discover
BROOKHAVEN
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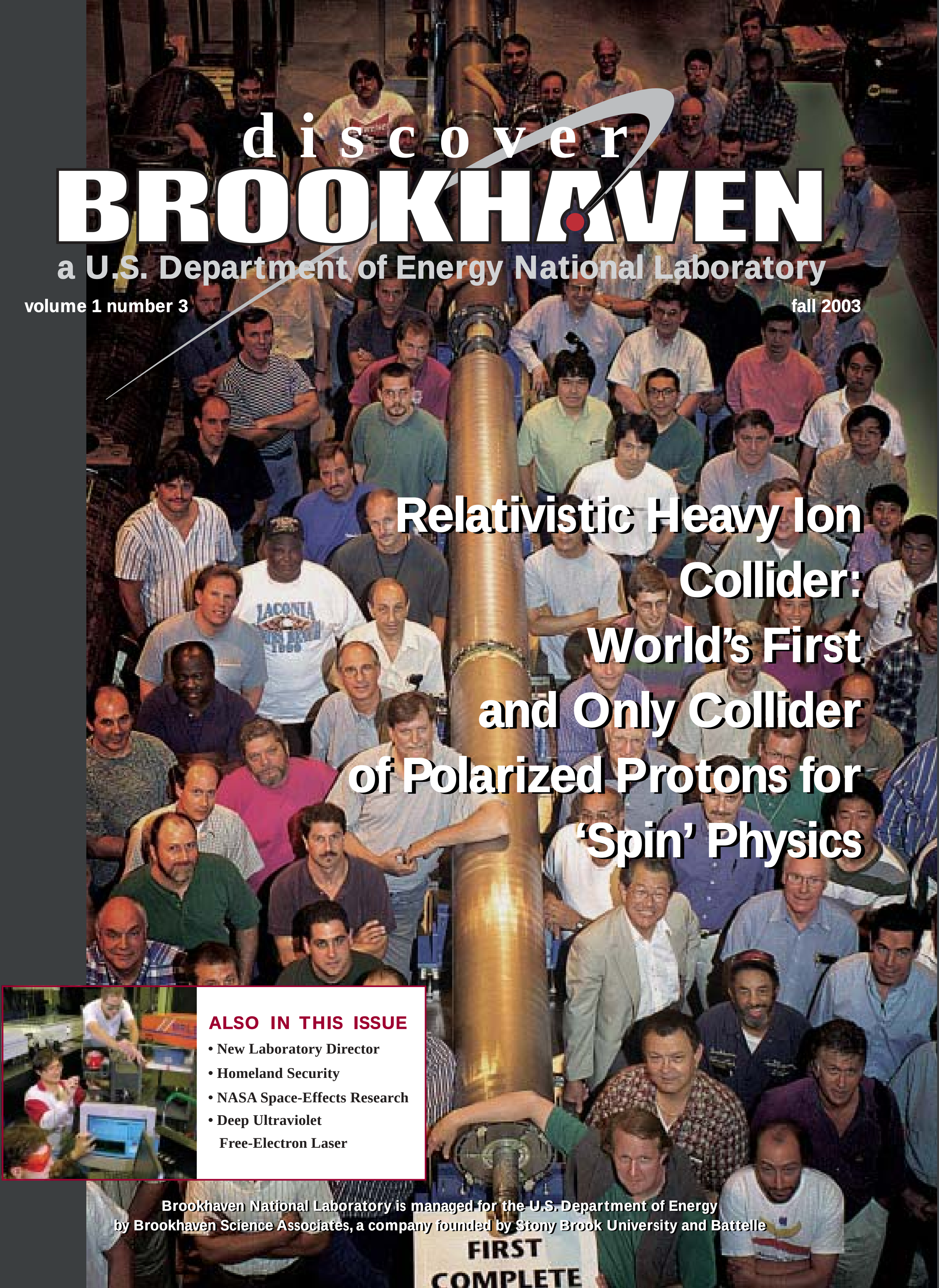


Relativistic Heavy Ion Collider: World's First and Only Collider of Polarized Protons for 'Spin' Physics

ALSO IN THIS ISSUE

- New Laboratory Director
- Homeland Security
- NASA Space-Effects Research
- Deep Ultraviolet Free-Electron Laser

