discover
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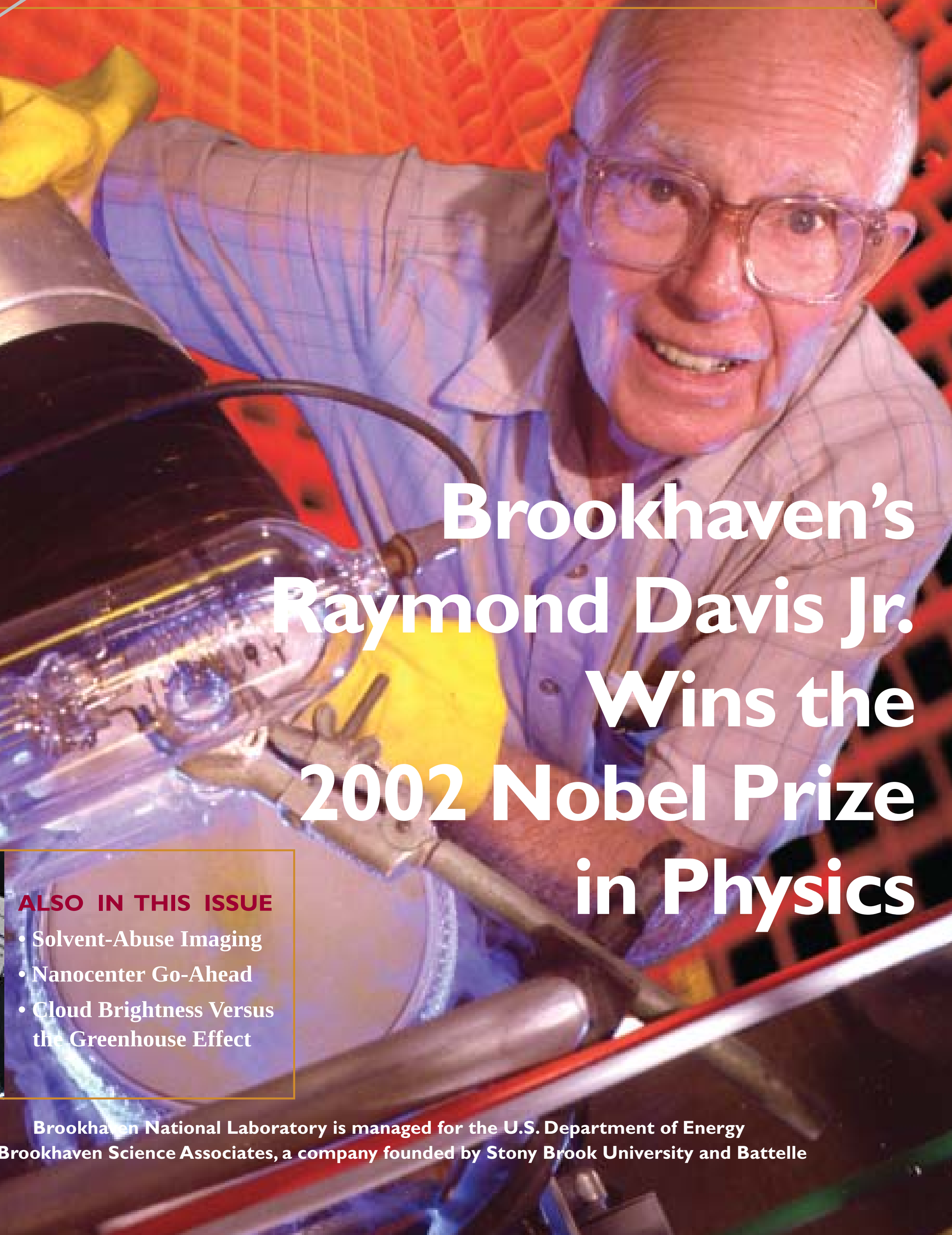

Brookhaven's Raymond Davis Jr. Wins the 2002 Nobel Prize in Physics

ALSO IN THIS ISSUE

- Solvent-Abuse Imaging
- Nanocenter Go-Ahead
- Cloud Brightness Versus the Greenhouse Effect

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Welcome to the second issue of
discover BROOKHAVEN,
a magazine dedicated to exploring and explaining
the scientific research and discoveries made at
the U.S. Department of Energy's
Brookhaven National Laboratory.

BY PETER PAUL
INTERIM BROOKHAVEN LABORATORY DIRECTOR
AND BROOKHAVEN SCIENCE ASSOCIATES PRESIDENT

Celebrating Brookhaven's Fifth Nobel Prize

IN STOCKHOLM ON DECEMBER 10, 2002, retired Brookhaven chemist Raymond Davis Jr. had the honor and the pleasure of receiving the 2002 Nobel Prize in Physics from the King of Sweden, a prize that Davis shares half with Masatoshi Koshiba of the University of Tokyo, Japan, "for pioneering contributions in astrophysics, in particular for the detection of cosmic neutrinos." Their work, respectively, proved that fusion powers the sun and showed that neutrinos oscillate among their three types as they travel from the Sun. The other half of the prize was awarded to Riccardo Giacconi of Associated Universities, Inc. in Washington, D.C., "for pioneering contributions to astrophysics, which have led to the discovery of cosmic x-ray sources."

Davis's prize is the fifth Physics Nobel to be awarded to scientists who have done research at the Laboratory. While three of these prizes were awarded for experiments at Brookhaven's Alternating Gradient Synchrotron accelerator and one was awarded for theory developed by visiting scientists, this is the first Nobel Prize in Physics to be awarded to a member of Brookhaven's scientific staff.

Retired Brookhaven chemist Raymond Davis Jr., with his wife Anna by his side, receives a standing ovation from the Laboratory crowd that celebrated his winning the 2002 Nobel Prize in Physics and his 88th birthday.

Following the October 8 announcement of Davis's win, several hundred of his colleagues and well-wishers gathered in the Laboratory's Berkner Hall on October 14, to celebrate his reward for having opened a new window on the universe by being the first to detect solar neutrinos, as well as the occasion of his 88th birthday. On behalf of Brookhaven, I was proud to congratulate Ray Davis because, starting early in his career and despite all odds, he had the single-minded vision, daring, and persistence of a person far ahead of his time and the rest of the world to do the impossible and succeed in solving a most fundamental problem in science.

As was recalled by the speakers at this gathering, Davis's work also represents the best of Brookhaven, as a place where scientists have been encouraged to chart the course of their research on the map of the Laboratory's interdisciplinary mission. At Brookhaven, theory and experiment aim for the science ahead of the curve, advanced detector and instrumentation development are the foundation for sound experimentation, and a passion for discovery inspires the Laboratory's staff, facility-users, and other visiting scientists every day.

