discover
BROOKHAVEN
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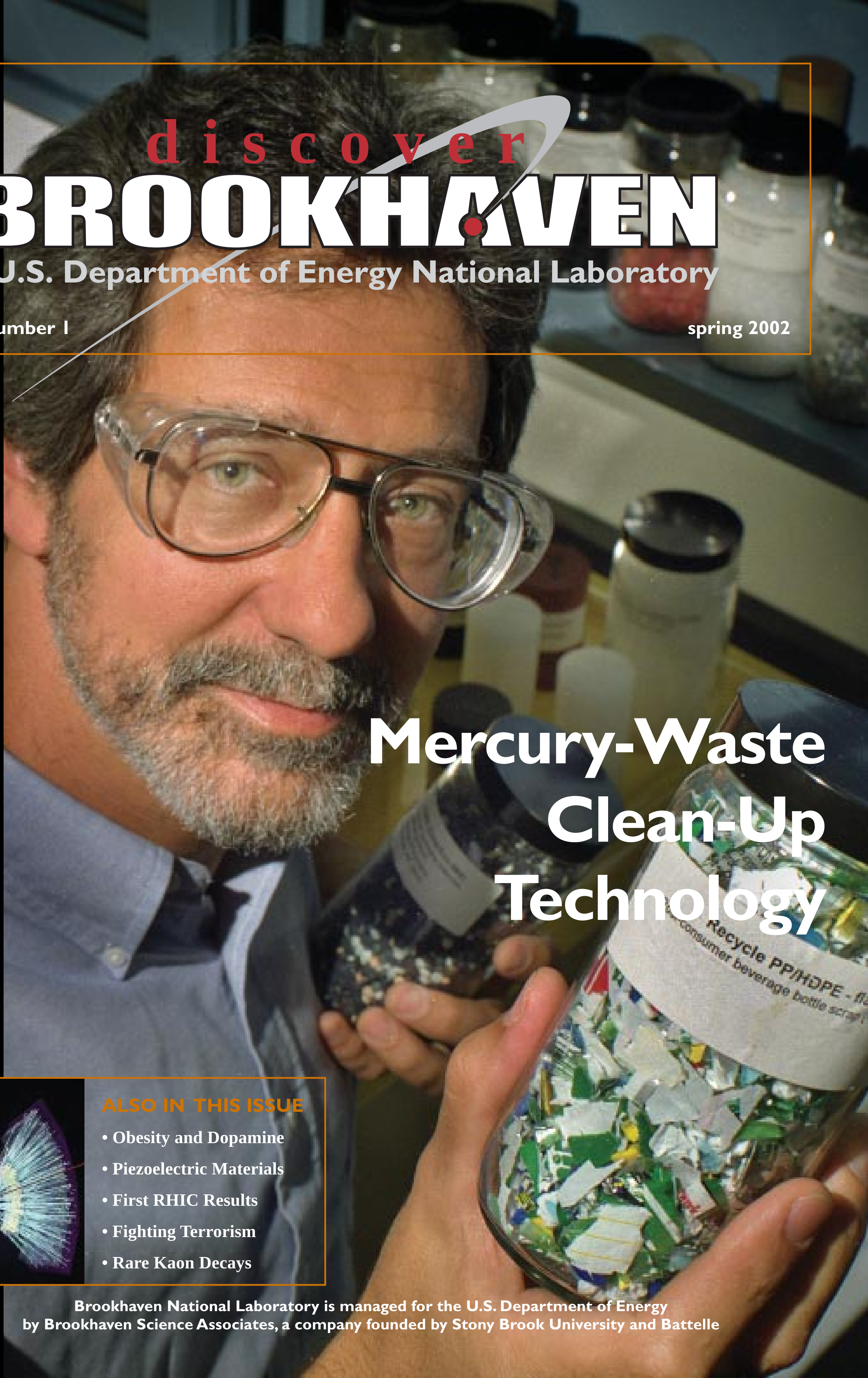

Mercury-Waste Clean-Up Technology

ALSO IN THIS ISSUE

Brookhaven National Laboratory is managed for the U.S. Department of Energy
by Brookhaven Science Associates, a company founded by Stony Brook University and Battelle

Welcome to the first 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

Discovering Brookhaven National Laboratory

SINCE ITS BIRTH OVER 50 YEARS AGO, Brookhaven National Laboratory has been a multidisciplinary research institution built around large and unique scientific facilities. Thus it is no surprise that we entered the new millennium with the operation of the largest and most energetic nuclear physics facility in the world, the Relativistic Heavy Ion Collider (RHIC).

Regardless of RHIC's status and size, and the fact that over 1,000 scientists perform their research there each year, RHIC is only a part of the whole panoply of science that is performed daily at Brookhaven.

For instance, the National Synchrotron Light Source (NSLS) at Brookhaven is the destination of over 2,500 visiting researchers each year, who perform work in material science, life science, or condensed-matter physics using the NSLS's beams of x-ray, ultraviolet, or infrared light. The Alternating Gradient Synchrotron today provides the most intense proton beams in the world for research into elementary particles and the forces acting on them. The Laboratory's Positron Emission Tomography facility supports a vibrant, collaborative program of medical and chemical research into the causes of addiction and other conditions. And many other Brookhaven research facilities and instrumentation also make possible advances in other areas of basic and applied science and technology, such as environmental waste management, as well as in national security and counterterrorism.

Working for the good of science, the nation and the world, Brookhaven has not only produced four Nobel Prize-winning physics discoveries and countless other scientific firsts, but also a passion for discovery that has characterized the Laboratory over its 50-plus years.

Of course, results from Brookhaven's research are published in the world's leading scientific journals and then often reported in newspapers and magazines around the world. However, we thought that producing a publication of our own — in which we featured the Laboratory's discoveries and the researchers who are responsible for making them — would convey the excitement of our science and technology to an even broader audience. Thus, we have published this first issue of *discover BROOKHAVEN* for you, the science-literate public. Our hope is that our passion for discovery will become yours.

discover BROOKHAVEN
a U.S. Department of Energy National Laboratory
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IN THIS ISSUE

ON THE COVER: Brookhaven researcher Paul Kalb holds samples from one of several Laboratory waste-disposal technologies that has been patented and licensed to industry (see cover story, pages 5-7).

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

Imaging Provides Insight Into the Obesity–Brain Chemistry Relationship

Brookhaven Lab scientists have found that obese people have fewer receptors for dopamine, the brain chemical associated with feelings of pleasure and reward. In fact, the more obese the individual, the lower the number of dopamine receptors.

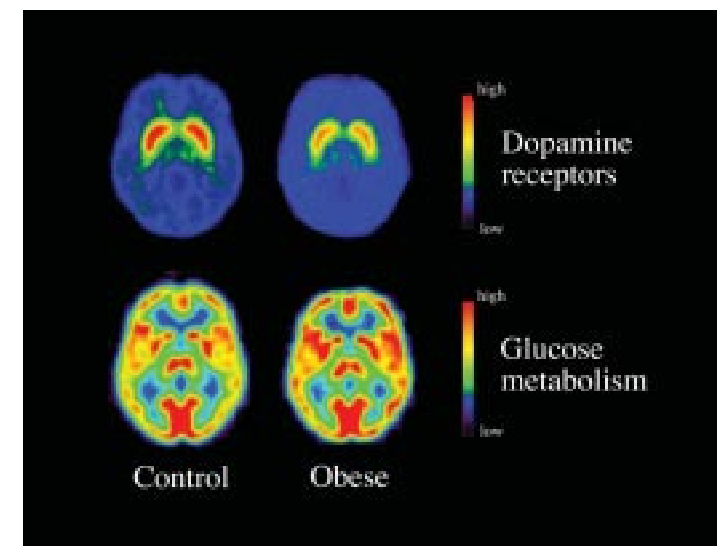
BY KAREN MCNULTY WALSH

Brookhaven Lab physician Nora Volkow administers a radiotracer to a patient before he undergoes a brain scan using what is called positron emission tomography (PET). The radiotracer allows PET to identify the location and concentration of dopamine receptors in the brain.

SCIENTISTS DO NOT YET UNDERSTAND WHY some people become obese or pathological overeaters. But brain imaging studies at Brookhaven Lab's positron emission tomography (PET) facility may offer some clues.

Through research funded by the U.S. Department of Energy and the National Institute on Drug Abuse, Laboratory scientists have found that, compared with people of normal weight, obese people have fewer receptors in their brains for dopamine, a brain chemical associated with feelings of pleasure and reward. This finding is very similar to what has been found in subjects addicted to cocaine, nicotine, and other drugs.

"These findings imply that obese people may eat more to try to stimulate their deficient dopamine pleasure circuits, just as addicts do by taking drugs," says physician Gene-Jack Wang, the Brookhaven Lab researcher leading the obesity studies.



PET scans show that obese and control subjects have similar metabolic rates overall, but that obese subjects have fewer receptors for dopamine, a brain chemical that transmits feelings of pleasure and reward.

Brookhaven scientists have done extensive research showing that dopamine plays an important role in drug addiction. Since eating, like the use of addictive drugs, is a highly reinforcing behavior, the scientists suspected that dopamine might play a role in overeating as well.

To test their hypothesis, Wang and his colleagues measured the number of dopamine receptors in the brains of ten severely obese individuals and ten normal weight subjects. First, each volunteer subject received an injection containing a radiotracer, a radioactive chemical "tag" designed to bind to dopamine receptors in the

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.

Relying upon radiotracers that label dopamine receptors, transporters, or precursors, or compounds with specificity for dopamine-degrading enzymes, PET was the first technology that enabled direct measurement of the components of the dopamine system in the living brain.

