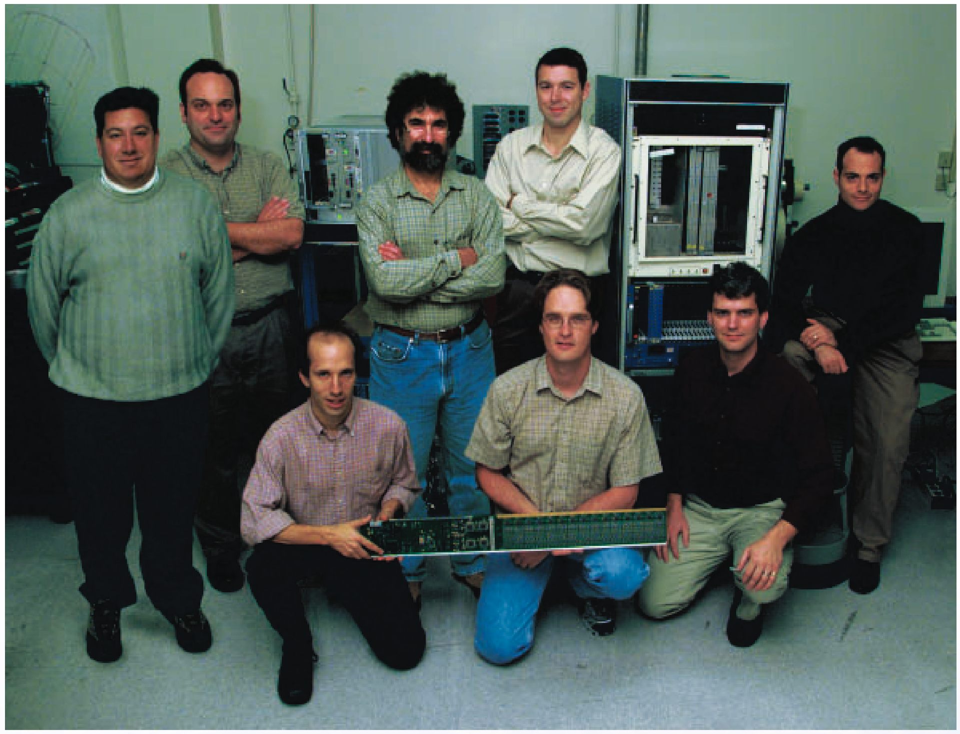
—Ann Parker

Key Words: Fermi National Accelerator Laboratory (Fermilab), high-energy physics, Main Injector Neutrino Oscillation Search (MINOS), Main Injector Particle Production (MIPP), neutrino oscillation, particle physics, proton radiography.

For more information contact Peter Barnes (925) 422-3384 (pdbarnes@llnl.gov).

For more information on the MINOS experiment, see:

www-numi.fnal.gov/index.html



Livermore's Main Injector Particle Production team in its laboratory with the test stand and computers. Team members are (from left) David Lange, Peter Barnes, Ron Soltz, Ed Hartouni, Doug Wright, Michael Heffner, Steve Johnson, and David Asner.

Toward a Common Data Model for Supercomputing

Livermore members of the award-winning HDF5 team are (from left) Robb Matzke, Mark Miller, Linnea Cook, and Kim Yates.

LAWRENCE Livermore won not five but six R&D 100 Awards in 2002. The October 2002 issue of this magazine described five awards for which Livermore was the primary developer. But the Laboratory was also a key member of a four-institution team that won a sixth R&D 100 Award for a software project called Hierarchical Data Format 5 (HDF5). As the primary developer, the National Center for Supercomputing Applications (NCSA) at the University of Illinois (Urbana–Champaign) worked in collaboration with Livermore, Los Alamos, and Sandia national laboratories.

HDF5 is the first widely used input/output (I/O) library specifically designed for massively parallel computing systems. An I/O library is a collection of programming routines that a computing code calls on to write or read data to or from a file on disk.

In the early years of scientific computing, roughly 1959 to 1980, I/O libraries took the form of little more than Fortran format statements to write or read binary or ASCII (text) files. Between 1980 and 2000, an important innovation emerged—the general purpose I/O library, which has two variants working at slightly different levels of data abstraction. One focused on computer science data structures, the other on computational science mesh structures. In addition to providing random access to named, abstract data objects, these libraries provided data that could be written on one machine architecture and read on another.

With the advent of massively parallel computers, computer scientists identified the need for a general-purpose I/O library that writes data from multiple processors into a single file, that can handle individual data structures larger than a gigabyte and individual files larger than a terabyte, and whose performance scales to large numbers of processors.

"With HDF5, we were also aiming at another big goal—to lay the foundation for solving the interoperability problem in scientific computing," says Livermore computer scientist Linnea Cook. "Many of the major supercomputing centers around the world—including Livermore, Los Alamos, and Sandia—had developed their own I/O libraries to address requirements not satisfied by existing libraries. None of these institutions could easily share data or software tools." Mark Miller, a Livermore expert on data modeling, agrees. "With HDF5, we have the beginnings of a solution to the interoperability problem. Plus we made an important contribution to the scientific community."