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IN THIS ISSUE

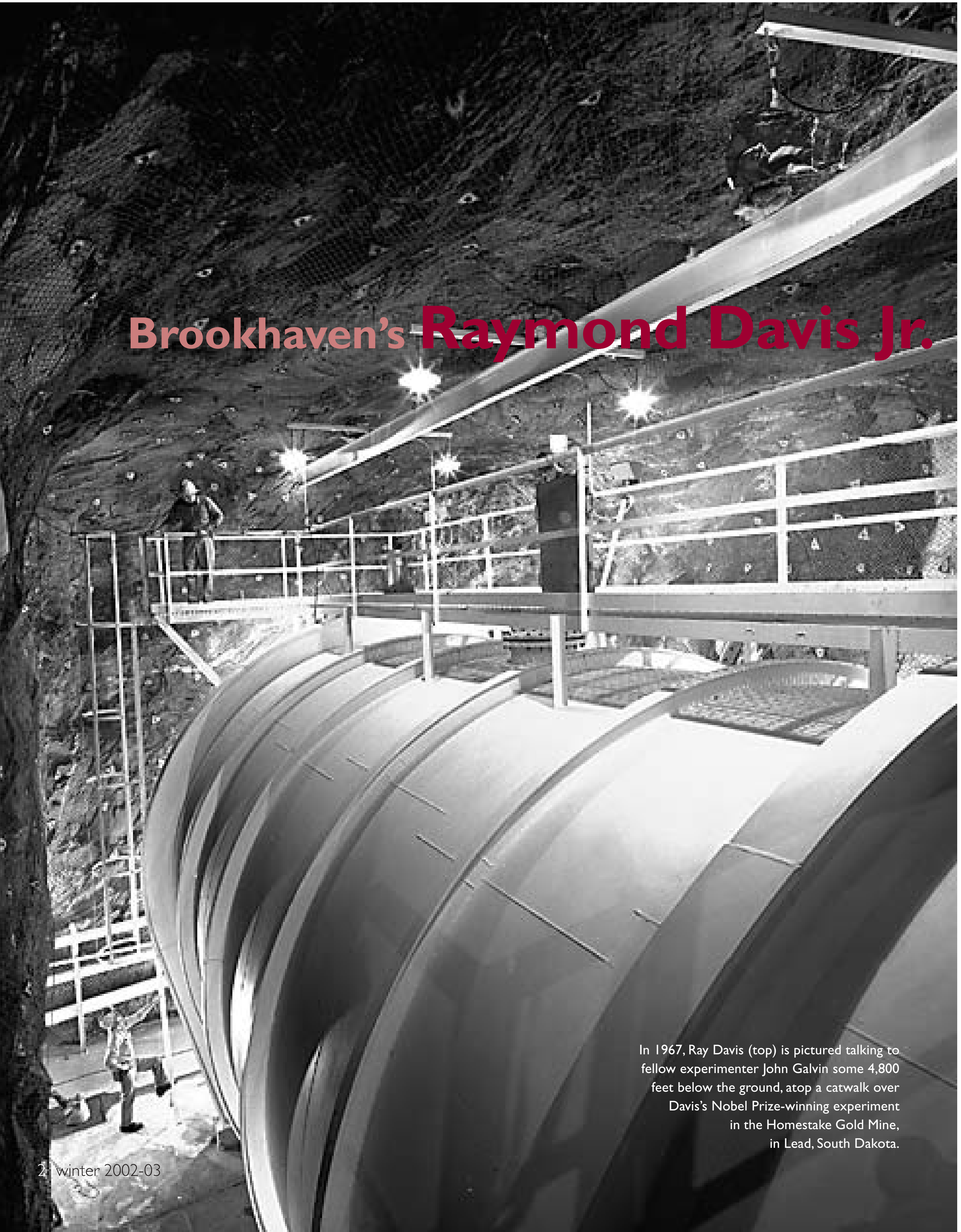
ON THE COVER: Retired Brookhaven chemist Raymond Davis Jr., who is a co-winner of the 2002 Nobel Prize in Physics, is seen in his Chemistry Department laboratory with part of a neutrino detection system (see cover story on page 2).

BROOKHAVEN
NATIONAL LABORATORY
managed for the U.S. Department of Energy by Brookhaven Science Associates, a company founded by Stony Brook University and Battelle
a passion for discovery

For being the first to detect neutrinos from the Sun, Brookhaven's Raymond Davis Jr. is co-recipient of the 2002 Nobel Prize in Physics. In answering the question, "Why does the Sun shine?" Davis's experiment also raised another question: "Do neutrinos change form as they travel from the Sun?" Inspired by Davis, later experiments have answered, "Yes!"

BY MONA S. ROWE

Brookhaven's Raymond Davis Jr. Wins the 2002 Nobel Prize in Physics

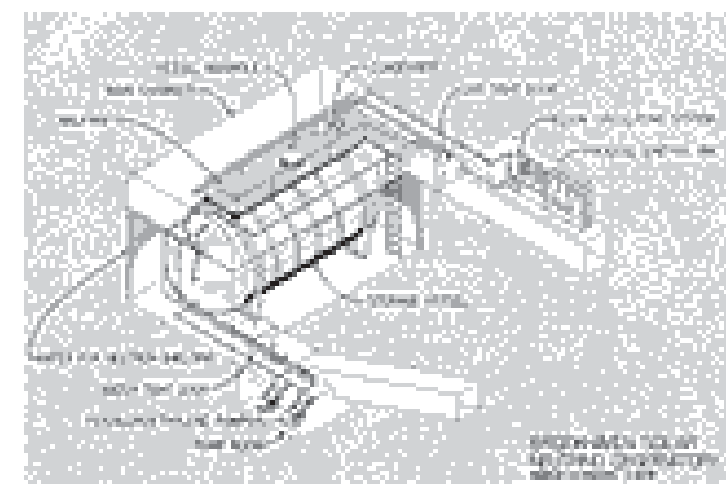


In 1967, Ray Davis (top) is pictured talking to fellow experimenter John Galvin some 4,800 feet below the ground, atop a catwalk over Davis's Nobel Prize-winning experiment in the Homestake Gold Mine, in Lead, South Dakota.

SOME 4,800 FEET UNDERGROUND, in a gold mine in the Black Hills of South Dakota, Brookhaven's Raymond Davis Jr. and his small research team operated a subterranean astronomy observatory from 1967 to 1985 to examine the core reaction of the Sun.

Within the core of the Sun, light and heat up to temperatures of 27 million degrees Fahrenheit are produced as a result of fusion, a reaction in which hydrogen nuclei — protons — are transformed into helium. In the process, two neutrinos arise for each helium nucleus formed.

These solar neutrinos are the only particles emerging from the Sun's nuclear furnace that survive the 93-million-mile trip to the Earth. By being the first to detect these ghostlike particles, Davis not only confirmed why the Sun shines, but also opened the scientific community's eyes to the field of neutrino astronomy. And, in doing so, Davis enabled others to figure out what puzzled him about his own results: Since he detected only one-third of the expected neutrinos, do neutrinos change form as they travel from the Sun? Eventually confirming Davis's results, later experiments found the answer to be yes, neutrinos do oscillate.



In the Homestake Gold Mine in Lead, South Dakota, the Brookhaven Solar Neutrino Experiment consisted of 100,000 gallons of tetrachloroethylene, a dry cleaning fluid, in a 20-foot-in-diameter by 48-foot-long tank; a pair of pumps to circulate helium through the liquid; and a small control-room building.

Now, 38 years after the publication of the first of many pivotal papers on his solar neutrino research, Davis, a BNL retired chemist, has been awarded the 2002 Nobel Prize in Physics. He shares one half of the prize with Masatoshi Koshiba, of the University of Tokyo, Japan, and both are cited "for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos." The other half of this year's physics prize was given to Riccardo Giacconi of Associated Universities, Inc., in Washington, D.C., who was cited "for pioneering contributions to astrophysics, which have led to the discovery of cosmic x-ray sources."

"I was very surprised by the news that I had received the Nobel Prize," says Davis. "I had a lot of fun doing the work, and I could never have done it without the help of colleagues all over the world, especially at BNL, the Homestake Mine, and the University of Pennsylvania."