Playing a pivotal role in the regulation and control of movement, motivation, and cognition, brain dopamine is linked to reward, reinforcement, and addiction. Disruptions of dopamine function have been implicated in neurological and psychiatric illness, including substance abuse. PET imaging studies at Brookhaven have shown significant reduction in the availability of D2 receptors, one of the five subtypes of dopamine receptors, in abusers of alcohol, cocaine and other drugs, and, now, in the obese people as well.

"My motivation is to find treatments for people who suffer from alcoholism, drug addiction, or obesity — people who are often stigmatized and overlooked by society."

GENE-JACK WANG

brain. The researchers then scanned the subjects' brains using a PET camera. The PET camera picks up the radioactive signal of the tracer and shows where it is bound to dopamine receptors in the brain. The strength of the signal indicates the number of receptors.

FEWER DOPAMINE RECEPTORS

Obese individuals, Brookhaven scientists found, have fewer dopamine receptors than normal weight subjects. In fact, the more obese the individual, the lower the number of dopamine receptors. But it is still not known whether the depletion in dopamine receptors is a cause — or a consequence — of obesity.

"It's possible that obese people have fewer dopamine receptors because their brains are trying to compensate for having chronically high dopamine levels, which are triggered by chronic overeating," says Wang. "It's also possible, however, that these people have low numbers of dopamine receptors to begin with, making them more vulnerable to addictive behaviors, including compulsive overeating."

Another intriguing finding is that, while normal weight and obese subjects' brains are equally active overall, some specific brain regions — such as those associated with sensation in the mouth, lips, and tongue — are more active in obese subjects than in normal weight controls.

"The regulation of body weight is extremely complex, involving many physiological mechanisms and neurotransmitters," explains Wang. "But these findings suggest that addressing the dopamine-receptor deficiency or finding other ways to regulate dopamine in obese people might help reduce their tendency to overeat."

It is unfortunate that many of the drugs shown to alter dopamine levels are also highly addictive. But research suggests that exercising, which has other obvious benefits, is another way that obese individuals might be able to stimulate dopamine pleasure and satisfaction circuits.

In animal studies conducted elsewhere, "Exercise has been found to increase dopamine release and to raise the number of dopamine receptors," adds Wang. "This suggests that obese people might be able to boost their dopamine response through exercise instead of eating — which is just one more reason to exercise if you are trying to lose weight."

MORE INFORMATION

- *funding:* Office of Biological & Environmental Research, Office of Science, U.S. Department of Energy; National Institute on Drug Abuse, National Institutes of Health
- *paper:* "Brain Dopamine and Obesity," Lancet, February 3, 2001, volume 357, issue 9253, pp. 354-57
- *contact:* Gene-Jack Wang, gjwang@bnl.gov or (631) 344-3608
- *Web:* http://www.bnl.gov/bnlweb/pubaf/pr/2001/bnlpr020101.htm

Meet Gene-Jack Wang

In collaboration with researchers at Brookhaven and around Long Island, physician Gene-Jack Wang uses the most sophisticated tools and techniques of nuclear medicine to study the neurological mechanisms and manifestations of alcoholism, drug addiction, and obesity.

Wang has also used brain imaging techniques such as positron emission tomography (PET) to study aging and to monitor radiation therapy in brain cancer patients — a technique that has helped to guide treatment and improve patients' quality of life.

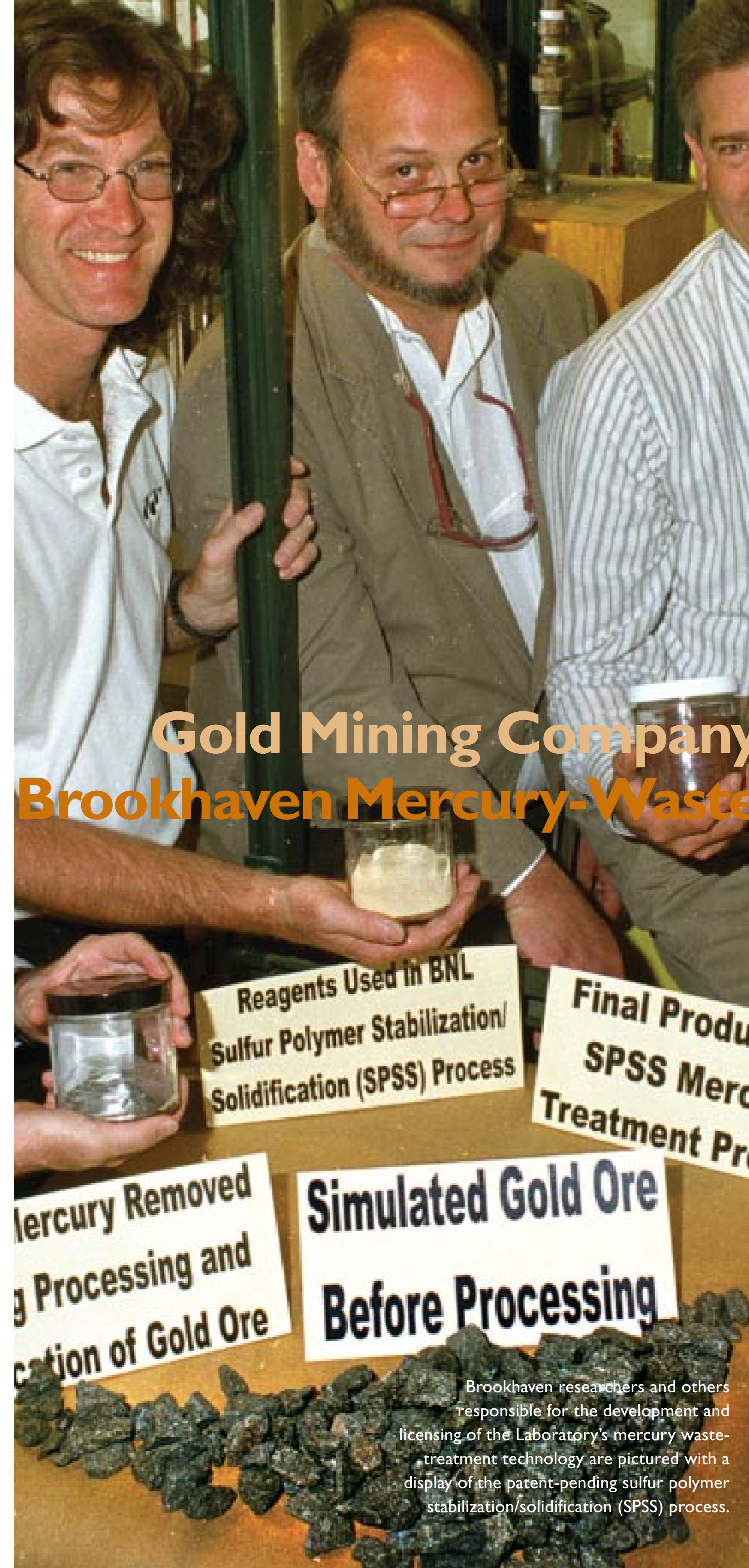
Wang came to Brookhaven Lab's Medical Department in 1990. In addition to performing his own research, he has headed the Lab's clinical research center and continues to hold a joint appointment as a research associate professor at Stony Brook University. He has published more than 100 peer-reviewed articles on his PET imaging research.

Gene-Jack Wang received his M.D. from Kaohsiung Medical University, Taiwan, in 1980. He earned a master of health sciences in radiation health sciences from The Johns Hopkins University in 1984.

Brookhaven Lab has recently licensed its patent-pending mercury waste-treatment technology, which allows this toxic metal to be disposed of safely and economically.

BY DIANE GREENBERG

Gold Mining Company Licenses Brookhaven Mercury-Waste Technology



Brookhaven researchers and others responsible for the development and licensing of the Laboratory's mercury waste-treatment technology are pictured with a display of the patent-pending sulfur polymer stabilization/solidification (SPSS) process.

UNTIL RECENTLY, mercury was a valuable by-product that gold-mining companies and others sold for industrial use.

Today, the industrial use of mercury has drastically declined. In the U.S. alone, the sale of by-product mercury has fallen from 2,000 tons per year in the 1980s to less than 50 tons per year today — leaving more mercury by-product requiring disposal.

A new technology developed at Brookhaven to treat mercury waste, however, makes the disposal of the growing excess of this toxic metal more practical, safe, and economical.

Called sulfur polymer stabilization/solidification (SPSS), the Laboratory's innovative waste-treatment technology works on elemental mercury by chemically stabilizing and solidifying the liquid. It was developed with funding from the U.S. Department of Energy, Los Alamos National Laboratory, and Newmont Mining Corporation, the largest gold producer in North America — and the company to which Brookhaven recently licensed this mercury waste-treatment technology. The license gives the Denver-based Newmont exclusive rights for mining applications under a pending patent application filed by Brookhaven. Licenses for all other non-mining uses of the new technology are still available.

Newmont will work with Brookhaven researchers to scale up the technology for industrial use. Once this is accomplished, Newmont will offer sublicenses to other mining operations around the world.

In SPSS, liquid mercury and/or mercury-contaminated soil, sludge, or debris is first mixed with sulfur-polymer cement and small amounts of additives in a heated vessel, until all the mercury is converted into mercuric sulfide, a compound with low solubility and low vapor pressure. This thermoplastic mixture is melted to form a homogeneous liquid. Once poured into a mold, the liquid is then allowed to cool and solidify.

The resulting solid not only immobilizes the mercury, but it also exceeds the U.S. Environmental Protection Agency's current and pending standards for leaching.

"Incorporating mercury into a solid form is an important part of our method," said Paul Kalb, Bookhaven's principal researcher for this project.