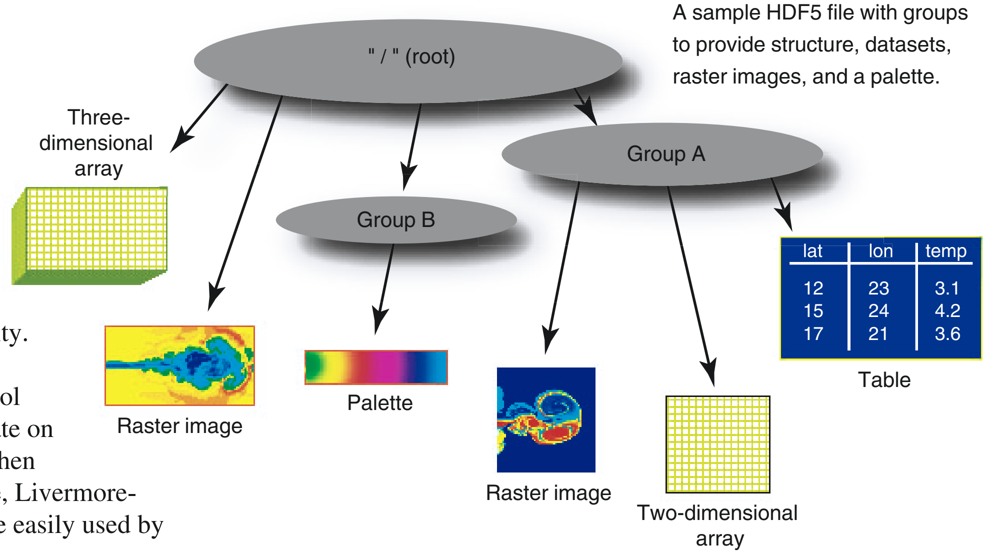
Problem, Solution

HDF5 is the successor to HDF1 through HDF4, a series of highly successful I/O libraries developed at NCSA and used around the world. HDF software includes I/O tools for analyzing, visualizing, and converting data between various numeric formats and storage schemes. By the mid-1990s, however, HDF4 had begun to show its limitations. It lacked the capacity to handle the enormous amounts of data being generated by many scientific research programs, and it was not designed to support parallel applications.

At about the same time, the Department of Energy established its Accelerated Strategic Computing Initiative (ASCI), now the National Nuclear Security Administration's Advanced Simulation and Computing Program, to develop a massively parallel computing capability. Livermore, Los Alamos, and Sandia established a group to explore the possibilities of developing visualization codes jointly. Cook served on this committee and initiated the effort to develop a common, tri-laboratory, parallel I/O library. She believed that the HDF group at NCSA might be part of the solution and invited them to participate.

Throughout the late 1990s, the three national laboratories worked with NCSA under ASCI auspices to develop an improved version of HDF. Livermore computer scientist Robb Matzke developed the majority of the first production versions of HDF5, with colleague Kim Yates making substantial contributions to the parallel version.

The team's primary goal was to produce a high-performance, parallel I/O library that would meet the requirements of all three laboratories. This meant that HDF5 needed to be delivered quickly, with sufficient functionality, robustness, and performance, before other libraries being built at all three laboratories became entrenched. The second goal was to develop a de facto standard library that would be widely used throughout the international scientific computing community. Once an I/O library becomes widely used, commercial software companies and free tool developers begin developing codes to operate on data stored in that format. Many users can then quickly and easily use these tools. Likewise, Livermore-built tools that read HDF5 data will be more easily used by other organizations that use HDF5.



A sample HDF5 file with groups to provide structure, datasets, raster images, and a palette.

Today, HDF5 can store, access, manage, exchange, and archive not only massive amounts of complex data but also any type of data suitable for digital storage, no matter its origin or size. HDF5 is a completely portable file format. A file can be written on any system and read on any other. Plus its I/O libraries can run on virtually any scientific research computing system, be it serial or parallel. The HDF5 file format and library are designed to evolve as requirements emerge.

HDF5 can handle, for example, trillions of bytes of computational modeling data or high-resolution electronic images in a continuously evolving computing and storage environment. With the help of lower-level libraries, HDF5 enables thousands of processors to simultaneously write data to a single file. Terabytes of remote-sensing data received from satellites, computational results from weather or nuclear testing models, and high-resolution magnetic resonance imaging brain scans can be stored in HDF5 files along with additional information needed for efficient data exchange, data processing, visualization, and archiving.

HDF5 can also write data to a file on disk, to memory, across the network, or to any device specified by using its Virtual File Layer. Applications can write a virtually unlimited number of objects to a file, and the maximum size of any object is limited only by the computer or the file system's capacity. HDF5 provides simple data types, user-defined data types, and compound data types of any degree of complexity, including nesting to any number of levels. Through its grouping and linking mechanism, the HDF5 data model supports complex data relationships and dependencies. Multidimensional arrays can be extended in any dimension. In addition, HDF5 provides partial I/O capabilities. For example, users may wish to read only a subset of an array containing hundreds of millions of elements.

Work continues on HDF5—as well as on the broader interoperability problem it helps to address. Groups that collaborated on this award-winning technology are also working on higher level libraries to capture the mathematical and physical abstractions of scientific data. In addition, the HDF group is defining conventions for using HDF5, which will also improve interoperability.

Some Interesting Uses for HDF5

HDF5 is used by government, academic, and commercial institutions in more than 60 countries. The three DOE laboratories are currently the largest users of HDF5's parallel capabilities, but that is beginning to change.

HDF5 is incorporated into the Globus Project at Argonne National Laboratory, which focuses on the fundamental technologies required to deploy computational grids. Argonne's NeXus, which provides a standard data format for work in neutron and synchrotron radiation internationally, is converting to HDF5. FLASH, a product used to study thermonuclear flashes on the surfaces of compact stars, is built on HDF5.

The big surprise of 2001 for the HDF group came when the Help Desk started getting e-mail messages from a programmer in New Zealand. His questions were not of the ordinary sort, and the technical support staff eventually asked him how he was using the library. All he was free to say at the time was that he was working on graphical special effects. Later information revealed that his company was using HDF5 to generate atmospheric effects—smoke, wind, and clouds—for *The Lord of the Rings* film trilogy.