Brookhaven's solar neutrino research at the Homestake Gold Mine was funded, in succession, by the Chemistry Office of the Atomic Energy Commission, the Energy Research & Development Administration, and the Division of Nuclear Physics of the U.S. Department of Energy (DOE).

To follow up upon Davis's research, other Laboratory scientists have been studying solar neutrino physics, first as part of the GALLEX experiment in Italy and, more recently, as collaborators at the Sudbury Neutrino Observatory (SNO) in Canada. Brookhaven's participation in GALLEX and SNO has been supported by the Office of High-Energy & Nuclear Physics within DOE's Office of Science.

CHLORINE-ARGON METHOD

Wolfgang Pauli first postulated the neutrino, in 1930. In 1938, Hans Bethe, who won the 1967 Nobel Prize in Physics for this work, established that the formation of helium from four protons is responsible for the energy generated by stars such as the Sun. Verifying this theory by detecting the resulting neutrinos, however, was considered an impossibility.

In 1956, Frederick Reines, who earned half of the 1995 Nobel Prize in Physics for this research, and Clyde Cowan were the first experimentally to prove the existence of the neutrino particle, by observing antineutrinos coming from the Savannah River nuclear reactor — where, in 1954, Raymond Davis had also set up an experiment, but one using what is called the chlorine-argon neutrino method for detecting neutrinos directly.

This method makes use of the neutrino capture reaction, whereby, when

“How lucky I was to land at Brookhaven, where I was encouraged to do exactly what I wanted — and get paid for it!”

RAYMOND DAVIS JR.

Meet Ray Davis

Raymond Davis Jr. earned a B.S. and an M.S. from the University of Maryland in 1937 and 1940, respectively, and a Ph.D. in physical chemistry from Yale University in 1942. After his 1942-46 service in the U.S. Army Air Force and two years at Monsanto Chemical Company, he joined Brookhaven's Chemistry Department in 1948. He received tenure in 1956 and was named senior chemist in 1964.

From 1971 to 1973, Davis was a member of the National Aeronautics and Space Administration's Lunar Sample Review Board, involved in the analysis of lunar dust and rocks collected by Apollo 11 on the National Aeronautics and Space Administration's historic first flight to the moon. Davis retired from Brookhaven in 1984, but has a research collaborator appointment in the Chemistry Department. In 1985, he joined the University of Pennsylvania as a research professor, to continue experiments at the Homestake Gold Mine.

A member of the National Academy of Sciences and the American Academy of Arts and Sciences, Davis has won numerous scientific awards, including: the 1978 Cyrus B. Comstock Prize from the National Academy of Sciences; the 1988 Tom W. Bonner Prize from the American Physical Society; the 1992 W.K.H. Panofsky Prize, also from APS; the 1999 Bruno Pontecorvo Prize from the Joint Institute for Nuclear Research in Dubna, Russia; the 2000 Wolf Prize in Physics, which he shared with Masatoshi Koshiba, University of Tokyo, Japan; and the 2002 U.S. National Medal of Science.

an atom of chlorine-37 captures a neutrino, it becomes argon-37. As his source of chlorine, Davis used the dry cleaning fluid carbon tetrachloride, in an experimental setup developed at the Brookhaven Graphite Research Reactor.

After his Savannah River experiments helped confirm that neutrinos and antineutrinos are different particles, Davis began considering an experiment to measure neutrinos from the Sun, as a way of testing the theory that hydrogen-helium fusion reactions are the source of solar energy. Again, he used the chlorine-argon detection method, but in experiments located deep within the Earth to avoid the production of argon-37 through the interaction of chlorine with cosmic rays.

Davis constructed his first solar neutrino detector in 1961, some 2,300 feet below ground in a limestone mine in Ohio. Building on this experience and testing prototype equipment in the Laboratory's swimming pool, he mounted a full-scale experiment in the Homestake Gold Mine, South Dakota.

The experimental apparatus consisted of 100,000 gallons of tetrachloroethylene, another dry cleaning fluid, in a 20-foot-in-diameter by 48-foot-long tank; a pair of pumps to circulate helium through the liquid; and a small control-room building — all located some 4,800 feet below the surface.

ONE-THIRD OF THE NEUTRINOS

Throughout the course of this research, Davis consistently found only one-third of the neutrinos predicted by standard solar theories. His results threw the field of astrophysics into an uproar, and, for nearly three decades, physicists tried to resolve what they called the solar neutrino puzzle.

Experiments in the 1990s using different detectors around the world eventually confirmed the discrepancy in the number of solar neutrinos that Davis detected. Davis's lower-than-expected neutrino detection rate is now accepted by the international science community as the first evidence that neutrinos have the ability to change from one of the three known neutrino types into another.

This characteristic, called neutrino oscillation, implies that the neutrino has mass, a property that is not included in the current standard model of elementary particles. Davis's detector was sensitive to only one type of the neutrino, the electron-type neutrino which is produced in the Sun. If these neutrinos had changed into the other types, then they would have seemed to have disappeared.

BROOKHAVEN'S FIFTH NOBEL

Davis's award is the fifth Nobel Prize in Physics won by scientists connected with Brookhaven — but the first to be awarded to a member of the Laboratory's scientific staff. The four previous Nobel Prizes were awarded for these discoveries:

- 1988: for the 1962 discovery at the Alternating Gradient Synchrotron (AGS) of the muon-type neutrino, by Leon Lederman, Melvin Schwartz and Jack Steinberger.
- 1980: for the 1963 discovery at the AGS by James Cronin and Val Fitch of CP violation.
- 1976: for the 1974 discovery by Samuel C.C. Ting at the AGS and Burton Richter at the Stanford Linear Accelerator of the J/psi particle.
- 1957: for the 1956 proof of the violation of parity conservation in weak interactions, by T.D. Lee and C.N. Yang.

MORE INFORMATION

- *paper:* “Solar Neutrinos,” Physical Review Letters, March 16, 1964, volume 12, number 11, pp. 303-305
- *contact:* Mona S. Rowe, mrowe@bnl.gov or (631) 344-5056
- *Web:* www.bnl.gov/bnlweb/history/Nobel/Nobel_02.html

Instrumentation Research & Development at Brookhaven

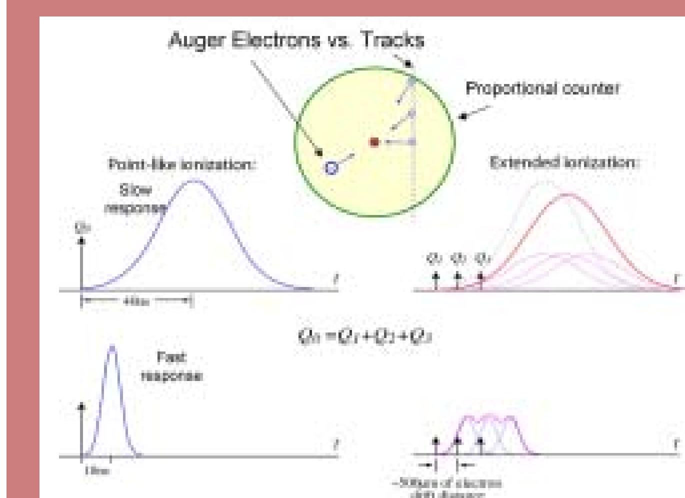
To detect solar neutrinos directly in his Homestake Mine experiment, Ray Davis made use of a neutrino capture reaction, whereby, when an atom of chlorine-37 captures a neutrino, it becomes argon-37. In the subsequent decay of argon-37 back to chlorine-37, two Auger electrons are emitted with a total energy of 2.8 kilo electron volts (keV), which Davis measured using a proportional counter.