He explains: "While amalgamation, which is the conventional method, also chemically stabilizes mercury, it transforms the element into a dispersible powder, which is more easily mobilized by wind and groundwater, thus posing a potential threat to the environment."

In contrast, "Our SPSS method makes it easier and safer to dispose of mercury, while isolating this toxic metal from the environment," concludes Kalb.

Technology Transfer
Successes and Opportunities at Brookhaven

PURPOSE

To enable industry to: develop and market Brookhaven's patented inventions, such as the Laboratory's technology to treat mercury waste; have access to the Laboratory's major scientific facilities; and benefit from Brookhaven's unique research capabilities, through —

- exclusive and non-exclusive licenses
- cooperative research & development agreements
- proprietary or non-proprietary use of the Laboratory's user facilities, such as the National Synchrotron Light Source
- collaborative research under Small Business Innovation Research and Small Business Technology Transfer awards to small businesses

TECHNOLOGY-TRANSFER SUCCESSES

- T7 gene-expression system, vectors, and protein products
- asbestos remediation technology
- red blood-cell labeling kit for cardiac diagnostic procedures
- polyethylene materials for encapsulation of radioactive and mixed wastes

NEW LICENSING OPPORTUNITIES

biotechnology & medical technology —

- recombinant constructs of *Borrelia burgdorferi* OspA and OspB for Lyme disease vaccines and diagnostics
- activated recombinant adenovirus proteinase
- methods for generating phosphorylation site-specific immunological reagents
- flexible nuclear medicine camera

environmental technology —

- phosphate glasses for immobilizing radioactive and mixed wastes
- process for the treatment of depleted uranium
- mini-Raman LIDAR for remote sensing of chemical and biological substances

instruments & electronics —

- accelerator target for producing radioisotopes using low-energy, high-current particle beams
- method for preparing niobium surfaces
- compact design for a high-brightness, photon-beam generator.

materials & chemistry —

- non-stoichiometric AB5 alloys for metal hydride electrodes
- method for producing electrodes using micro- or nanoscale materials from hydrogen-driven metallurgical reactions
- electrocatalysts for alcohol oxidation in fuel cells

AVAILABLE R&D FACILITIES

- Accelerator Test Facility
- Alternating Gradient Synchrotron
- High-Field Magnetic Resonance Imaging facility
- Medical cyclotrons
- National Synchrotron Light Source
- Positron Emission Tomography facility
- Relativistic Heavy Ion Collider
- Scanning Transmission Electron Microscope
- Tandem Van de Graaf accelerators
- Transmission Electron Microscope

U.S. DEPARTMENT OF ENERGY FUNDING SOURCES

- Office of Industrial Technology
- Small Business Innovation Research and Small Business Technology Transfer awards

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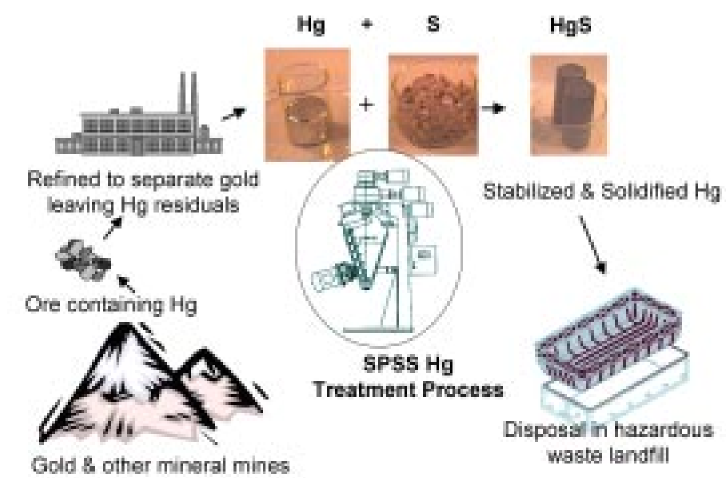
"It's challenging to develop environmental cleanup technologies — and I find it especially rewarding to advance them from the laboratory to industry, so they can be used to solve real problems"

PAUL KALB



How SPSS Treats Mercury Waste

Brookhaven's sulfur polymer stabilization/solidification (SPSS) technology successfully treats radioactive, hazardous, and mixed mercury-contaminated wastes, creating a durable waste form that meets current U.S. Environmental Protection Agency and Nuclear Regulatory Commission regulations. A significant improvement over conventional approaches, SPSS is based on the Laboratory's patented sulfur polymer microencapsulation process, which uses sulfur polymer cement (SPC) to contain waste physically. SPC consists of 95 percent elemental sulfur by weight reacted with 5 percent organic modifiers by weight, which enhance mechanical integrity and long-term durability. The SPSS treatment of mercury is conducted in two steps: stabilization and solidification. In the first step, mercury is reacted with powdered SPC, to form mercuric sulfide. The reaction vessel is placed under an inert gas atmosphere to prevent the formation of mercuric oxide, which is a water soluble and highly leachable compound. To accelerate the reaction between mercury and SPC, a small quantity of additive is included. In the second step, the vessel is heated to approximately 40°C, to accelerate the formation of sulfide, and the materials are mixed until the mercury is completely reacted with the sulfur. Once mercury is chemically stabilized, more SPC is added, and the mixture is heated to about 130°C until a homogenous molten mixture is formed. That mixture is then poured into a suitable mold, in which it cools into a monolithic non-dispersible solid, which safely contains the mercury for long-term disposal.

MORE INFORMATION

- *funding:* Office of Environmental Management, U.S. Department of Energy; Los Alamos National Laboratory; Newmont Mining Corporation, Inc.
- *paper:* "Sulfur Polymer Solidification/Stabilization of Elemental Mercury Waste," Waste Management Journal, in press
- *contact:* Paul Kalb, kalb@bnl.gov or (631) 344-7644
- *Web:* http://www.bnl.gov/bnlweb/pubaf/pr/2001/bnlpr053101.htm

Meet Paul Kalb

Paul Kalb, a senior research engineer at Brookhaven, specializes in hazardous- and radioactive-waste management, environmental restoration, and health and safety aspects of emerging energy technologies.

Kalb earned a bachelor's degree in mechanical engineering technology from the State University of New York at Binghamton, and a master's degree in nuclear engineering and a certificate in energy policy and engineering from the Polytechnic Institute of New York.

At Brookhaven since 1980, Kalb heads environmental research and technology development within Brookhaven's Environmental Sciences Department.

Currently, he works on characterizing contaminants for the cleanup of contaminated sites and nuclear facilities. Kalb also develops waste-treatment technologies for the U.S. Department of Energy and industry.

He is listed as the co-inventor on seven U.S. patents. Kalb has coauthored several books on innovative technology for waste treatment and has written numerous peer-reviewed articles on waste encapsulation.

High-Performance Transducers Explained by Novel Crystalline Phase

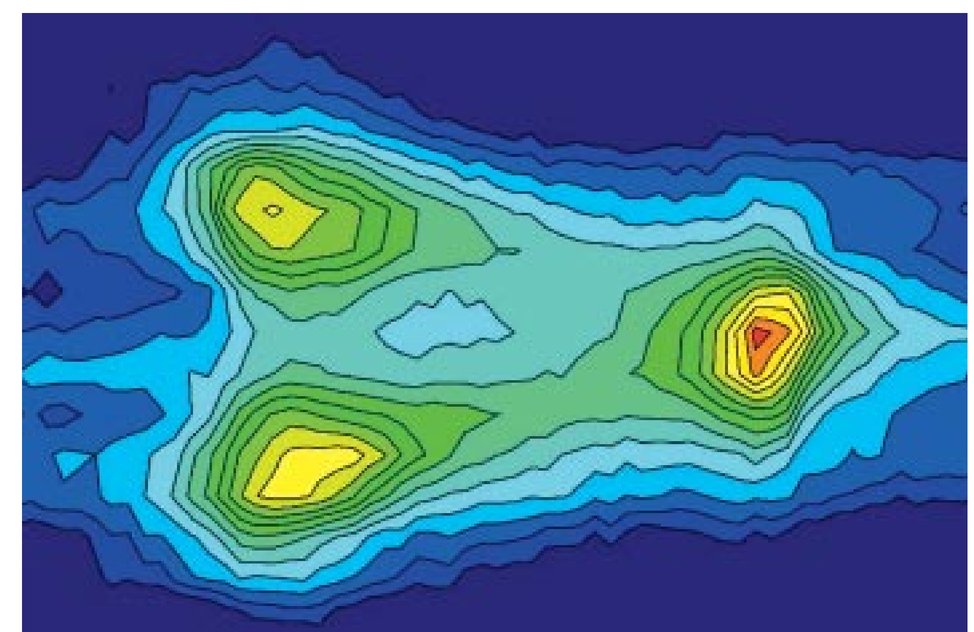
A Brookhaven Lab scientist and her colleagues have discovered that a ceramic material called PZT has a crystalline phase that explains its useful properties. Applying this basic discovery may lead to the next generation of solid-state transducers.

BY KAREN MCNULTY WALSH

BEATRIZ NOHEDA OF BROOKHAVEN'S PHYSICS DEPARTMENT and her colleagues have made great advances in the study of piezoelectric materials, which are materials that can be deformed by the application of an electric field or, conversely, produce an electric current when physically deformed.

One of the most important piezoelectric materials is known as PZT, a ceramic discovered in the 1950s. It is used as a transducer for transforming the vibrations of sound waves, for example, into electrical current and vice versa in devices such as telephones, sonar systems, and ultrasound machines.