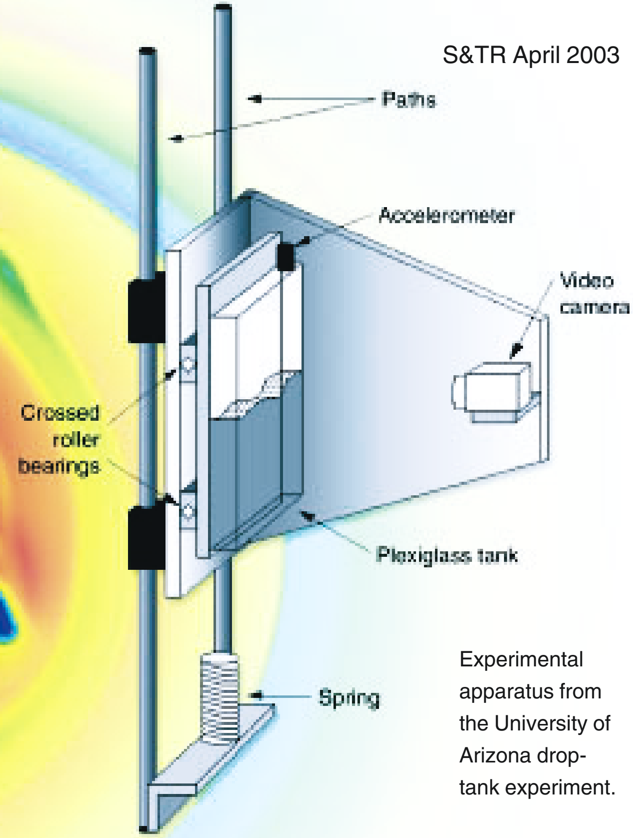
—Katie Walter

Key Words: Advanced Simulation and Computing (ASCI), Hierarchical Data Format 5 (HDF5), input/output (I/O) libraries, R&D 100 Award, supercomputing.

For further information contact Linnea Cook (925) 422-1686 (cook13@llnl.gov).

Into the Vortex

New Insights into the Behavior of Dynamic Fluids



Experimental apparatus from the University of Arizona drop-tank experiment.

STIR a cup of tea, and watch how the tea leaves swirl and dip. Imagine what it might take to predict that movement, given only the initial forces and conditions of cup, tea, spoon, and leaves. Now add milk. The more-or-less orderly motion of tea and leaves suddenly becomes incredibly more complex, as do the forces that drive the flow and eddies of the liquids. The pathway to understanding and prediction becomes less clear as well. Welcome to the world of fluid dynamics—the study of fluids in motion.

Lawrence Livermore physicists Paul Miller and Andrew Cook delved into the details of fluids on the move to simulate an experiment conducted at the University of Arizona (UA) and predict interactions of two dissimilar liquids. With the help of powerful visualization tools created by Livermore computer scientist Peter Lindstrom, they revealed the inner workings of a perplexing characteristic that, under certain situations, is key to the mixing of dissimilar fluids. Termed centrifugal baroclinic instability, the phenomenon embodies the interaction of two fluids with varying pressures and densities as they spin around each other. This fluid dynamic dance occurs in a broad range of circumstances, from deep ocean eddies to convection currents in the cores of dying stars.

Doing the Bounce

Miller and Cook's work had its genesis with a UA experiment to explore what happens at the interface between two liquids of different densities when that interface is accelerated.

In the experiment, conducted by UA professor Jeffrey Jacobs and former UA graduate student Charles Niederhaus (now with the National Aeronautics and Space Administration), a small rectangular transparent tank was mounted on vertical rails and suspended above a spring on a platform. The tank contained a heavier liquid (salt water) and a lighter liquid (an alcohol–water mix). Initially, it was moved from side to side to set up standing waves on the liquid interface. Then the tank was released, falling and bouncing off the spring before coasting up and down to a final stop. Since the tank was essentially in free-fall before and after the bounce, the only force the liquids experienced was the sharp acceleration—50 times that of gravity—of the 30-millisecond bounce. A video camera documented what happened at the liquid interface from initial standing wave to the final jolt.

The part of the experiment that interested Miller and Cook was the 1 second after the bounce during which the tank is again in free-fall. At bounce time, the acceleration pushed the peak of the standing wave down, while the trough moved upward. These opposing actions resulted from a twisting force (a torque) acting on the liquid interface. In this case, the twisting is called baroclinic torque because it involves differing pressures (baro) and inclined (clinic) density interfaces. In stable configurations—when light fluid is on top of heavy fluid, for instance—baroclinic torque drives phenomena such as ocean waves. In unstable configurations—when heavy fluids are on top of light or when fluids in a stable configuration are accelerated—baroclinic torque drives Rayleigh–Taylor and Richtmyer–Meshkov instabilities. These instabilities typically lead to mushroom-shaped structures forming in fluids. In the UA experiment, the fluids continued to move after the bounce, forming these mushroom shapes, with the interface rolling up at the sides of the mushroom.

What happened at the core of this roll-up drew Miller and Cook's attention. Rather than a smooth, continual spiral inward, the roll-up began to disintegrate because of a small secondary instability. (The primary instability was the Richtmyer–Meshkov instability that created the large-scale roll-up.) "This secondary instability happens long after the bounce," explains Miller, "so it was not caused by the acceleration of the bounce itself. The source of these perturbations deep inside the vortex and how they evolved were not well understood."

Turning and Turning in the Widening Gyre

To gain insights into the nature of these secondary instabilities, Miller and Cook used MIRANDA, a direct numerical simulation code created by Cook. MIRANDA's hybrid spectral and compact-finite-difference algorithms resolve all scales of motion in a flow, down to the viscous and diffusive scales. "These were direct numerical simulations, meaning we tried to work from first principles—or as close as we could get—without making assumptions or using models for some of the smaller dynamics of the system," says Miller.