During the first three years of the now Nobel-prize winning experiment, a “single-parameter” technique was employed to detect the Auger electrons. While this technique did produce an upper limit for the neutrino capture rate, it could not distinguish between the point-like ionization produced by the Auger electrons and the extended ionization tracks of more energetic electrons arising from gamma-ray and other background events.

To solve this problem, Lee Rogers and Veljko Radeka of Brookhaven's Instrumentation Division employed a two-parameter technique that rejected between 85 and 98 percent of the background-radiation events. To apply this “pulse rise-time” method to Davis's experiment, the Instrumentation researchers developed low-noise amplification and signal processing on a nanosecond time scale.

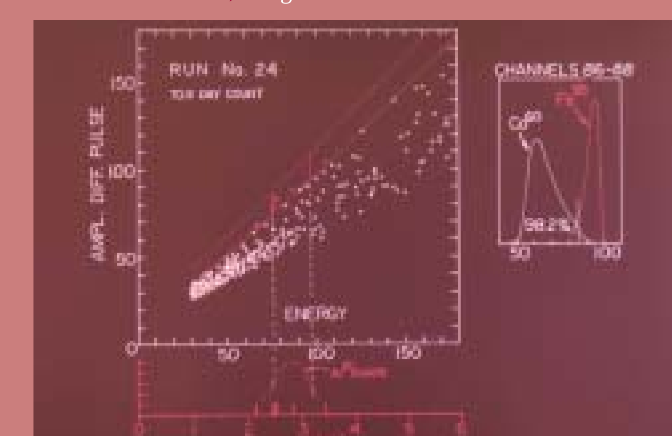
The new detection system was introduced in 1970, and, after one year of its operation, the first clear signal of a solar neutrino was observed. As Ray Davis has commented, “The pulse rise-time system development gave the Homestake experiment new life,” thanks to instrumentation research and development at Brookhaven Lab.

The very small number of argon-37 atoms created by solar neutrino capture are first extracted from the large tank (background) containing about 10^{31} chlorine-37 atoms and then transferred into a proportional counter (foreground) with an active volume of approximately 0.5 cubic centimeters.



(Above) Emitted following the electron-capture decay of argon-37 to chlorine 37, the Auger electrons lose all of their energy (2.8 keV) over a very short distance in the counter gas and produce a point-like ionization. Background events, due mostly to gamma rays, produce much more energetic electrons, which result in extended ionization tracks. The charge due to ionization is amplified by an avalanche process near the center wire, which is an anode, and produces signals as illustrated in the figure. On the very short time scale of a few nanoseconds, there is a clear distinction in the signal waveforms between point-like and extended ionization, which provides the unique signature that distinguishes argon-37 decays from background radiation.

(Below) The electronic counting system developed to distinguish between argon-37 decays and background radiation shows the peak signal current (“Ampl. Diff. Pulse”) as a function of energy deposited for each detected event. Red circles represent argon-37-like events, while white circles show the background-like events. The discrimination properties are shown by illuminating the counter using iron-55 x-rays for point-like ionization, and cobalt-60 gamma rays for extended ionization. The response for energies around 2.8 keV is shown in the inset.



Introducing DOE's Nanoscience Initiative

In 1959, physicist Richard Feynman spoke to the American Physical Society on how "There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics." Besides reviewing the difficulties of assembling things atom by atom, Feynman discussed the rewards for science, technology, and humankind that can result from the atomic level synthesis of new materials. As the famed American physicist said: "[I]t is something, in principle, that can be done, but, in practice, it has not been done because we are too big."

With the advent of scientific instruments and facilities to investigate the world of the ultra-small — such as the synchrotrons, electron microscopes and laser accelerators found at Brookhaven — the emerging field of nanoscience — as Feynman's new interdisciplinary area is now called — is being heralded as the driving force behind what will be the next industrial revolution.

Recognizing that some nanoscience research may take years, the U.S. government began investing in a National Nanotechnology Initiative in fiscal year 2001. As a leader of this initiative, the U.S. Department of Energy is building on its infrastructure of user facilities, by establishing nanoscience and technology centers around the country, at national labs such as Brookhaven.

Energy Secretary Abraham Gives Nanocenter Go-Ahead

To advance the national initiative to study the science of materials at ultra-small dimensions, the Center for Functional Nanomaterials will be built at Brookhaven Lab, next to the National Synchrotron Light Source. In announcing the center's approval, Energy Secretary Spencer Abraham affirmed the practical importance of basic science and Brookhaven's place in the world as a valuable center for scientific research.

BY PATRICE PAGES

"ON BEHALF OF THE U.S. DEPARTMENT OF ENERGY, I am pleased today to officially announce our approval to begin the conceptual design of the $85-million Center for Functional Nanomaterials here at Brookhaven."

With this statement, U.S. Secretary of Energy Spencer Abraham in June declared that DOE will establish a Northeast center for nanoscience research at the Laboratory. To be called the Center for Functional Nanomaterials and to be located next to the National Synchrotron Light Source, Brookhaven's nanocenter will be one of five such facilities to be built around the country under the U.S. National Nanotechnology Initiative (see sidebar, at left).

Nanoscience is the study of materials at ultra-small dimensions — on the scale of a nanometer, or a billionth of a meter, which is 1,000 times smaller than a human hair. Nanoscale science, engineering, and technology is an emerging, interdisciplinary area involving material scientists, chemists, physicists, biologists, and other researchers. Their goal: to work atom by atom, molecule by molecule to design and assemble new structures, materials that have desired properties and functions.

For example, it is thought that nanoscience research and development will result in improved solar energy conversion, lighting, and lightweight materials, all of which will reduce energy costs.

In addition, nanoscale technology may enable improvements in the early detection of cancer, the speed and capacity of computers, and the development of objects not yet imagined to very exact specifications, to meet a variety of technological challenges.

Abraham announced his good news — giving the go-ahead for the Laboratory's first project to construct a new scientific facility since the building of the Relativistic Heavy Ion Collider — during his first visit to Brookhaven, which the Energy Secretary made with DOE Office of Science Director Raymond Orbach.

The design of the nanocenter at the Laboratory is expected to start in fiscal year (FY) 2004, with commissioning planned for FY2007. The project's preliminary cost estimate is $70-85 million. The conceptual design report for the center is being prepared under the Office of Science, so that construction funding can be requested from Congress.

Following the announcement, Abraham received a standing ovation from an audience of Brookhaven employees, facility-users, and other guests, as they showed their enthusiasm for a new scientific facility that allows the Laboratory to become a major player in a new field.

"Nanoscience offers the potential for a second Industrial Revolution," Abraham said. "The implications are enormous. That is why we are so serious about America's leading the way in nanoscience.

"With the nanoscience center which we launch today, Brookhaven is on track to remain one of America's, and the world's, most valuable centers for scientific research," Abraham concluded.

NANOSCIENCE EXPERTISE

As Abraham elaborated, Brookhaven's new center will be a user facility open to researchers in a range of disciplines from across the country and around the world, who will gain access to the nanocenter's state-of-the-art instrumentation and equipment through a peer-review process.

"When this center is complete, physicists, chemists, materials scientists, and biologists will work with computer scientists and engineers to explore the world atom by atom," added Abraham.

"You need major facilities for this kind of work, with the best new technology and the best minds that America has to offer," the Secretary continued. "We have all of this here at Brookhaven."