In diffraction studies at the National Synchrotron Light Source at Brookhaven, Noheda has helped to discover that certain compositions of PZT have a previously undetected phase, or crystal-



The signature of the monoclinic phase in the piezoelectric material PZN-8%PT is seen in this two-dimensional x-ray diffraction scan around the (hkl)=(020) reflection of a PZN-8%PT single crystal. The horizontal axis is the scan along k, and the vertical axis is the can along l. The colors show the x-ray diffraction intensity, from minimum (dark blue) to maximum (red) intensity. This intensity distribution is characteristic of the monoclinic distortion.

The many beam lines and experiments surrounding the vacuum ultraviolet ring, one of the two synchrotrons used by 4,000 experimenters who come annually to do their research the National Synchrotron Light Source at Brookhaven Lab.

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 Basic Energy Sciences, U.S. Department of Energy

OPERATING COSTS

$35 million per year

FEATURES

- Two electron synchrotron storage rings that produce beams of x-ray, ultraviolet, and infrared light
- 85 beam lines for experiments
- An array of sophisticated imaging techniques

FACILITY USERS

More than 2,500 per year from over 400 universities, research institutions, corporations, and other government laboratories in the U.S. and abroad.

COMPLEMENTARY FACILITIES

- Advanced Photon Source at the U.S. Department of Energy's Argonne National Laboratory
- Advanced Light Source at the U.S. Department of Energy's Lawrence Berkeley National Laboratory
- Stanford Synchrotron Radiation at the U.S. Department of Energy's Stanford Linear Accelerator Center

WEB ADDRESS

www.bnl.gov/bnlweb/facilities/NSLS.html

Meet Beatriz Noheda

One of Beatriz Noheda's first contacts with science as ayoung girl was watching a movie about Marie Curie. Noheda regards the patient, hard-working chemist as an important role model, even today.

An assistant physicist at Brookhaven since 2000, Beatriz Noheda was born in Cuenca, Spain. She earned her Ph. D. in physics at the University Autonoma in Madrid in 1996. Noheda was an associate professor there from 1996 to 2001, and she has been collaborating on research at the Lab since 1998.

line shape, that explains their very high piezoelectric response.

NOVEL PHASE

Using high-energy x-rays, Noheda and her colleagues examined crystals of PZT and two different but related materials, studying the diffraction patterns, or how the light waves were redistributed in space as they scattered off the crystals. The scientists were particularly interested in how each crystal's structure changed in response to an electric field.

They found that, when an electric field above a certain value was applied to each crystal, the symmetry of its structure changed irreversibly. The crystals were transformed from what is called the rhombohedral phase into what is known as a monoclinic phase.

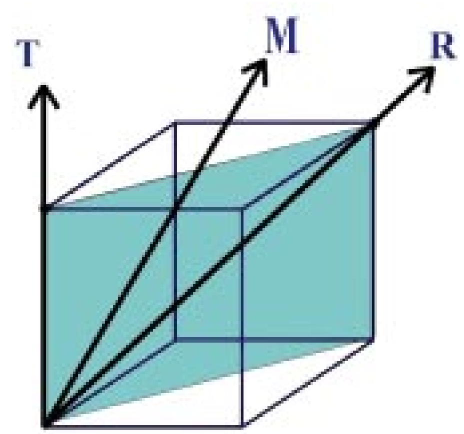
In addition, once the rhombohedral phase is irreversibly transformed into the monoclinic one, the monoclinic crystalline lattice shows reversible changes as the strength of the electric field applied to it is increased or decreased.

Studying the same materials in powder form has confirmed these findings.

MORE SENSITIVE TRANSDUCERS

Says Noheda, "With this new monoclinic phase, you no longer have to apply the electric field in the exact direction of the deformation. So this material has a lot more freedom to deform."

Scientists can now look for this monoclinic phase in other materials, using them and PZT and its related compounds to make the next generation of more sensitive solid-state transducers.



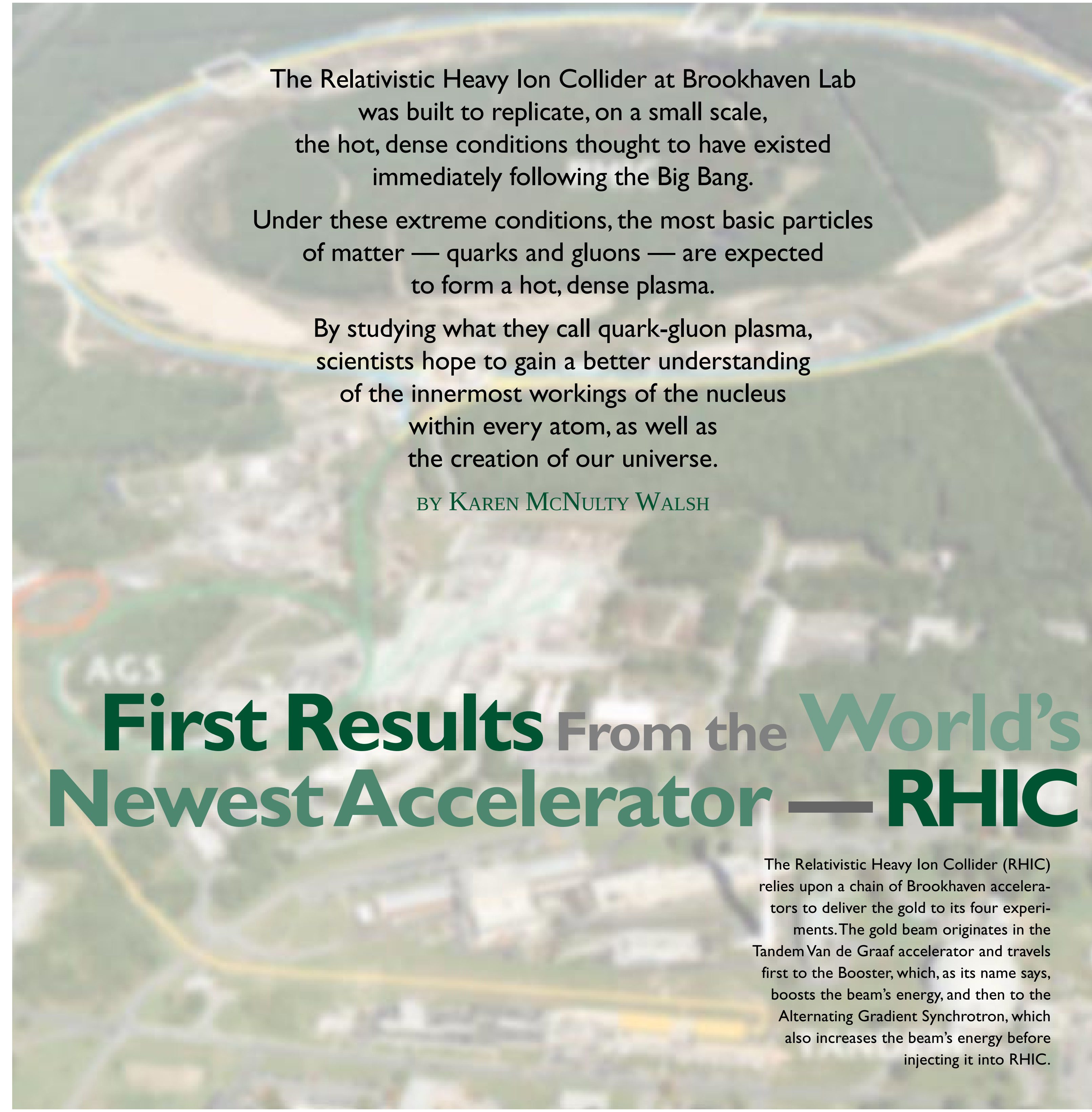
The ferroelectric polarization in the monoclinic plane is seen rotating between the rhombohedral (R) and tetragonal (T) phases in this three-dimensional representation of a unit cell of the piezoelectric material PZN-8%PT.

"PZTs are the most important of what are called functional materials. Acting as sensors and actuators, PZTs can adapt to changes in their environment, so they have become the basis for a new generation of 'smart' materials."

Beatriz Noheda

MORE INFORMATION

- *funding:* Materials Sciences & Engineering Division, Office of Basic Energy Sciences, Office of Science, U.S. Department of Energy
- *paper:* "Polarization Rotation via a Monoclinic Phase in the Piezoelectric 92%$PbZn_{1/3}Nb_{2/3}O_3$-8%$PbTiO_3$," Physical Review Letters, April 23, 2001, volume 86, issue 177, pp. 3891-94.
- *contact:* Beatriz Noheda, noheda@bnl.gov or (631) 344-5065
- *Web:* http://www.bnl.gov/bnlweb/pubaf/pr/2001bnlpr031601.htm



The Relativistic Heavy Ion Collider at Brookhaven Lab was built to replicate, on a small scale, the hot, dense conditions thought to have existed immediately following the Big Bang.

Under these extreme conditions, the most basic particles of matter — quarks and gluons — are expected to form a hot, dense plasma.

By studying what they call quark-gluon plasma, scientists hope to gain a better understanding of the innermost workings of the nucleus within every atom, as well as the creation of our universe.

BY KAREN MCNULTY WALSH

First Results From the World's Newest Accelerator — RHIC

The Relativistic Heavy Ion Collider (RHIC) relies upon a chain of Brookhaven accelerators to deliver the gold to its four experiments. The gold beam originates in the Tandem Van de Graaf accelerator and travels first to the Booster, which, as its name says, boosts the beam's energy, and then to the Alternating Gradient Synchrotron, which also increases the beam's energy before injecting it into RHIC.

AS EVERY CHILD LEARNS, you can find out a lot about how something works if you take it apart. That is what physicists do when they use accelerators and colliders — or "atom smashers" — to take apart matter.