The computational mesh was a two-dimensional slab one cell thick (1,025 by 1 by 5,000 grid points). Each computational cell was 41 micrometers across, or less than half the width of a human hair. "Since the experiment was essentially two dimensional," says Miller, "we were able to increase the resolution by running a two-dimensional simulation. Particularly in the timeframe we were interested in, three-dimensional physics—such as three-dimensional tilt or stretch in the vortices—doesn't play an important role."

The simulation ran on 64 of the 1,088 processors that make up ASCI Frost, the unclassified portion of the Advanced Simulation and Computing (ASCI) Program's White supercomputer system. The simulation re-creates 2.5 seconds from the experiment, starting with the motion of the initial standing wave and continuing for about 1 second after the bounce. Re-creating the details of the wave allowed Miller and Cook to replicate the low-level velocity from the wave that was present when the bounce occurred.

The results of that calculation were then used to simulate the instabilities that developed during and after the bounce,

Flying through the Data

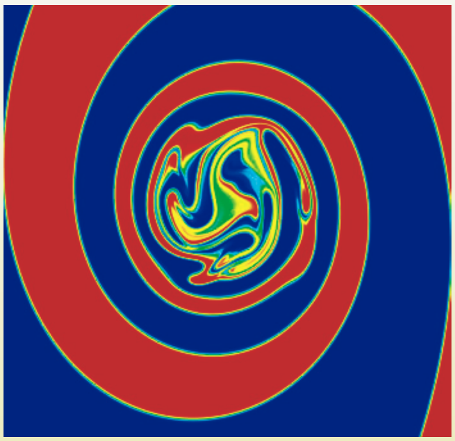
Once Livermore physicists Paul Miller and Andrew Cook ran their simulation, they were faced with the need to interpret their results, so they turned to computer scientist Peter Lindstrom for help in visualizing their data. Lindstrom explains that he specializes in creating tools to visualize giant data sets. One of these is a software tool called Visualization Streams for Ultimate Scalability (ViSUS). Lindstrom worked closely with Miller and Cook to create movies that looked at how quantities such as density and pressure varied over time and space and how they correlated with the vorticity—that is, how much local rotation was generated in the fluid, in what areas, and in what direction. Some of the visualizations incorporate as many as five variables: two spatial dimensions, vorticity, vorticity production, and time.

"We also worked up a tool that allows researchers to interact with a 3D simulation," Lindstrom explains. "Basically, we put them in the driver's seat, giving them full control over the visualization parameters so they can explore and interact with their data in ways that are useful to them. This is potentially so much more powerful than having someone such as me create a single image or canned movie where all the parameters are fixed. It is not likely that a single setting of many parameters is sufficient or that I know exactly what to emphasize in the visualization. Also, for large data sets—and in particular three-dimensional data where things might be occluded or hidden deep within the data—the scientist needs to be able to move around the data set to obtain the most meaningful picture of the data. With ViSUS, the scientist can zoom in on small features, look at more global trends in the data, and explore it from many different vantage points, while at the same time turning the control knobs for the visualization itself. This control is possible only with interactive visualization."

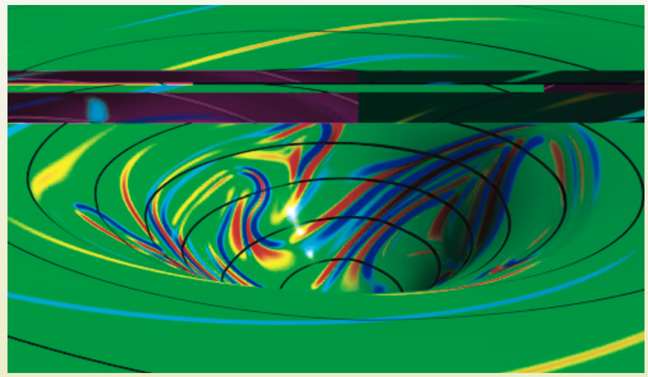
Such tools allow researchers to look at the simulation while it is progressing, so they can stop it—to tinker with the mesh, for instance—and correct it as needed. No longer do they need to wait two weeks for a visual result to make corrections. Tools such as ViSUS are beginning to show up on physicists' desktops and will, in the long run, only make it easier for scientists to stay on top of complex simulations created on the Advanced Simulation and Computing Program's supercomputing systems.

About the Simulations

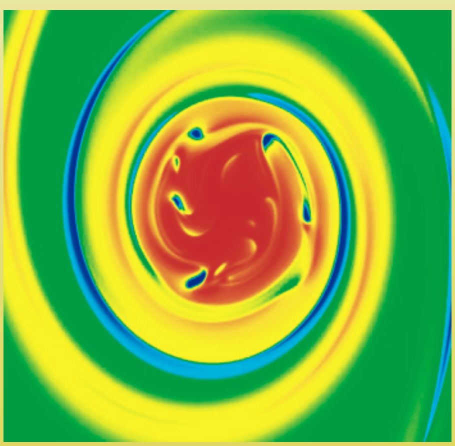
The high-fidelity computer simulations developed by Livermore's Andrew Cook and Paul Miller were carried out on a 1,025- by 5,000- node mesh, at a Schmidt number of 100, and a circulation Reynolds number of 3,800. A suite of two-dimensional animations of calculated quantities and a fly-over of a three-dimensional animated rendering of the vorticity field allowed researchers to visualize the fluid flow as it developed. All of the still shots below were taken at the same time (0.75 second after the bounce). The award-winning movie "Visualizations of the Dynamics of a Vortical Flow" is available online at the VIEWS Visualization Project: Image and Movie Gallery www.llnl.gov/icc/sdd/img/images.shtml.