To advance the study of nanoscale materials, Brookhaven will exercise three major strengths, which are based on the Laboratory's expertise, experience, and existing facilities:

1. The Laboratory operates three key facilities for studying the properties of nanomaterials.

"With the nanoscience center which we launch today, Brookhaven is on track to remain one of America's and the world's most valuable centers for scientific research."

U.S. DEPARTMENT OF ENERGY SECRETARY SPENCER ABRAHAM

The National Synchrotron Light Source at Brookhaven

PURPOSE
To provide intense beams of x-ray, ultraviolet, and infrared light for basic and applied research in physics, chemistry, medicine, geophysics, and environmental and materials sciences.

SPONSOR
Office of Science, U.S. Department of Energy

OPERATING COSTS
$35 million per year

FEATURES
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- An array of sophisticated imaging techniques

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COMPLEMENTARY DOE FACILITIES
- Advanced Photon Source at Argonne National Laboratory
- Advanced Light Source at Lawrence Berkeley National Laboratory
- Stanford Synchrotron Radiation at the Stanford Linear Accelerator Center

WEB ADDRESS
nslsweb.nsls.bnl.gov/nsls

These facilities are —

- NATIONAL SYNCHROTRON LIGHT SOURCE (NSLS): One of the world's most widely used scientific facilities, the NSLS is host to more than 2,500 guest researchers from nearly 500 universities, laboratories, and corporations. They use its very bright beams of x-rays, ultraviolet, and infrared light to reveal the structure and function of a range of physical materials and biological specimens.

- LASER ELECTRON ACCELERATOR FACILITY (LEAF): The fastest device in the U.S. for studying the rates and energetics of chemical reactions induced by pulses of electrons, LEAF is ideal for investigating the transport of charge between molecules while they react.

- TRANSMISSION ELECTRON MICROSCOPE (TEM): The best of its kind in the U.S. and one of three such microscopes in the world, TEM is used to visualize the electronic, magnetic, and optical properties of materials down to the atomic level.

2. Brookhaven's scientific staff and facility-users have a long history of achievement in understanding the structure and function of materials. For instance, Brookhaven scientists have accomplished and are continuing research into the structure and self-assembly of what are called organic thin films, which are essential components of coatings, computer displays, and organic based electronics.

What's more, by looking inside the crystals of materials, Laboratory researchers have detected the shifting of atoms within the crystalline lattice as small as a one-hundredth of an atom's width, which is ten times better resolution than previously accomplished. This understanding will allow scientists to control how the lattice shifts as the crystal is manipulated to introduce desirable electronic, optical, or magnetic traits.

Also, Brookhaven researchers have developed methods to make nanocatalysts, for instance, to speed up chemical reactions within a car's catalytic converter or during the production of antifreeze.

3. With its user-facilities and collaborative research, the Laboratory is, respectively, a resource for and a partner in university- and industry-based research in the Northeast.

In addition to Brookhaven's long-standing affiliation with Stony Brook University — which is the largest academic user of the Laboratory's facilities and a member of Brookhaven Science Associates — Brookhaven will expand its nanoscience collaborations with faculty at universities in the Northeast.

In fact, many of these universities are performing National Science Foundation-funded research complementary to that at Brookhaven.

And, since its start, the NSLS has hosted the materials science beam lines and staff scientists of corporations such as Dupont, ExxonMobil, IBM, and Lucent. These companies and others will expand their role and research as the nanoscience center is established.

The Center for Functional Nanomaterials (at right) at Brookhaven will be a 78,000-square-foot, two-story building of laboratories and offices located adjacent to the National Synchrotron Light Source (NSLS) (left, front) and the Instrumentation Division (left, back). The center will feature five laboratory clusters, a theory and computer center, and stations dedicated to nanoscience experiments to be conducted at the end of NSLS beam lines.

SIX PROJECT AREAS

The work at the nanocenter at Brookhaven will be focused in six project areas:

- STRONGLY CORRELATED METAL OXIDES: Since many superconductors, which are materials that, below a certain temperature, can conduct electricity with no resistance, are metal oxides, understanding how they operate at the nanoscale may lead to their everyday use to provide much less expensive electrical power.

- MAGNETIC NANOASSEMBLIES: Because the spin of electrons and nuclei are responsible for magnetism, learning how to manipulate magnetic materials on the nanoscale may increase the storage capacity and retrieval speed for magnetic storage devices such as computers, CDs, and more.

- NANOCATALYSTS: By changing the structure and function of catalysts on the nanoscale, new and improved ways of speeding up chemical reactions could be developed, thereby reducing the cost and environmental impact of existing products and processes, and increasing the development of new, energy-efficient, environmentally friendly goods and methods.

- CHARGE INJECTION & TRANSPORT: Understanding the transfer of electrons between molecules within a material at the nanoscale is important in creating more sophisticated electronics and other devices, such as photonics, which convert light into electricity.

- NANOMETER-THICK ORGANIC FILMS: Improving the physical and chemical properties of organic films that are used in protective coatings, sensor equipment, and more may result from developing a nanoscale understanding of how the molecules within the film interact with each other and with the molecules of the substrate on which the films are grown.

- NANOSCIENCE APPLICATIONS: Brookhaven scientists, university researchers, and their industrial partners will explore ways to apply the knowledge gained within the above five project areas, to develop new devices and processes for the benefit of humankind.

MORE INFORMATION

- *funding:* Office of Science, U.S. Department of Energy
- *document*: "Nanoscale Science Research Center for Functional Materials at Brookhaven National Laboratory" Proposal for Approval of Conceptual Design, March 2001
- *contact:* John Taylor, Special Assistant to the Associate Laboratory Director for Basic Energy Sciences, jtaylor @bnl.gov or (631) 344-7005
- *Web:* www.bnl.gov/cfn

The Laser Electron Accelerator Facility

PURPOSE

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FEATURES

- measures chemical reactions with 7-picosecond resolution
- studies photochemistry of radical species with 50-femtosecond resolution

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- ten U.S. universities, one federal institute
- five universities and institutes in five countries

OTHER BNL FACILITIES

- 2-MeV electron Van de Graaff accelerator for 40-nanosecond pulse radiolysis
- Cobalt-60 gamma source for continuous irradiation

WEB ADDRESS

www.chm.bnl.gov/sciandtech/prc/wishart/crcrintr.html

The Transmission Electron Microscope

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WEB ADDRESS

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Brookhaven chemist Madina Gerasimov, who is lead author of the journal article describing the first brain imaging of "huffing," and her colleague, neuroanatomist Stephen Dewey, who is one of the paper's co-authors.

According to a recent national survey, some two million American children and teens have reported inhaling solvents to experience a high at least once in their lives.

Inspired by the questions from schoolchildren about the negative effects of inhalant abuse or "huffing," Brookhaven Lab scientists have produced the first images showing what parts of the brain and body are most affected by toluene, one of the solvents misused by inhalant abusers. These images reveal why solvents are so addictive.

BY KAREN MCNULTY WALSH

Brain-Imaging Study Offers First Clues to the Abuse of Inhaled Solvents

INHALANT ABUSE, OR "HUFFING," is the intentional breathing of gases or vapors to get "high." Inhalants that can be huffed include such common household products as spray paint, hairspray, and nail polish. They are legal, easily obtained at home or stores, and free or inexpensive. No dealers or paraphernalia are involved, and use can occur anywhere.