Brookhaven's Relativistic Heavy Ion Collider, better known by the acronym RHIC (pronounced "Rick"), is the world's newest and biggest particle accelerator for nuclear physics.

Unique among atom smashers, RHIC is designed to open a new domain of scientific exploration by probing the forces acting among the most basic and mysterious constituents that make up the matter in our universe: quarks and gluons. When combined in the form of protons and neutrons, these fundamental particles are found within the nuclei of all atoms of ordinary matter.

Funded by the U.S. Department of Energy and constructed at Brookhaven, RHIC provides physicists worldwide with extraordinary potential for new discoveries. By colliding beams of heavy nuclei at very high energies, RHIC replicates, on a small scale, the hot, dense conditions thought to have existed immediately following the Big Bang, the explosion that created the early universe. Under these extreme conditions, quarks and gluons are expected to form a hot, dense plasma

RHIC Facts & Figures

PURPOSE

To recreate on an atomic scale the hot, dense conditions at the dawn of the universe, in the attempt to create a predicted form of matter — called quark-gluon plasma — last thought to have a few microseconds after the Big Bang. By studying quark-gluon plasma, nuclear physicists will gain new insight into the particles within the atomic nucleus and the forces holding them together.

SPONSOR

Division of Nuclear Physics, Office of High Energy & Nuclear Physics, Office of Science, U.S. Department of Energy

PROJECT COST

$600 million

OPERATING COSTS

$130 million per year

FEATURES

- Two 3.8-kilometer-in-circumference accelerators, which circulate beams of gold ions in opposite directions and collide them at six intersection points
- 1,740 superconducting magnets, which make up the collider's accelerator lattice
- Four heavy-ion experiments: BRAHMS, PHENIX, PHOBOS, and STAR

FACILITY USERS

More than 1,000 per year from over 100 universities, other government laboratories, and research institutions in the U.S. and abroad

COMPLEMENTARY FACILITIES

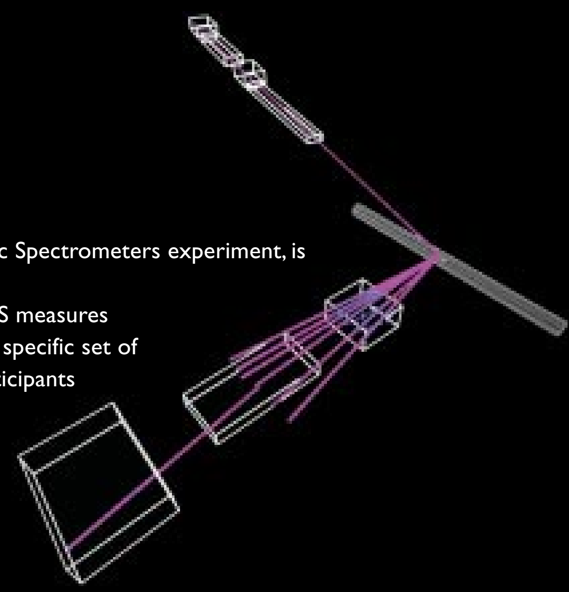
- at present: none
- beginning 2007: the Large Hadron Collider (LHC), now under construction at CERN, the European particle and nuclear physics laboratory in Switzerland

WEB ADDRESSES

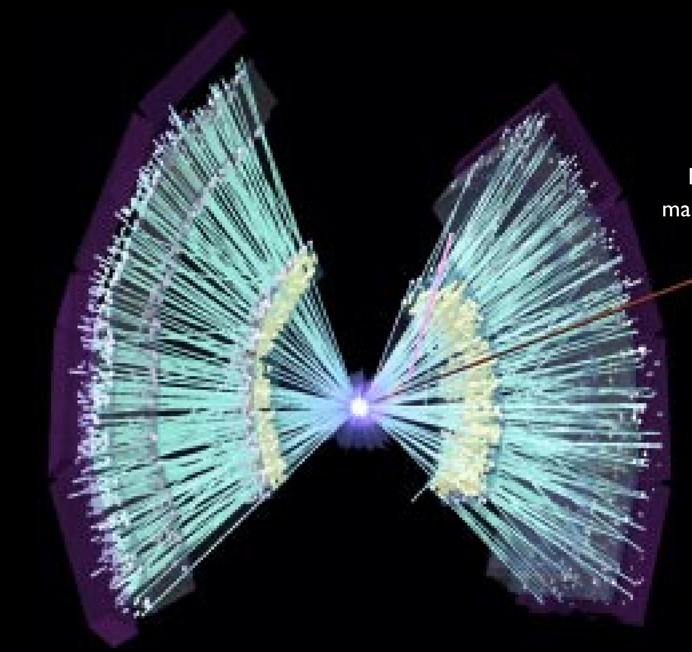
- RHIC: www.bnl.gov/rhic/
- BRAHMS: www4.rcf.bnl.gov/brahms/www/
- PHENIX: www.phenix.bnl.gov/
- PHOBOS: phobos-srv.chm.bnl.gov/
- STAR: www.star.bnl.gov/

Introducing the Detectors at RHIC — BRAHMS, PHENIX, PHOBOS, STAR

TO STUDY RHIC COLLISIONS, physicists have built four heavy-ion experiments: two large detectors, named STAR and PHENIX, and two smaller detectors, called PHOBOS and BRAHMS. All use sophisticated technology — including computers that generate the gorgeous displays of particle events seen here — to help scientists explore the subatomic world produced by high-energy, gold-on-gold collisions, in the search for what is called quark-gluon plasma.

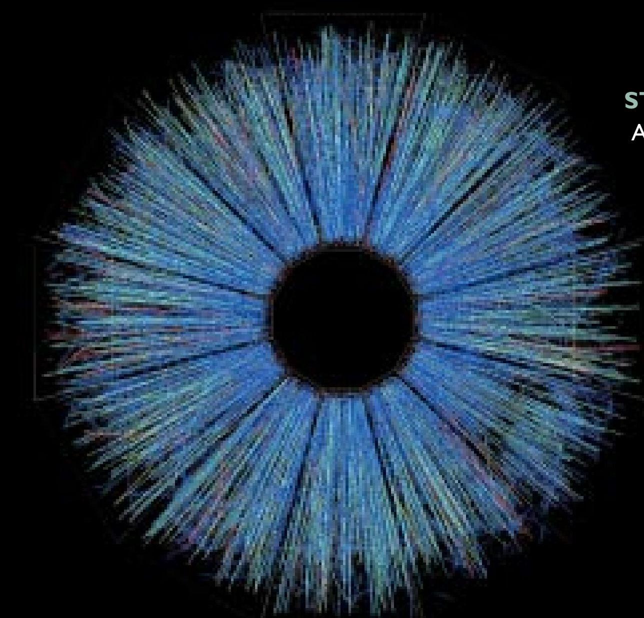


BRAHMS, or the Broad RAnge Hadron Magnetic Spectrometers experiment, is one of two small detectors at RHIC. Located at the 2 o'clock position on the RHIC ring, BRAHMS measures only a small number of particles emerging from a specific set of angles during each collision. BRAHMS has 51 participants from 14 institutions in eight countries.



PHENIX, or the Pioneering High Energy Nuclear Interaction eXperiment, looks for many different particles, some of which carry information about processes or actions within the collision, such as the collision temperature. Larger than STAR, but built to detect far fewer and far lighter particles, PHENIX has more than 450 collaborators from 45 institutions in ten countries. The PHENIX detector is found at 8 o'clock on the RHIC ring.

PHOBOS, the other of RHIC's two smaller experiments, is designed to examine a very large number of collisions and develop a broad view of the overall consequences. When quark-gluon plasma is formed, PHOBOS will be able to count nearly all of the charged particles produced in the collision and to determine detailed properties about a subset of those particles. Seventy scientists from eight institutions in three nations are working on PHOBOS, which is located at the 10 o'clock position on the RHIC ring.



STAR, or the Solenoid Tracker At RHIC, tracks the thousands of electrically charged particles produced by each RHIC collision. As big as a house, this detector is found at 6 o'clock on the RHIC ring and is operated by a team of more than 400 scientists and engineers from 33 institutions in seven countries.

— a state of matter that is appropriately called quark-gluon plasma.

Scientists will study this plasma to understand its behavior and the conditions under which the first such plasma condensed to form ordinary matter some 13 billion years ago.

Preliminary results from RHIC's four detectors — known as BRAHMS, PHENIX, PHOBOS, and STAR — indicate that RHIC is well on its way to achieving its goals.

HIGHEST ENERGY DENSITY

One finding coming out of the study of RHIC collisions is that matter is being produced in a slight excess over antimatter — a situation similar to what is thought to have happened after the Big Bang. As the universe evolved over time after its birth, antiparticles and particles annihilated, leaving the excess of matter which makes up today's universe.

Another finding is that, within RHIC's collisions, the energy density — which is a measure of the energy deposited in the collision region by the colliding nuclei — is the highest ever achieved in a laboratory. To achieve such a density on a human scale, the Earth's moon would have to be stuffed into a backyard swimming pool!

One of the most intriguing findings from RHIC so far is the possibility that the most energetic particles are actually losing lots of energy as they emerge from the collisions. Just as marbles would have to slow down when encountering a puddle of honey spilled on a kitchen table, these particles might be slowed down by having to traverse a blob of matter — such as quark-gluon plasma — created in the collisions.

These bits of data are like pieces of a puzzle that scientists are still fitting together. How much these early results from RHIC will contribute to scientists' understanding of quark-gluon plasma is not yet clear. What is clear is the importance of the ongoing analysis of RHIC data, as the four detectors continue to collect it from collisions at a range of energies.