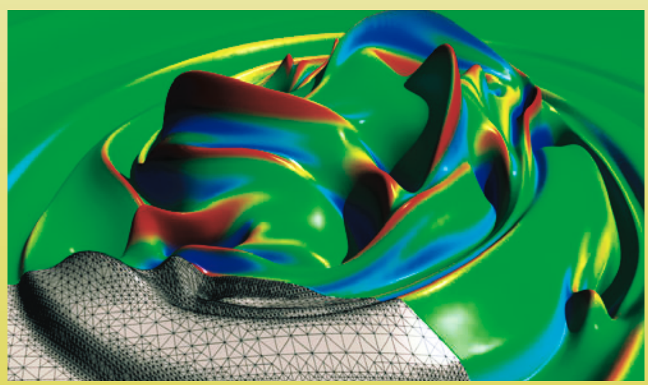
Fluid density visualization. Red shows the higher density liquid and blue the lower. Green shows where the two liquids have mixed. The interface between the two liquids is rolled up around a large vortex in the middle. In the core of the vortex, where a low-pressure region exists, the secondary instability has led to increased mixing of the two fluids.



Pressure (shown by height and contour lines) visualization with a superimposed color map of the vorticity production (or baroclinic torque). Areas of fluid rotation are springing up on the sides of the pressure well where the change in pressure is steepest. Clockwise and counterclockwise vortices are generated in alternating thin sheets. Eventually, these small areas of oppositely rotating fluid will break down the orderly structure of the rolled-up fluids, resulting in increased mixing.



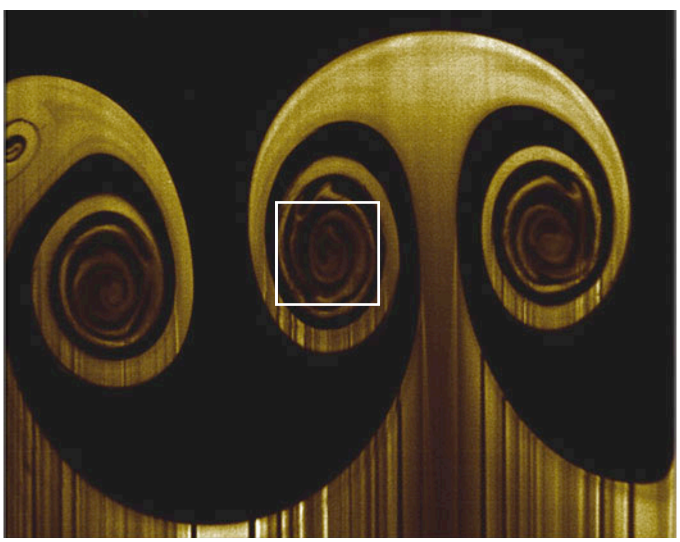
Vorticity (local fluid rotation) visualization. Red and its variants (yellow and orange) indicate areas where liquid is rotating in a counterclockwise direction; blue indicates areas where it is rotating in a clockwise direction. Green represents areas where no rotation is taking place. The pockets and strips of blue in the midst of the red core indicate areas that have been affected by the secondary instability and are rotating in the opposite direction from the surrounding fluid.



Vorticity production visualized onto a heightmap of the vorticity field, with the visualization mesh partially exposed. Peaks are areas of most counterclockwise rotation; valleys are areas of highest clockwise rotation. Flat surrounding areas are locations of little or no rotation. The colors show vorticity being produced by the secondary instability. Red indicates counterclockwise rotation; blue indicates clockwise rotation. Blue patches on high peaks are particularly telling. Since the rotation being produced (clockwise) does not correlate with the rotation that is ongoing (counterclockwise), the secondary instability is responsible.

particularly the secondary instability in the core of the vortex. By using visualization software developed by Peter Lindstrom of the Center for Applied Scientific Computing (see the box on p. 23), Miller and Cook discovered the cause of this secondary instability—the interaction of the low-pressure field in the center of the vortex (similar to the low-pressure "eye" in the center of a cyclone or the "well" that appears in the cup of vigorously stirred tea) with the varying densities in the fluid whirling around in the vortex.

According to Miller, this instability evolves as follows. The interface of the two liquids begins to roll up because of the vorticity deposited by the bounce. The simulation (see the box on p. 24) shows that at the start of this process, the two liquids remain mostly unmixed, curling around the center of the roll-up and forming a spiral pattern. As the liquid interface spirals inward, centrifugal force (the pseudoforce that appears to push matter outward from the center of rotation) comes into play, producing a low-pressure well at the center of the evolving "jelly roll." The pressure increases up the sides of this well, while the density alternates between light and heavy. Prior to the secondary instability, all of the fluid spins counterclockwise. The interaction of varying pressure and density generates new vortices—some spinning clockwise, others counterclockwise—on the sides of the pressure well. These tiny harbingers of disorder increase in number, spread,



One image from a set taken during a University of Arizona experiment exploring the interface between two liquids—one of lighter density (black) and one of heavier density (white)—when the interface was accelerated. This image was taken 749 milliseconds after acceleration. Livermore physicists wanted to uncover the mechanism that destroyed the orderly roll-up in the sides of the mushroom shape (boxed in white).

and grow, eventually leading to the breakdown of the orderly spiral of fluids and an increase in fluid mix.

The visualizations created by Lindstrom allowed Miller and Cook to more easily see correlations and relationships in their numerical results, which included data on pressure, density, vorticity, and vorticity production (baroclinic torque) at different points in time during the experiment.