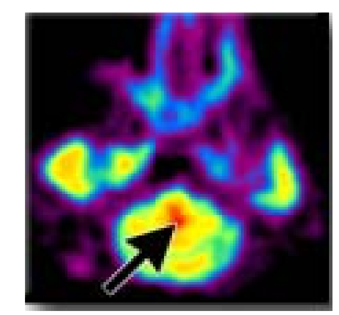
While many parents may not be aware of the abuse of inhalable household products, children are. In fact, according to a recent national survey, some two million American children and teens have reported inhaling solvents to experience a high at least once in their lives.

However, many abusers are unaware of the destructive physiological and psychological consequences of inhalant abuse on the body and brain, including long-term organ damage and what is called sudden sniffing death syndrome.

Inspired by questions from schoolchildren about the negative effects of huffing, Brookhaven Lab scientists have produced the first images showing what parts of the brain and body are most affected by toluene, a clear, sweet-smelling liquid solvent found in many of the paints, fingernail polishes, and adhesives abused by huffers.

These brain scans show where toluene, a common solvent, goes in the brain 2 minutes after injection. The red end of the scale indicates the highest concentration. The image below shows how toluene quickly enters the brain's striatal region (two arrows), which is associated with reward and pleasure.

Images from this study, which was performed using positron emission tomography on animals, reveal why solvents such as toluene are so addictive. The images show that toluene moves rapidly into the brain, initially affecting the same brain regions as do cocaine and other abused drugs. Toluene then spreads more generally to the entire brain before being cleared rapidly from the body via the kidneys.



The image above shows how toluene enters deep cerebellar nuclei, which are involved in voluntary movement. These findings agree with clinical evidence that toluene "huffers" experience a rapid "high" and suffer neurological symptoms, such as a lack of coordination and slurred speech.

"This affinity for brain regions associated with reward and pleasure, as well as the solvent's quick uptake and clearance, may help to explain why inhalants are so commonly abused," says Brookhaven chemist Madina Gerasimov, who is the lead author of the journal paper reporting the study's results.

"For the first time, we have shown in living animals where the most commonly used solvent goes in the brain and the whole body," adds Brookhaven neuroanatomist Stephen Dewey, a coauthor. The study was funded by the U.S. Department of Energy and the National Institute on Drug Abuse.

REGIONAL DISTRIBUTION EQUALS GLOBAL EFFECTS

To label the toluene, Brookhaven chemists replaced some of the compound's carbon atoms with a radioactive isotope, carbon-11. This

> "These exciting, new findings will provide the basis for an entirely new research direction targeted at an important field of scientific inquiry."
>
> MADINA GERASIMOV

Meet Stephen Dewey and Madina Gerasimov

"This study was really born out of my going to local elementary schools, where, since 1995, I've been giving talks about Brookhaven's addiction research," says neuroanatomist Stephen Dewey.

Following his talks, children as young as fourth and fifth graders would sometimes ask him about huffing. "After about the third or fourth time that someone asked me, I proposed that we develop a way to label and image solvents, which seem to be a 'gateway' drug of abuse for some young children," explains Dewey.

He then asked his colleague Madina Gerasimov if she thought it were possible to label the solvent. While Gerasimov told Dewey, "No one had ever done this before," that did not mean that it could not be done.

Since toluene evaporates quickly and since the carbon-11 radioisotope used to label it for the imaging studies has a short half-life, she had to work quickly. "It was very challenging," she says.

With solvent-labeling and the first study

(continued on page 13, right column)

radiolabeled toluene was then injected into the experimental animals. The scientists used injection rather than inhalation as an administration route so that they would know precisely how much toluene the animals were given.

The level of the radioisotope was then measured using a positron emission tomography (PET) camera, which picks up the radioactive signal. The PET camera shows exactly where the toluene is located in the body and tracks its location over time. Other tissue-sampling methods were used to track the toluene as well.

The scientists were surprised by the findings. "I couldn't believe it," comments Dewey. "The theory has always been that the effects of solvents would not be very specific — that if you breathe them in, they'd go everywhere equally."

"But, in fact, it looks as if there's a regional distribution," Dewey continues. "They first go to specific regions associated with reward and pleasure, just like other abused drugs. But, then, over time, they redistribute." The initial specificity for the brain's reward centers may help to explain the addictive potential of inhalants, while the redistribution to the entire brain seems to mirror clinical changes observed in huffers.

Unlike other drug abusers, whose reward centers have become damaged, "Huffers have a much more global disease," Dewey explains, since they undergo changes in areas of the brain that may interrupt normal learning and memory more quickly than do users of other drugs.

ADVANCEMENT OF RADIOCHEMISTRY

In addition to offering insight into the nature and effects of inhalant abuse, Gerasimov says, this study is also a technical advance in radiochemistry. "It's the first time chemists have labeled and purified a solvent for imaging," she explains.

This new ability may open up a whole new field of study into the effects of a wide array of solvents found in common, everyday products from cleaning fluids to hairsprays. Studying solvent distribution in the brain and body is something to consider, as "There isn't a person among us who isn't exposed to solvents," Dewey said.

MORE INFORMATION

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- *paper:* "Study of Brain Uptake and Biodistribution of an Abused Inhalant Using PET and a Novel Radiotracer [11C]Toluene," Life Sciences, April 26, 2002, volume 70, issue 23, pp. 2811-2828
- *contact:* Madina Gerasimov, madina@bnl.gov or (631) 344-4383; Stephen Dewey, sld@bnl.gov or (631) 344-4395
- *Web:* www.bnl.gov/bnlweb/pubaf/pr/2002/bnlpr041502.htm

Positron Emission Tomography at Brookhaven

Positron emission tomography (PET) is an imaging method used to track the regional distribution and kinetics in the living body of chemical compounds labeled with short-lived, positron-emitting isotopes. A positron emitted by one of these light-element radioisotopes travels only a short distance from the nucleus before interacting with an electron and annihilating. This produces two 511-kilo-electron-volt photons emitted in opposite directions, which are of sufficient energy to penetrate the body. These photon pairs allow the radiotracer to be located by triggering detector pairs within PET's circular array, which is placed around the region of the body under study.

In the inhalant study, the radiotracer was carbon-11-labeled toluene. This is the first study allowing scientists to trace the pharmacokinetics of this common industrial solvent as it moves through the body. The Brookhaven team is already applying for grants to label other solvents and study their pharmacokinetics, first in animals and then in human beings. Laboratory researchers are also working to develop a method to study these chemicals in inhaled as well as injected form, to further their understanding of the mechanisms of solvent intoxication and addiction.

successfully accomplished, Gerasimov, Dewey, and their colleagues are collaborating on additional studies of the effects of other solvents in animals and human beings.

Formerly a doctor of dental surgery in Russia, Madina Gerasimov came to the United States in 1993. She earned a master's degree in medicinal chemistry from Purdue University before joining Brookhaven Lab in 1998.

Gerasimov has collaborated with Dewey and others on many of the Laboratory's addiction studies. She has a college-age son, and she enjoys reading and working out. Gerasimov has been accepted by the medical school of New York University, where she will matriculate in fall 2003.

Stephen Dewey did his undergraduate work in biology and chemistry at Fairleigh Dickenson University, earned a Ph.D. in anatomy from the University of Iowa, performed postdoctoral work in neurology at Stony Brook University, and joined Brookhaven's staff in 1986.

Married and the father of two children, he enjoys teaching, writing, and riding his motorcycle — when not speaking to children in the local schools about his research into the causes and results of addiction.