Even once quark-gluon plasma is discovered, RHIC will keep America's scientists among the world's leaders in nuclear physics for decades to come. In addition to advancing human understanding of the universe, RHIC experiments may lead to unforeseen advances in technology and applications in medicine and consumer products, as much basic research throughout the history of science has done before.

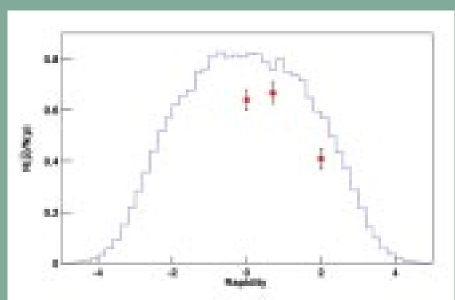
Recent Publications By the Detector Collaborations at RHIC

BRAHMS

Rapidity Dependence of Antiproton to Proton Ratios in Au + Au Collisions at $\sqrt{s_{NN}}$ = 130 GeV

Physical Review Letters
10 September 2001, volume 87, number 11, pp. 112305-1 to 4

In this paper, the BRAHMS collaboration notes its finding that, while there is a high degree of balance between the number of antiprotons to protons created in RHIC gold-gold collisions at 130 billion-electron-volt (GeV) center-of-mass energy in the midrapidity range, the ratio of antimatter to matter is significantly less than unity and decreases toward forward rapidity. In this graph, the ratio of antiprotons to protons is shown and compared to the Hijing model. Not predicted by this or two other theoretical models, this finding suggests that, in the measured collisions, a high degree of transparency is attained in midrapidity, although there is still a significant contribution from baryons over the entire rapidity range.

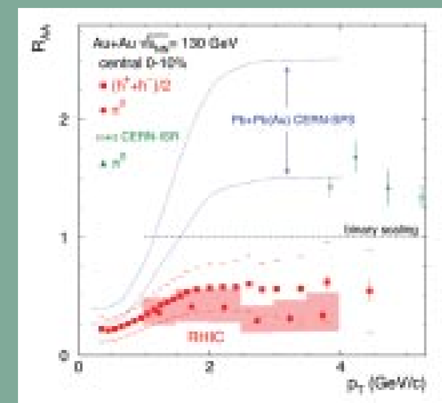


PHENIX

Suppression of Hadrons With Large Transverse Momentum in Central Au + Au Collisions at $\sqrt{s_{NN}}$ = 130 GeV

Physical Review Letters
14 January 2002, volume 88, number 2, pp. 022301-1 to 6

The PHENIX publication concerns a novel effect seen in central nuclear collisions at 130 GeV center-of-mass energy RHIC. As seen in this graph comparing the yields of high-momentum particles from heavy-ion nuclear collisions at RHIC to those from the ISR and SPS accelerators at CERN, the higher energy results from RHIC for gold-gold collisions show a suppression in yield, in contrast to previously observed enhancements. This suggests that the hot, dense nuclear matter formed in collisions at RHIC is much more opaque than that found in collisions at lower energies.

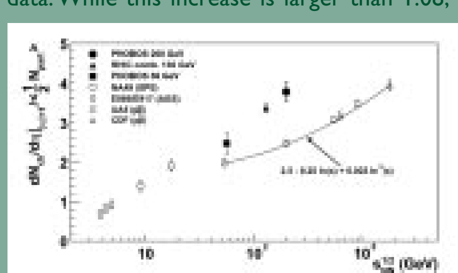


PHOBOS

Energy Dependence of Particle Multiplicities in Central Au + Au Collisions

Physical Review Letters
14 January 2002, volume 88, number 2, pp. 022302-1 to 4

The PHOBOS collaboration has published its finding that the pseudorapidity density in gold-gold collisions increases by a factor of 1.14 +/– 0.05 between 200 and 130 GeV center-of-mass energy. In this graph, energy dependence of pseudorapidity density is shown normalized per participant pair for central nucleus-nucleus collisions, as compared to nucleus-nucleus data from lower energies and proton-proton data. While this increase is larger than 1.08, which was measured for proton-proton collisions at the same energies, this increase is slower than that predicted by theoretical models, for which particle production is dominated by hard processes.

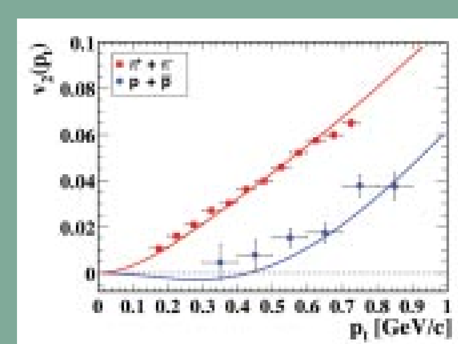


STAR

Identified Particle Elliptic Flow in Au + Au collisions at $\sqrt{s_{NN}}$ 130 GeV

Physical Review Letters
29 October 2001, volume 87, number 18, pp. 182301-1 to 6

In this publication, the STAR collaboration discusses how the measured elliptic flow of identified particles at midrapidity in gold-gold collisions at 130 GeV center-of-mass energy at RHIC differs significantly for particle of different masses. In this figure, differential elliptic flow for pions and protons is shown as a function of transverse momentum, with the pions showing a linear dependence and protons a more quadratic dependence as the momentum increases. The solid lines are calculations using a hydrodynamic model, and the agreement suggests that heavy-ion collisions are in thermodynamical equilibrium early in the collision process, which was not expected. The model is an unexpectedly good description of pion, protons, and other particles observed by STAR.



In the wake of the devastating September 11 attacks upon the United States, Brookhaven National Laboratory has mobilized researchers from across its scientific disciplines to devise or apply existing know-how and technology to counter future terrorism.

by Peter Genzer

Brookhaven Counters Terrorism

AS A MULTI-PROGRAM, MULTI-DISCIPLINARY national laboratory, Brookhaven has developed advanced capabilities and expertise that put it in a unique position to contribute to counterterrorism efforts in the U.S. and abroad. In the wake of the devastating September 11 terrorist attacks, the Laboratory established a counterterrorism working group to identify innovative approaches that may help to preserve the safety and enhance the long-term security of the United States of America and its people.

The 32-member Brookhaven working group builds on an urban anti-terrorism technical support organization established at the Laboratory in March 2001. The working group is headed by Ralph James, Associate Laboratory Director for Energy, Environment & National Security, and it aims to consolidate Brookhaven's unique capabilities and develop cutting-edge, science-based technologies that could help the nation predict, detect, preempt, and respond to terrorism.

"The destructive and vicious attacks of September 11 created an enormous challenge to build an improved security framework for our nation," said James. "As vanguards for the advancement of technological solutions, scientists at Brookhaven and elsewhere are now mobilizing to answer that challenge."

The working group represents most of the scientific disciplines within the Laboratory. Many of the group's ideas emphasize improved means to prevent and protect against attacks and to provide emergency response should prevention and protection fail. Brookhaven approaches and technologies currently being explored include the following:

Brookhaven's one-of-a-kind chemical sensor — Mini-Raman LIDAR, or the LIght Detection And Ranging device — is seen in action, surveying chemicals in a simulated event. The Mini-Raman LIDAR is a short-range, non-contact tool for identifying chemicals at a distance, without the need for collecting and handling a potentially hazardous or toxic sample.

DETECT, LOCATE & IDENTIFY

• Brookhaven is developing sensors for the early detection of nuclear, chemical, and biological agents and explosives that have the ability to register trace quantities of these materials. For instance, radiation detectors could be used to check baggage at airports and other transportation centers.

• Devised at the Laboratory, a one-of-a-kind chemical sensor to locate and identify chemical spills or ground contamination from a safe distance has been used in simulations. The system uses laser scattering to identify substances by their distinct chemical "fingerprints."

• Another technique under development uses microwaves to image unknown materials.

ANTIDOTES & VACCINES

• Methods are being worked upon to detoxify nerve gas agents using an enzyme that can degrade such compounds. This work could lead to topical lotions to protect the skin.

• Structural studies of viruses are being carried out to determine how these organisms attack the human body. This work may help scientists design vaccines and antidotes against biological weapons and aid in identifying these agents.

• Similar structural studies of chemicals may lead to the design of countermeasures for chemical weapons.

SEARCH & RESCUE

• Brookhaven has developed a jackhammer-like device which could be used to break up concrete and other debris in enclosed spaces. The team that developed the prototype has won several awards and is now working to commercialize the concept.

• A magnetic imaging tool designed to locate and map iron structures hidden in debris has been devised at the Laboratory. In addition to use in search-and-rescue missions, the tool could be developed further to map other materials within a debris field.

TRACK & OUTSMART

• Brookhaven has perfected techniques to model and track aerosols and chemicals as they move through air, and to identify and assess sources and trajectories of these atmospheric contaminants.

• Materials studies at the Laboratory may lead to "smart" buildings, structures more resistant to terrorist attacks involving explosives, or chemical or biological agents.

ASSESSMENT & TRAINING

• Brookhaven researchers are improving methods to assess security risks at office buildings, energy supply/distribution systems, airports, and other infrastructure elements, incorporating weighted analysis of threats, vulnerabilities, and consequences.