From Fusion Pellets to Planet Rotation

Cook and Miller validated their simulations using data from the UA experiment and presented the results of their research at the 55th Annual Meeting of the American Physical Society, Division of Fluid Dynamics, held in Dallas, Texas, in November 2002. A video created with Lindstrom describing their work and highlighting the visualizations was honored in the meeting's "Gallery of Fluid Motion."

Understanding such fluid instabilities—how and why they form and evolve and being able to predict them—is important to understanding how fluids, including both liquids and gases, behave. Such instabilities occur on scales from the microscopic to astronomical and can have a dramatic effect. Richtmyer–Meshkov instabilities, for instance, may affect the performance of laser fusion pellets and nuclear weapons and can occur in the explosions of supernovas. "After all," Miller concludes, "the same physical laws that apply to supernovas govern a cup of tea."

—Ann Parker

Key Words: centrifugal baroclinic torque, fluid dynamics, Richtmyer–Meshkov instability, secondary instability.

For further information contact Paul Miller (925) 423-6455 (miller3@llnl.gov).

To view a video of the University of Arizona experiment, see:
info-center.ccit.arizona.edu/~fluidlab/incomp.html

To view the "Visualizations of the Dynamics of a Vortical Flow," the award-winning video on the work described in this article, see:
www.llnl.gov/icc/sdd/img/images/aps02.mov

To view examples from the American Physical Society's "Gallery of Fluid Motion," see:
ojps.aip.org/phf/gallery/index1.jsp

[The work discussed in this article is scheduled to be posted to the APS site during 2003.]

Patents and Awards

Each month in this space we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Laser and Acoustic Lens for Lithotripsy

Steven R. Visuri, Anthony J. Makarewicz, Richard A. London, William J. Benett, Peter Krulevitch, Luiz B. Da Silva

U.S. Patent 6,491,685 B2

December 10, 2002

An acoustic focusing device whose acoustic waves are generated by laser radiation through an optical fiber. The acoustic energy can efficiently destroy renal and biliary calculi and is delivered to the site of the calculi via an endoscopic procedure. The device includes a transducer tip attached to the distal end of an optical fiber through which laser energy is directed. The transducer tip encapsulates an exogenous absorbing dye. Under proper irradiation conditions (high absorbed energy density, short pulse duration), a stress wave is produced via thermoelastic expansion of the absorber for the destruction of the calculi. The transducer tip can be configured into an acoustic lens such that the transmitted acoustic wave is shaped or focused. Also, compressive stress waves can be reflected off a high density–low density interface to invert the compressive wave into a tensile stress wave. Tensile stresses may be more effective in some instances in disrupting material because most materials are weaker in tension than compression. Estimations indicate that stress amplitudes provided by this device can be magnified more than 100 times, greatly improving the efficiency of optical energy for targeted material destruction.

Optical Add/Drop Filter for Wavelength Division Multiplexed Systems

Robert J. Deri, Oliver T. Strand, Henry E. Garrett

U.S. Patent 6,493,484 B1

December 10, 2002

An optical add/drop filter for wavelength division multiplex systems and construction methods. The add/drop filter includes a first ferrule having a first preformed opening for receiving a first optical fiber; an interference filter oriented to pass a first set of wavelengths along the first optical fiber and reflect a second set of wavelengths; and a second ferrule having a second preformed opening for receiving the second optical fiber and the reflected second set of wavelengths. The method for constructing the optical add/drop filter consists of forming a first set of openings in a first ferrule; inserting a first set of optical fibers into the first set of openings; forming a first set of guide pin openings in the first ferrule; dividing the first ferrule into a first ferrule portion and a second ferrule portion; forming an interference filter on the first ferrule portion; inserting guide pins through the first set of guide pin openings in the first ferrule portion and second ferrule portion to passively align the first set of optical fibers; removing material such that light reflected from the interference filter from the first set of optical fibers is accessible; forming a second set of openings in a second ferrule; inserting a second set of optical fibers into the second set of openings; and positioning the second ferrule with respect to the first ferrule such that the second set of optical fibers receive the light reflected from the interference filter.

Method for Enhancing the Solubility of Boron and Indium in Silicon

Babak Sadigh, Thomas J. Lenosky, Tomas Diaz de la Rubia, Martin Giles, Maria-Jose Caturla, Vidvuds Ozolins, Mark Asta, Silva Theiss, Majeed Foad, Andrew Quong

U.S. Patent 6,498,078 B2

December 24, 2002

A method for enhancing the equilibrium solubility of boron and indium in silicon. The method involves first-principles quantum mechanical calculations to determine the temperature dependence of the equilibrium solubility of two important p-type dopants in silicon, namely boron and indium, under various strain conditions. The equilibrium thermodynamic solubility of size-mismatched impurities, such as boron and indium in silicon, can be raised significantly if the silicon substrate is strained appropriately. For example, for boron, a 1-percent compressive strain raises the equilibrium solubility by 100 percent at 1,100°C; and for indium, a 1-percent tensile strain at 1,100°C corresponds to an enhancement of the solubility by 200 percent.

Micro-Machined Thermo-Conductivity Detector

Conrad Yu

U.S. Patent 6,502,983 B2

January 7, 2003

A micromachined thermal conductivity detector for a portable gas chromatograph. The detector is highly sensitive and has fast response time to enable detection of small gas samples, on the order of nanoliters, in a portable gas chromatograph. The high sensitivity and fast response time are achieved through micromachined devices composed of a nickel wire, for example, on a silicon nitride window, about a millimeter square, formed in a silicon member. In addition to operating as a thermal conductivity detector, the silicon nitride window with a micromachined wire therein can be used as a fast response heater for polymerase chain reaction applications.