> "This work came directly from questions raised by local schoolchildren, which speaks to our ongoing dedication to helping the community, especially its youngest members."
>
> STEPHEN DEWEY

Atmospheric scientists have long suspected that aerosol particles from industrial processes increase the brightness of clouds, resulting in greater reflection of sunlight and cooling of the Earth's climate. Now, using direct satellite observations and a computer-based atmospheric chemical transport model, Brookhaven Lab scientists and their university collaborators demonstrate that the brightening effect is real.

BY KAREN MCNULTY WALSH

Quantifying **Cloud Brightness** May Help Gauge the **Magnitude** of the **Greenhouse Effect**

Brookhaven chemical engineer Carmen Benkowitz and atmospheric chemist Stephen Schwartz, who co-developed a computer-based atmospheric chemical transport model to calculate the distribution of aerosol particles Earth's atmos

MINUTE PARTICLES SUSPENDED IN THE ATMOSPHERE, aerosols result from active volcanos, desert dust, and many human activities, including the ever-increasing burning of fossil fuels that began with the Industrial Revolution. Because clouds form when water vapor condenses on the ever-present aerosols, it has been long known that clouds owe their existence to these atmospheric particles.

By reflecting or absorbing sunlight, aerosols have long been thought to have an important direct and indirect effect on the Earth's climate, by influencing the amount of heat and light coming to the Earth from the Sun.

Now, scientists at Brookhaven Lab and their collaborators at Purdue University have determined that the brightness of clouds actually depends upon aerosol particles. This finding is important because the brighter the cloud, the more sunlight that is reflected away from the Earth, and the cooler the climate.

Using funding from the U.S. Department of Energy and the National Aeronautics and Space Administration, the Laboratory's Stephen Schwartz and his collaborators at Brookhaven and Purdue University used experimental data to demonstrate this cloud-brightening effect on a geographic scale the size of an ocean basin. An atmospheric chemist, Schwartz and his colleagues accomplished this by combining satellite measurements of cloud brightness, water content, and other variables with calculations of atmospheric aerosols.

Before, says Schwartz, it was only a supposition that aerosols had an impact on cloud brightness, and that supposition was based largely on computer-model calculations instead of on data from experimental observation.

This new understanding of the relationship between aerosols and cloud brightness, the researchers say, can now be used in assessing the magnitude of global climate change resulting from human activity since the Industrial Revolution.

"Our study provides a method of quantifying the cloud-brightness phenomenon globally over the past 15 years using archived satellite data," explains Schwartz. "Once this is done, we will have a much better idea of the true magnitude of the greenhouse effect."

The greenhouse effect is caused by carbon dioxide, methane, and other atmospheric gases, which trap heat from the Sun in the Earth's atmosphere, causing it to act like a greenhouse in keeping the world's climate warm. Because of the increase in the atmospheric concentration of these greenhouse gases, the greenhouse effect is thought to have been increasing since the Industrial Revolution and, therefore, affecting the global climate.

"We're not saying that, by increasing cloud reflectivity, aerosols can counteract the greenhouse effect," adds Schwartz, "but, rather, that we need to know how much of a cooling effect they do have so that we can have a clearer picture of the greenhouse effect. To whatever extent aerosols are offsetting greenhouse warming, then the offset is the unseen part of the greenhouse 'iceberg.' "

TWO WEEKS IN APRIL 1987

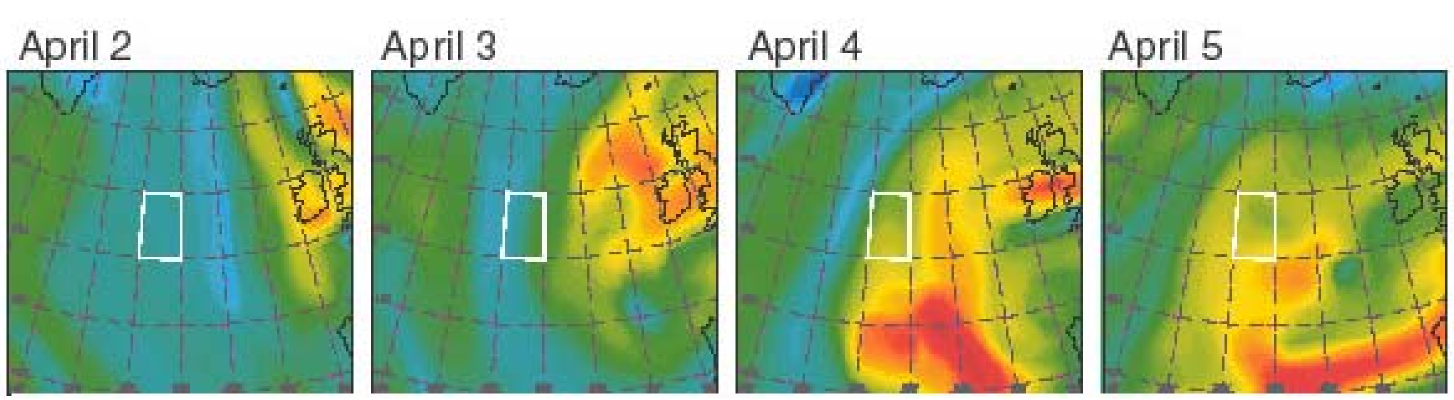
Typically, aerosols are present in the lowest 3 to 4 kilometers above Earth's surface, and they precipitate out of the atmosphere in about a week after their emission from either a natural or human-made source.

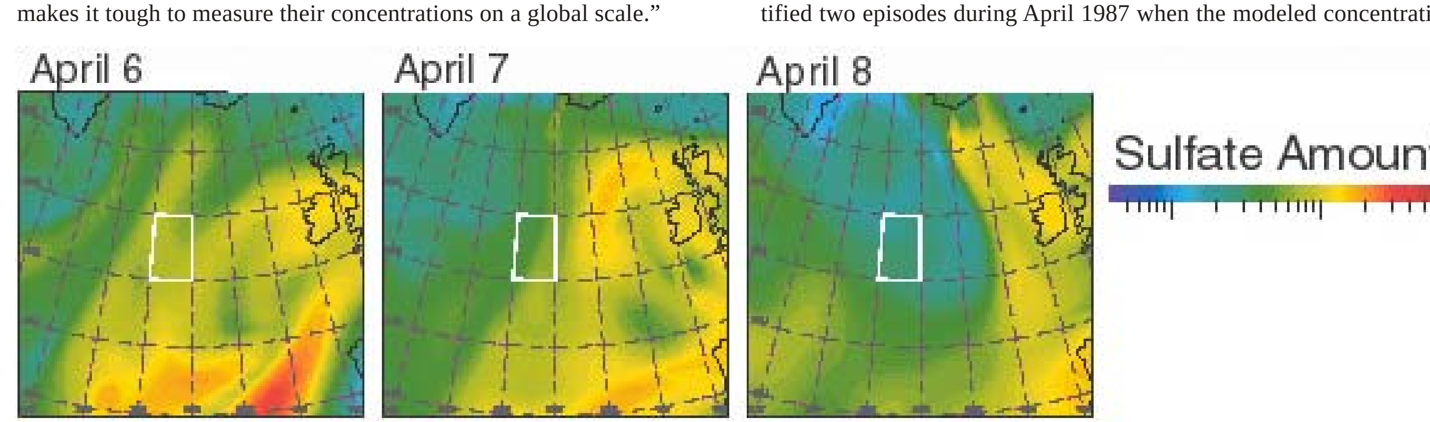
One difficulty of measuring the effect of aerosols is knowing their concentration. Explains Schwartz, "Because of their short residence time, aerosols are highly variable as a function of location and time, which makes it tough to measure their concentrations on a global scale."