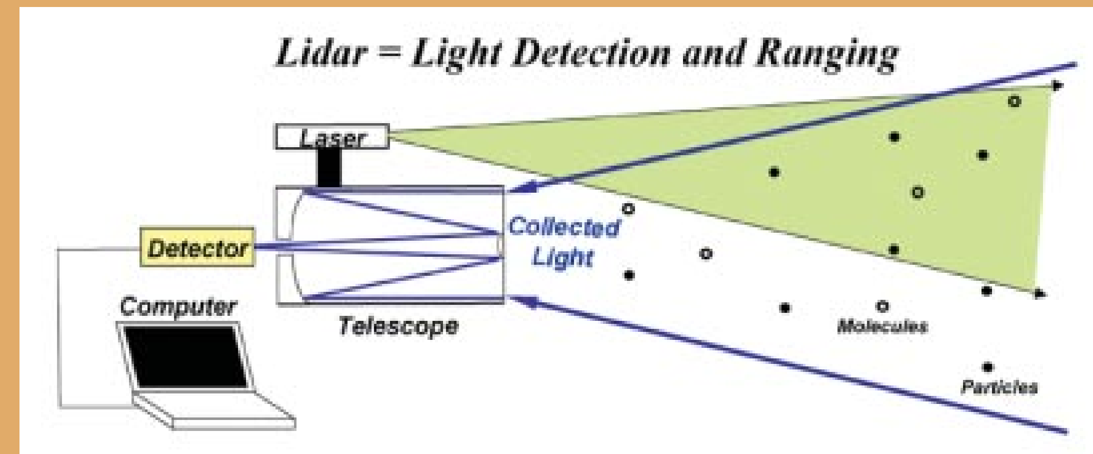
• Training and role-playing exercises, such as simulations of a biological weapons attack on a city, are being developed to help first-responders prepare for possible terrorist attacks.

Brookhaven's Mini-Raman LIDAR Chemical Sensor

The Brookhaven-designed Mini-Raman Light Detection and Ranging (LIDAR) chemical sensor is one promising tool that could help emergency responders working at a safe distance to detect and identify chemicals involved in a terrorist attack, narcotics operation, or accidental spill.

Small enough to fit on the back of a pickup truck, the mini-sensor works at distances up to 150 feet and combines the latest laser and detector technology with a phenomenon known as Raman scattering, or the Raman effect.

Light scatters when a photon of light changes direction as a result of a collision with a substance such as a chemical molecule. In Raman scattering, light changes in frequency and phase as a result of this interaction. Because a beam of laser light is intense, polarized, coherent, and monochromatic, the laser is an ideal source for the production of the Raman effect.



As illustrated above, Brookhaven's Mini-Raman LIDAR chemical sensor works by projecting a beam of light from an aluminium-garnet laser at the substance under investigation. The light that scatters off the substance is collected by a detector via a telescope. Once analyzed by a spectrometer, the device produces a unique chemical fingerprint, which is compared via computer with a library of such information to identify the chemical involved.

The results from Raman scattering are analyzed by a spectrometer, an instrument that measures the unique pattern of light from the collected signal. Because of the Raman effect, each substance produces its own pattern of frequencies — a characteristic chemical "fingerprint" that can be used to identify the substance. As a result, Raman spectroscopy has long been of great value in chemical analysis of solid, liquids, gases, and aerosols — and is now being considered as a tool to counter terrorism.

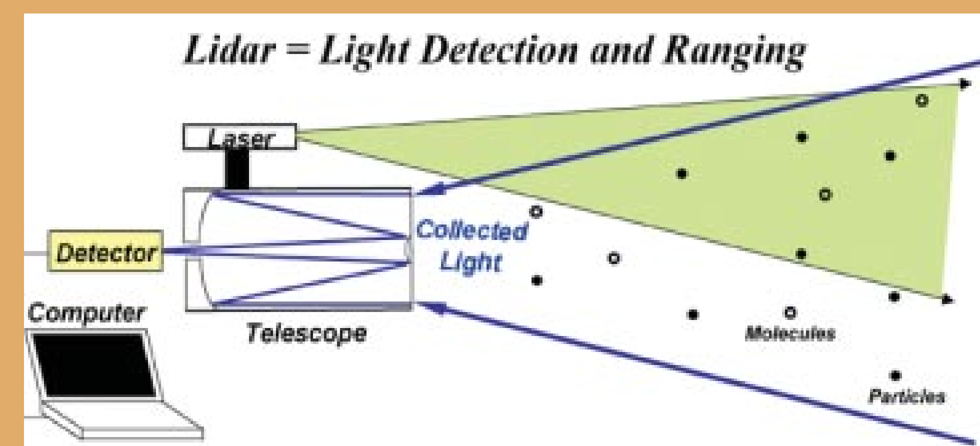
In fact, Brookhaven's Mini-Raman LIDAR was tested in 1997 during a terrorist-attack exercise conducted by the Office of Emergency Management of New York City. In this simulation, the device successfully detected the surrogate chemical agent, liquid acetone, at a distance of five meters outdoors in a rain storm. Thus, the feasibility of using the Mini-Raman LIDAR to assess surfaces such as streets, walls, and clothing following a biological or chemical attack was proven.

In the field, Brookhaven's Mini-Raman LIDAR works by projecting a beam of light from an yttrium-aluminium-garnet laser at the substance under investigation. The light that scatters off the substance is collected by a detector via a telescope. Once analyzed by a spectrometer, the unique chemical fingerprint is compared via computer with a library of such information to identify the chemical involved rapidly.

The mini-sensor is an offshoot of a large, chemical sensor system developed at Brookhaven — a 33-foot-long mobile detection van that can identify chemicals in the atmosphere from several miles away. While the larger sensor system is best used for atmospheric applications, the mini-sensor is more efficient in determining surface or ground contamination.

In addition to using the mini-sensor in response to terrorist attacks, potential applications include:

- identifying chemical weapons production
- locating narcotics operations
- monitoring industrial factory emissions
- investigating environmental crimes
- determining the effectiveness of environmental clean-ups
- assessing the hazards of chemical fires



In Raman scattering, light changes in frequency and phase as a result of interaction with a substance. Because of the Raman effect, each substance produces its own pattern of frequencies in the spectrum — a characteristic chemical "fingerprint" that can be used to identify the substance. As a result, Raman spectroscopy has long been of great value in chemical analysis of solid, liquids, gases, and aerosols — and is now being considered as a tool to counter terrorism.

LOCAL, STATE & FEDERAL

To ensure that Brookhaven's efforts are in step with the needs of local, state, and federal authorities, the Laboratory's working group is collaborating with the following agencies:

- U.S. Department of Energy
- U.S. Department of Defense
- U.S. Federal Aviation Administration
- U.S. Nuclear Regulatory Commission
- U.S. Merchant Marine Academy
- N.Y. State Battery Park City Authority
- N.Y. City Office of Emergency Management

MORE INFORMATION

- *funding:* Office of Basic Energy Sciences, Office of Biological & Environmental Research, U.S. Department of Energy; National Nuclear Security Administration; National Institutes of Health; U.S. Nuclear Regulatory Commission; and others
- *paper:* "Ultraviolet Mini-Raman LIDAR for Standoff, In-situ Identification of Chemical Surface Contaminants," Review of Scientific Instruments, September 2000, volume 71, number 9, pp. 3485-89
- *contact:* Ralph James, rjames@bnl.gov or (631) 344-8633
- *Web:* http://www.bnl.gov/bnlweb/pubaf/pr/2001/bnlpr111601a.htm

Meet Ralph James

Ralph James, Brookhaven's Associate Laboratory Director for Energy, Environment & National Security since 2001, is internationally recognized for materials research that has led to the development of a new class of radiation sensors and medical-imaging devices.

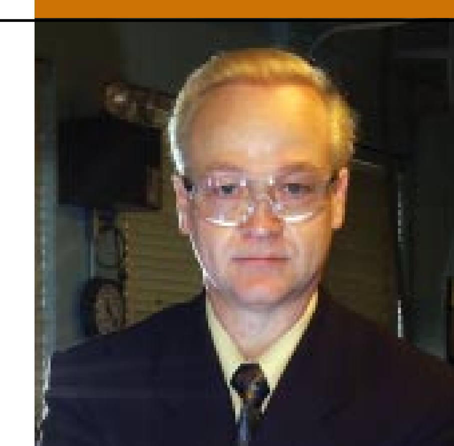
James earned an M.S. in physics from the Georgia Institute of Technology in 1977, another M.S. in applied physics from the California Institute of Technology (Caltech) in 1978, and a Ph.D. in applied physics from Caltech in 1980.

With a staff of 282 and a budget of $78 million, James oversees basic and applied research, including such projects as the relationship between aerosol chemistry and global climate and air pollution; research in biological and chemical processes to produce ultra-clean fuels; and development of new technology to safeguard nuclear materials.

James holds nine patents, has authored more than 280 scientific publications and 11 book chapters, and edited ten books. James won *Discover* magazine's 1997 Innovator of the Year award for developing radiation detection devices, and he also is a three-time winner of *R&D Magazine's* R&D 100 Award, which honors the top 100 inventions of the year.

"Brookhaven Lab scientists are determined to apply their skills to reduce the likelihood that the pain we experienced on September 11 is ever felt again."

RALPH JAMES



A second sighting of a rarely occurring decay of the subatomic particle known as the kaon has not only confirmed the original discovery, but also upholds some of the more exotic aspects of the Standard Model — physicists' description of elementary particles and the forces that act on them.

BY KAREN MCNULTY WALSH

Physicists See Once-in-a-Trillion Event — Again!

Since kaons only exist for about 12 billionths of a second, the E787 collaboration built a state-of-the-art particle detector the size of a small house to examine one million decays every second in detail

AFTER CAREFUL STUDY of six trillion subatomic particle decays, an international collaboration announced that its physicists have spotted one of the rarest occurrences in the subatomic world — for a second time. The 50 researchers — from the United States, Canada, and Japan — have spent 12 years searching for this rare decay at Brookhaven National Laboratory's Alternating Gradient Synchrotron (AGS).

The collaboration, which operates AGS experiment E787, reported the first-ever example of this rare decay four years ago. Now, the second observation, reported in *Physical Review Letters*, represents an important confirmation of that discovery.