PCR Thermocycler

William J. Benett, James B. Richards

U.S. Patent 6,503,750 B1

January 7, 2003

A sleeve-type silicon polymerase chain reaction (PCR) chamber or thermocycler having improved thermal performance. The improved thermal performance comes from etched features in the chamber that reduce thermal mass and increase the surface area of the sleeve for cooling. The improved thermal performance increases the speed and efficiency of the reaction chamber. The improvement is accomplished by providing grooves in the faces of the sleeve and a series of grooves on the interior surfaces that connect with the grooves on the faces of the sleeve. The grooves can be anisotropically etched in the silicon sleeve simultaneously with formation of the chamber.

Compensated Individually Addressable Array Technology for Human Breast Imaging

D. Kent Lewis
U.S. Patent 6,504,288 B2
January 7, 2003

A method of forming broad bandwidth acoustic or microwave beams that encompass array design, array excitation, source signal preprocessing, and received signal postprocessing. This technique uses several different methods to achieve improvement over conventional array systems. These methods are (1) individually addressable array elements without any moving parts, which allow scanning around and over an object such as a human breast; (2) digital-to-analog converters for the source signals, which allow virtually any radiated field to be created in the half-space in front of the array; (3) inverse filtering from source precompensation, which allows for corrections in the system, most notably in the response of the individual elements and in the ability to increase contrast and resolution of signal propagating through the medium under investigation; and (4) spectral extrapolation to expand the bandwidth of the received signals. Used together, the system allows for compensation to create beams of any desired shape, control the wave fields generated to correct for medium differences, and improve contrast and resolution in and through the medium.

Versatile, High-Sensitivity Faraday Cup Array for Ion Implanters

Ronald G. Musket, Robert G. Patterson
U.S. Patent 6,507,033 B1
January 14, 2003

An improved Faraday cup array for determining the dose of ions delivered to a substrate during ion implantation and for monitoring the uniformity of the dose delivered to the substrate. The improved Faraday cup array incorporates a variable size ion beam aperture by changing only an insertable plate that defines the aperture without changing the position of the Faraday cup, which is positioned for the operation of the largest ion beam aperture. The design enables the dose sensitivity range, typically from 10^{11} to 10^{18} ions per square centimeter, to be extended to below a million (10^{6}) ions per square centimeter. The insertable plate-aperture arrangement is structurally simple and enables scaling to aperture areas between lesser than 1 square centimeter and greater than 750 square centimeters, and enables ultrahigh vacuum (UHV) applications by incorporation of UHV-compatible materials.

Chemical Method for Producing Smooth Surfaces on Silicon

Conrad Yu
U.S. Patent 6,514,875 B1
February 4, 2003

An improved method for producing optically smooth surfaces in silicon wafers during wet chemical etching involves a pretreatment rinse of the wafer before etching and a postetching rinse. The pretreatment with an organic solvent provides a well-wetted surface that ensures uniform mass transfer during etching, which results in optically smooth surfaces. The postetching treatment with an acetic acid solution stops the etching instantly, preventing any uneven etching that leads to surface roughness. This method can be used to etch silicon surfaces to a depth of 200 micrometers or more, while the finished surfaces have a surface roughness of only 1.5 to 5.0 nanometers.

High-Resolution Imaging and Target Designation through Clouds or Smoke

Michael D. Perry
U.S. Patent 6,515,737 B2
February 4, 2003

A method and system of combining gated intensifiers and advances in solid-state, short-pulse laser technology to create compact systems capable of producing high-resolution (that is, approximately less than 20 centimeters) optical images through a scattering medium such as dense clouds, fog, or smoke from air- or ground-based platforms. Laser target designation through a scattering medium is also enabled by using a short-pulse illumination laser and a relatively minor change to the detectors on laser-guided munitions.

Awards

The Federal Laboratory Consortium (FLC) for Technology Transfer has awarded the **Extreme Ultraviolet Lithography** (EUVL) project **Excellence in Technology Transfer.** The award is for transferring to industry a technology that will lead to microprocessors that are tens of times faster than today's most powerful computer chips and create memory chips with similar increases in storage capacity. The computer industry has targeted EUVL as the next-generation lithography approach to be introduced in 2007 for high-volume manufacturing.

The EUVL team is made up of scientists and researchers from Lawrence Livermore, Lawrence Berkeley, and Sandia national laboratories collaborating as the Virtual National Laboratory. Under a multiyear Cooperative Research and Development Agreement, the team has successfully transferred EUVL technology to the Extreme Ultraviolet Limited Liability Company, a consortium headed by Intel Corporation that includes Advanced Micro Devices, IBM, Infineon, Micron Technologies, and Motorola.

Livermore members of the EUVL team are **Don Sweeney**, Livermore's EUV program manager and director of the Virtual National Laboratory, **Jennifer Alameda**, **Sasa Bajt**, **Anton Barty**, **Sherry Baker**, **Butch Bradsher**, **Henry Chapman**, **Carl Chung**, **Al Edge**, **Jim Folta**, **Layton Hale**, **Stefan Hau-Riege**, **Michael Johnson**, **Patrick Kearney**, **Cindy Larson**, **Rick Levesque**, **Paul Mirkarimi**, **Nhan Nguyen**, **Gary Otani**, **Don Phillion**, **Jeff Robinson**, **Mark Schmidt**, **Frank Snell**, **Gary Sonnargren**, **Regina Soufli**, **Victor Sperry**, **Eberhard Spiller**, **John S. Taylor**, and **Chris Walton**.