Along with other collaborators, Schwartz and Brookhaven's Carmen Benkovitz, who is a chemical engineer, have been working for more than a decade to develop and refine a computer-based, atmospheric chemical transport model to calculate aerosol distribution. Their model uses archived data from weather prediction models to track the distribution of aerosols from industrial sources within various parts of the atmosphere.

"This model is the key to knowing where and when to look for the aerosol effect," comments Schwartz.

By analyzing data from their model, the Brookhaven-Purdue team identified two episodes during April 1987 when the modeled concentration





The images above show amounts of sulfate aerosol over the North Atlantic from April 2 to 8, 1987, as calculated by Brookhaven's computer-based, atmospheric chemical transport model. The aerosol amount in the indicated area peaked on April 5. Satellite measurements confirm theoretical predictions of enhanced cloud reflectivity for a given liquid water path in the clouds coinciding with increased amounts of aerosol. These observations point the way to measuring quantitatively cloud brightening by aerosols on global scales and, thus, determining the resultant cooling effect on climate.

"So that we can make sensible policy decisions about energy use, we must understand fully the greenhouse effect, which means understanding the influence of aerosols on atmospheric processes."

STEPHEN SCHWARTZ

Meet
Stephen Schwartz

Atmospheric chemist Stephen Schwartz has had his head in cloud chemistry since joining Brookhaven Lab's Atmospheric Sciences Division in 1975.

Schwartz's early days at the Laboratory were devoted to learning about how cloud chemistry might affect acid rain. "There wasn't much known at that time, so we pretty much had to invent the field," he explains. Schwartz divided his time among doing chemistry experiments in the lab, analyzing data collected in the field, and representing the data in models.

Now Schwartz focuses on clouds at both the microscopic level — how individual cloud droplets form around tiny particles — and the global level — how aerosol particles affect cloud brightness and, ultimately, Earth's climate. "It's very interesting science, and science that is relevant to our country and the world," he comments.

Schwartz earned a bachelor's degree in chemistry at Harvard University and a Ph.D. in physical chemistry from the University of California, Berkeley. Before coming to Brookhaven, he taught chemistry at Stony Brook University. Married to a retired school teacher with two grown children, he enjoys giving talks on atmospheric chemistry to students and other Laboratory visitors.

of sulfate aerosol over the North Atlantic Ocean — which is far from any local sources of aerosol emission — first increased significantly, and then decreased over the course of about a week. These large variations in aerosol concentration and the fact that there were no high-atmosphere clouds to obscure sunlight during these events made them ideal episodes for studying the effect of aerosols on cloud brightening.

The next challenge was to get the data on cloud brightness for that area over the same time period.

To do this, the scientists retrieved satellite measurements of radiance, which is how much light the clouds reflect, at two different wavelengths. They then used these measurements to derive important cloud properties, in particular the optical depth, which is a value related to how much light is transmitted through the cloud, and the liquid water path, which is the amount of liquid water in the cloud. The researchers were also able to analyze how these variables were related to one another, and how one variable changed as a function of the other.

The findings show that, for a given liquid water path, cloud reflectivity was indeed higher on the days with higher aerosol content than on the days with lower aerosol levels. "If the effect is as widespread as we think it is, then it would produce quite a substantial cooling effect on climate," states Schwartz.

AEROSOLS VERSUS GREENHOUSE GASES

Could aerosols be deliberately employed to offset the greenhouse effect?

"This is an attractive thought," comments Schwartz, "but it cannot work in the long run because aerosols are so short-lived in the atmosphere, whereas greenhouse gases accumulate over time. An ever-increasing amount of aerosols would be required. We'd never solve the long-term problem."

Also, says Schwartz, the aerosol effect may have a different geographical distribution from the greenhouse effect, and "the consequence of this mismatch is unknown." One key to assessing the overall impact of aerosols, concludes the Brookhaven atmospheric chemist, will be the further development of the satellite-based measurements.

MORE INFORMATION

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- *paper:* "Aerosol enhancement of cloud albedo shown by satellite measurements and chemical transport modeling," Proceedings National Academy of Sciences, February 19, 2002, volume 99, issue 4, pp. 1784-1789
- *contact:* Stephen E. Schwartz, ses@bnl.gov or (631) 344-3100
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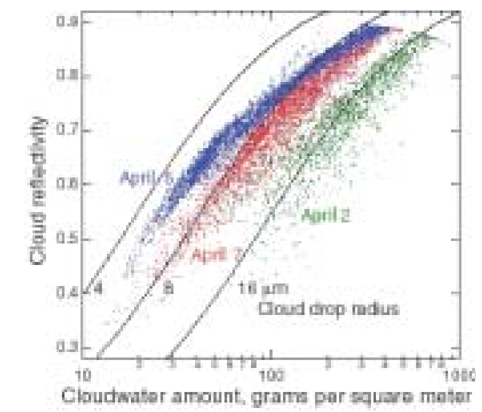
Cloud Reflectivity Versus Cloud Water

The figure below shows cloud reflectivity for individual pixels in the study area, which is the region outlined on the map (see pages 14 and 15, bottom), plotted as a function of the amount of liquid water in the cloud in that pixel. The more cloud water, the brighter the clouds as seen by the satellite from above, which corresponds to darker clouds as seen from below.

The high variability in cloud water amount makes it difficult to discern the brightening influence of aerosols. However, the brightening effect is made evident by plotting the cloud reflectivity as a function of the amount of liquid water and comparing the data for days with different sulfate levels (April 5, blue = high sulfate; April 7, red = somewhat lower sulfate; and April 2 green = low sulfate). For a given amount of cloud water, clouds reflect more sunlight on days with more sulfate aerosol (April 5) than on the other two days. The more aerosol present on a given day, the more cloud droplets, and, hence, the smaller the drops are for a given amount of cloud water.



More, smaller drops have been hypothesized to lead to increased reflectivity. This hypothesis is represented by the black curves drawn for different cloud-drop radius values. The present study uses satellite data to confirm this hypothesis and to measure the increase in reflectivity quantitatively.

Brookhaven's Atmospheric Chemical Transport Computer Model

ONCE SCIENTISTS RECOGNIZED THE POTENTIAL for aerosols to influence cloud properties and the potential global magnitude of this influence, they needed a way to quantify the effect. So, Brookhaven researchers developed a computer-based, atmospheric chemical transport model to calculate sulfate concentrations as a function of location, date, and time, so they would know where to look for the aerosol effect.

The model divides the atmosphere into roughly 800,000 model grid cells, each of which is 1° latitude by 1° longitude from the equator to 82° north latitude over the Northern Hemisphere, with 27 layers of cells in the vertical direction from the surface up to an altitude of about 16 kilometers, or roughly 50,000 feet.

The sulfate concentration must be calculated in each grid cell, taking into account the many processes responsible for sulfate concentrations in the atmosphere, including:

- emissions of sulfates and precursor chemicals, principally sulfur dioxide (SO_2) from industrial sources such as power plants and natural sources such as volcanoes, and dimethylsulfide from marine organisms
- the location and intensity of these emissions
- weather data that account for how these chemicals are transported and influence the chemistry of these materials and their removal from the atmosphere
- the chemical reactions that transform SO_2 and other precursors into various sulfates in the clouds.

The program runs for six weeks at a time, allowing scientists to predict sulfate concentrations. The model has been extensively evaluated by comparison with measurements at air quality stations throughout the Northern Hemisphere.

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