The reported rare decay involves an unstable particle called a kaon, which can decay, or break apart, in a variety of ways. One particular decay mode, in which the kaon turns into a positively charged pion, a neutrino, and an antineutrino (which is written by physicists as $K^+ \rightarrow \pi^+, \nu, \bar{\nu}$), is so rare that theory predicts it happens only several times in every hundred billion kaon decays.

Because of difficulties in distinguishing this type of decay from the many others like it, E787 physicists had to search through many times that number of events just to have a chance of spotting even one.

SIX TRILLION KAONS

To search through six trillion kaon decays, the E787 collaboration first needed six trillion kaons. Brookhaven's AGS, a particle accelerator capable of producing the world's most intense beam of kaons, was the perfect place for E787's search.

Since kaons only exist for about 12 billionths of a second, the E787 collaboration had to build a state-of-the-art particle detector the size of a small house to examine in detail one million decays every second. The decays that the detector decided were promising were collected on magnetic tape.

This short list, which was thousands of gigabytes in size, was pored over by E787 physicists as they reconstructed what really happened inside the detector.

"Out of all that data, we've now found two events explicable only by the rare kaon decay we were searching for," said E787 co-spokesperson

(continued on page 20)

Meet Laurence Littenberg

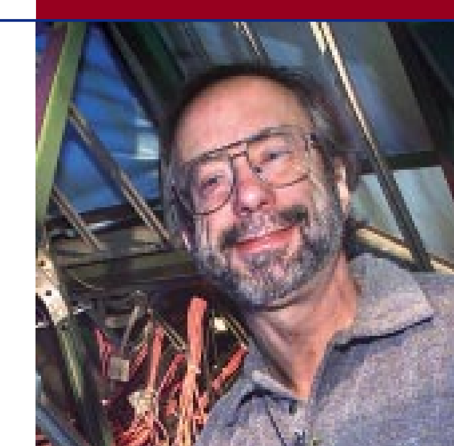
Laurence Littenberg, who is known to friends and colleagues as Laurie, came to Brookhaven National Laboratory in 1974. A senior physicist since 1989 and leader of the Physics Department's Electronic Detector Group, Littenberg has helped to keep Brookhaven at the forefront of experimental particle physics.

His primary quest has been the experimental search for rare kaon decays, as well as the theoretical study of a kaon decay process that may help to explain the excess of matter over antimatter in the universe.

Interested in the subject from quite an early age, Littenberg earned a B.A. in physics from Cornell University in 1963, and then an M.S. and Ph.D., also in physics, from the University of California, San Diego, in 1965 and 1969, respectively.

"Particle physics is now quite a mature field. All the 'easy' experiments have been done. To make significant progress requires very sophisticated techniques, which are fun to develop and work on."

Laurence Littenberg



The Alternating Gradient Synchrotron at Brookhaven

The Alternating Gradient Synchrotron (AGS) is an accelerator that has produced three major discoveries — the J/psi particle, CP violation, and the muon-neutrino particle — for which the 1988, 1980, and 1976 Nobel Prizes in physics, respectively, were awarded. Research at the AGS has also uncovered other particles, such as the omega-minus, and certain physics phenomena, such as short- and long-lived neutral kaons.

In addition, the AGS is proof of the strong focusing principle, the Brookhaven-developed concept that underlies the design of all modern circular accelerators, including the Relativistic Heavy Ion Collider (RHIC) at the Laboratory. Today, when not serving as the heavy-ion injector for RHIC, the AGS is the world's highest intensity, high-energy proton accelerator, used to search for "new physics."

The AGS is also the only U.S. heavy-ion accelerator suitable for experiments to determine the biological effects of space travel on biological systems and human beings. As a result, the National Aeronautics and Space Administration (NASA) sponsors radiobiology research at the AGS and is expanding its research capabilities by building a new experimental facility at the AGS.

and Brookhaven physicist Laurence Littenberg.

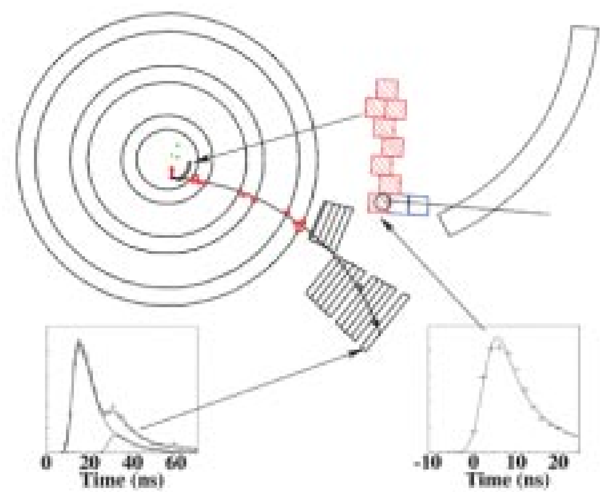
STRANGE SCIENCE

Co-spokesman Doug Bryman of the University of British Columbia and TRIUMF, which is Canada's national laboratory for subatomic physics, says that this rare decay is one of the keys to understanding the universe's most elemental forces and particles.

In fact, this decay is worth so much careful study because it involves some of the more exotic aspects of the Standard Model, the theory that describes the subatomic world. Kaon decays in general have proved a rich, often surprising source of information on fundamental questions in particle physics because kaons contain a "strange" quark, a heavy relative of the quarks that comprise ordinary matter such as the protons and neutrons in the nucleus of an atom.

When a positive kaon, the lightest particle to contain a strange quark, decays to a positive pion, which is composed of ordinary quarks only, the strange quark is converted into a "down" quark. This is forbidden in any direct process by the Standard Model.

A kaon's decaying into a positively charged pion, a neutrino, and an antineutrino, however, still has a small chance of occurring by means of an indirect, two-step process involving two very massive gauge-boson force carriers and quarks — specifically, the massive "top" quark, an exotic particle co-discovered by Brookhaven scientists and their colleagues in two Fermi National Accelerator Laboratory experiments in 1995.



The rare kaon decay event $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ is reconstructed in this schematic. In the upper left is the end view of the E787 detector, where a K^+ enters near the center of the concentric circles representing the cylindrical tracking chamber. The K^+ loses energy, stops in a segmented target of scintillating plastic counters, and then decays to a π^+. The π^+ leaves the target and, as indicated by the small circles, is tracked through the chambers into an array of large scintillation counters surrounding the chamber. The π^+ stops in the 15th counter on the path. On the upper right is a blowup of the stopping target region. The hatched red squares indicate target elements hit by the K^+, and the blue squares are those hit by the π^+ as it leaves the target. The curved element is a trigger scintillation counter adjacent to the target, which the π^+ also hits on its way out. The curve on the lower right is the pulse of energy left by the K^+ in the target element in which it stopped. The curve on the lower left shows the pattern of energy deposition in the last counter on the π^+ trajectory. The pulse of energy left by the stopping pion is shown by the muon into which it decayed after about 15 billionths of a second. The lack of other tracks or significant energy depositions indicates that the π^+ was unaccompanied by any detectable particles (neutrinos are not detectable in this apparatus).

MORE INFORMATION

- *funding:* Office of Science, U.S. Department of Energy; Ministry of Education, Culture, Sports, Science & Technology, Japan; and the Natural Sciences & Engineering Research Council and the National Research Council of Canada
- *paper:* "Further Evidence for the Decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$," Physical Review Letters, January 28, 2002, volume 88, issue 4, article 041803, pp. 041803-1 to 041803-4
- *contact:* Laurence Littenberg, litt@bnl.gov or (631) 344-3811
- *Web:* http://www.bnl.gov/bnlweb/pubaf/pr/2002/bnlpr011002.htm

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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

In managing and operating the Laboratory for the U.S. Department of Energy, BSA strives for excellence in scientific research, facility operations, and staff management.

Introducing Brookhaven Science Associates

IN 1998, the U.S. Department of Energy (DOE) selected Brookhaven Science Associates (BSA) — a company founded by Stony Brook University and Battelle — to manage and operate Brookhaven National Laboratory. The affiliation developed from Stony Brook's proximity and historical participation in Brookhaven research as the largest academic user of Laboratory facilities, and from Battelle's experience serving DOE as the manager of other DOE labs.

BSA relies upon a board of 16 directors, five each from Stony Brook and Battelle, and one each from six core universities: Columbia, Cornell, Harvard, Massachusetts Institute of Technology, Princeton, and Yale.

Under BSA, Brookhaven works to fulfill DOE's science mission by maximizing the effectiveness of the Laboratory's user facilities and interdisciplinary know-how. In addition, BSA has introduced new systems emphasizing improved environment, safety, and health performance, including pollution prevention and waste minimization. BSA is also working with various communities — from local neighbors to international scientists — to involve them appropriately in Laboratory issues and decision-making.

Fulfilling the DOE Science Mission

As the nation's third largest government sponsor of basic scientific research, the U.S. Department of Energy leads the nation in funding the physical sciences and is a significant contributor of funds for the biological sciences.

The majority of DOE's science portfolio is managed by the Office of Science, which supports science in two important ways: first, by funding the research itself; and, second, by maintaining the scientific infrastructure necessary to do this research.

As one of the U.S. Department of Energy's national laboratories, Brookhaven is funded to carry out research and development in four areas: science and technology, environmental quality, national security, and energy resources. Brookhaven accomplishes this research and development mission by:

- designing, constructing, and operating some of the world's largest and most sophisticated research facilities for laboratory, university, and industry scientists from across the nation and around the world
- carrying out long-term programs of basic and applied research at the frontier of science
- advancing technology to meet national need, and then transferring technical know-how to industry
- educating tomorrow's scientists and technology-savvy citizens today