The **Society of Mexican American Engineers and Scientists** (MAES) recently presented Livermore's **Frank Robles** with its highest honor, the **Medalla de Oro** (gold medallion) for his many years of successful recruitment of promising young Mexican–American scientists and engineers to the Laboratory. In the past seven years, sixteen of the students Robles helped recruit at MAES conferences have been hired by the Laboratory as full-time employees.

The Medalla de Oro is given to members and supporters of MAES "who have distinguished themselves by demonstrating a dedication to serve and to greatness, a kind of dedication to humankind that carries with it responsibilities and strict disciplines." In addition to the medallion, a Padrino Scholarship was presented to a MAES student in Robles's name. "Padrino" means "godfather," and giving this name to the scholarship symbolizes the society's desire to award it to build a bridge to the future.

Robles, a long-time employee of Livermore's Affirmative Action and Diversity Program, recently became the deputy leader of the Laboratory's Employee Relations Office.

Jeff Wadsworth, former deputy director for Science and Technology and former associate director of Chemistry and Materials Science, and **Craig Smith**, a nuclear engineer and project leader in the Energy and Environment Directorate, have been named **fellows** of the **American Association for the Advancement of Science** (AAAS).

Wadsworth, now senior executive with Battelle Corporation's technology development and commercialization organization, was cited for his "distinguished contributions in developing advanced materials and superplasticity and in determining the origins and history of Damascus and other steels and for broad scientific leadership supporting national security," work he did while at the Laboratory.

Smith, who has 30 years of experience in the nuclear and environmental fields at the Laboratory and in private industry, was named for his "distinguished contributions to the advancement of nuclear science and technology."

Each year, a group of peers selects AAAS members to become fellows. This year, 291 members became fellows in recognition of their efforts to advance science or foster applications that are deemed scientifically or socially distinguished.

Abstracts

Finding the Missing Piece in the Climate Change Puzzle

In the past 10 to 15 years, scientists have begun to consider the role aerosols may play in changing the planet's climate. In particular, increasing concentrations of anthropogenic aerosols in the atmosphere appear to be cooling the planet and so partially counteracting the effects from greenhouse gases. Large variations in aerosol concentrations, combined with complex chemical reactions, have made it difficult to assess the magnitude of their effects on climate. Livermore atmospheric scientists are using extremely sophisticated computer simulations to gain insight into aerosols' climatic effects. The simulations show that in some industrial regions, the generation of aerosols from fossil fuel combustion and biomass burning may be as important to climate change as greenhouse gases. Also, climate changes caused by aerosols vary significantly by season and by region. The Livermore team is linking a revised version of IMPACT (an atmospheric chemistry code) with a microphysics module and Community Climate Model-3, the fourth-generation global climate model developed by the National Center for Atmospheric Research. By early next year when the latest modeling elements are in place, Livermore scientists will further improve simulations of the global and regional climate changes caused by both aerosols and major greenhouse gases.

Contact:
Catherine Chuang (925) 423-2572 (chuang1@llnl.gov).

An Elusive Transformation—The Mystery of Oscillating Neutrinos

Livermore is part of an international collaboration examining neutrino oscillations, a phenomenon in which one type of neutrino transforms into another type. Results from the Main Injector Neutrino Oscillation Search (MINOS) experiment at Fermi National Accelerator Laboratory (Fermilab) could affect the prevailing physics theory that describes elementary particles and forces of the universe. MINOS will point a neutrino beam generated at Fermilab in Illinois at a massive detector weighing 5.4 million kilograms located deep in the Soudan Mine 735 kilometers away in Minnesota. Livermore designed the neutrino detector's 8-meter-diameter steel planes such that 450 planes could be transported down a 2-meter-wide shaft into the mine for assembly. Livermore is also a key participant in another MINOS-related effort to quantify the particle production of the proton beam that is the precursor to the neutrino beam. Details of particle production are the largest systematic uncertainty in the MINOS system. They have important ramifications for other efforts where particle beams interact with targets such as in accelerators of the future and in proton radiography.

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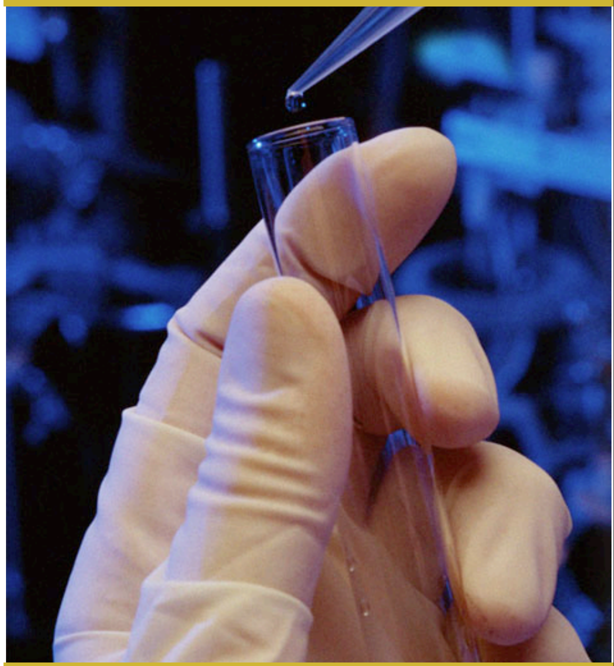
U.S. Government Printing Office: 2003/583-047-80031

Capabilities for Chemical Weapons Inspections



The International Organisation for the Prohibition of Chemical Weapons certifies Livermore's Forensic Science Center to support chemical weapons inspections.

Also in May

- ***Geobotanical sensing can help detect pipeline leaks, hidden geothermal resources, and carbon dioxide leaks from underground formations.***

- ***The age of groundwater is a factor in its susceptibility to contamination.***

- ***Studies of truck aerodynamics are helping to improve truck fuel efficiency.***

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