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

Introducing
Our New Laboratory Director

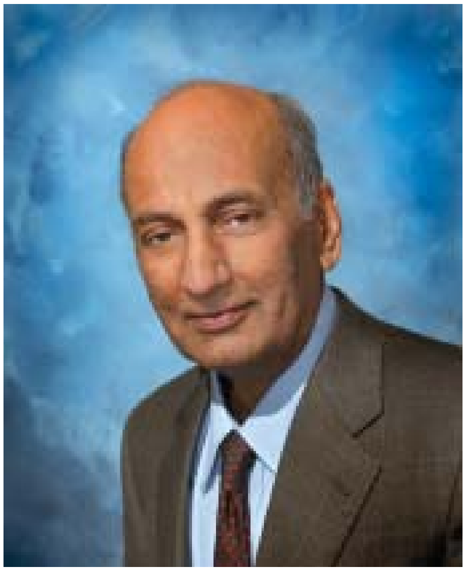
BEGINNING BEFORE HE BECAME LABORATORY DIRECTOR ON APRIL 1ST, Praveen Chaudhari has been mapping the terrain of Brookhaven National Laboratory. In preparation for charting Brookhaven's future course, the new Director is getting to know the lay of the laboratory, by surveying our people, gauging our personalities, and appraising our relationships with our internal and external communities.

These communities are many and varied. They include our biggest customer, the U.S. Department of Energy (DOE), as well as the other federal and state agencies for which we work. Within the Lab, we have communities of scientific and support staff, and facility-users and other guest researchers. Outside our geographical boundaries are our immediate Long Island neighbors; the elected and appointed officials of the county, state, and nation; and the local, national, and international media reporting upon us.

In noting our coordinates, the new Director is not only learning his way around our campus-like site, with its address-free, numbered buildings and facilities, and its 5,300 acres of scrub oak and pitch pine. But, more importantly, Chaudhari is also finding out what inroads we have made over our 50-plus years, where we stand in the field nowadays, and what frontiers we have the ability and motivation to challenge in the future.

In the process, we are learning what expectations the Laboratory's seventh Director has for us, individually and collectively as members of this dynamic scientific institution. So far, the one theme articulated by Chaudhari that is resonating within many of our 2,900 scientific and support staff is this: We are one Laboratory, united in our effort to advance scientific understanding and technological solutions for the good of the nation and the world.

"It is clear to me that this national laboratory plays a vital role in the world of science," says Chaudhari. "But only by working as one can we further strengthen and expand our science programs, to become and be perceived as the best value for the money invested in any national laboratory." For instance, by employing the research abilities that cut across Brookhaven's scientific departments in a coordinated fashion, we can use Laboratory-wide skills to find answers to the even more probing questions in science, as well as to develop technical solutions to the nation and world's ever more difficult problems.



Brookhaven National Laboratory Director and President of Brookhaven Science Associates Praveen Chaudhari.

A distinguished scientist and proven research and laboratory-operations manager with a 36-year career at IBM, Praveen Chaudhari was selected as Laboratory Director by Brookhaven Science Associates (BSA). Chaudhari also serves a President of BSA, the company founded by Stony Brook University and Battelle Memorial Institute which has been managing and operating Brookhaven since 1997 for DOE's Office of Science (OS). As OS Director Raymond Orbach noted about the appointment: "Dr. Chaudhari's scientific leadership and international breadth of experience will shape Brookhaven's future, so this is a great choice for the Laboratory, its local community, and the nation."

Chaudhari earned his B.S. from the Indian Institute of Technology in 1961, and an M.S. and Sc.D., both from the Massachusetts Institute of Technology, in 1963 and 1966, respectively. In 1966, he joined IBM's Research Division, headquartered at the Watson Research Center in Yorktown, New York. Appointed Director in 1981 and Vice-President of Science in 1982, Chaudhari was responsible for IBM's science programs not only at Watson, but also at the Almaden Research Center in California, and at the Zurich Research Laboratory in Switzerland. Under Chaudhari's watch, IBM scientists captured Nobel Prizes in physics for two consecutive years: in 1986, for developing the scanning tunneling microscope; and, in 1987, for discovering high-temperature superconductivity in a new class of materials. In 1991, Chaudhari returned full-time to research.

As a scientist who has published over 150 papers and who holds over 20 patents, Chaudhari is most well known for the discovery of amorphous magnetic materials and their development into read-write, optical storage technology, which has made fast, affordable, high-volume computer-data storage possible. For his achievements, Chaudhari has been recognized with a number of awards, among them the 1995 National Medal of Technology. Upon coming to Brookhaven, he was already a Member of the National Academy of Engineering, and a Fellow of the American Academy of Arts and Sciences and the American Physical Society. Then, at the end of his first month at the Laboratory, Chaudhari was again honored, this time by being named a Member of the National Academy of Sciences.

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IN THIS ISSUE

ON THE COVER: Pictured are many of the Brookhaven Lab staff involved in the design and fabrication of the Relativistic Heavy Ion Collider's first Siberian "snake," hardware that makes possible the acceleration of beams of polarized protons (see cover story, page 10).

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

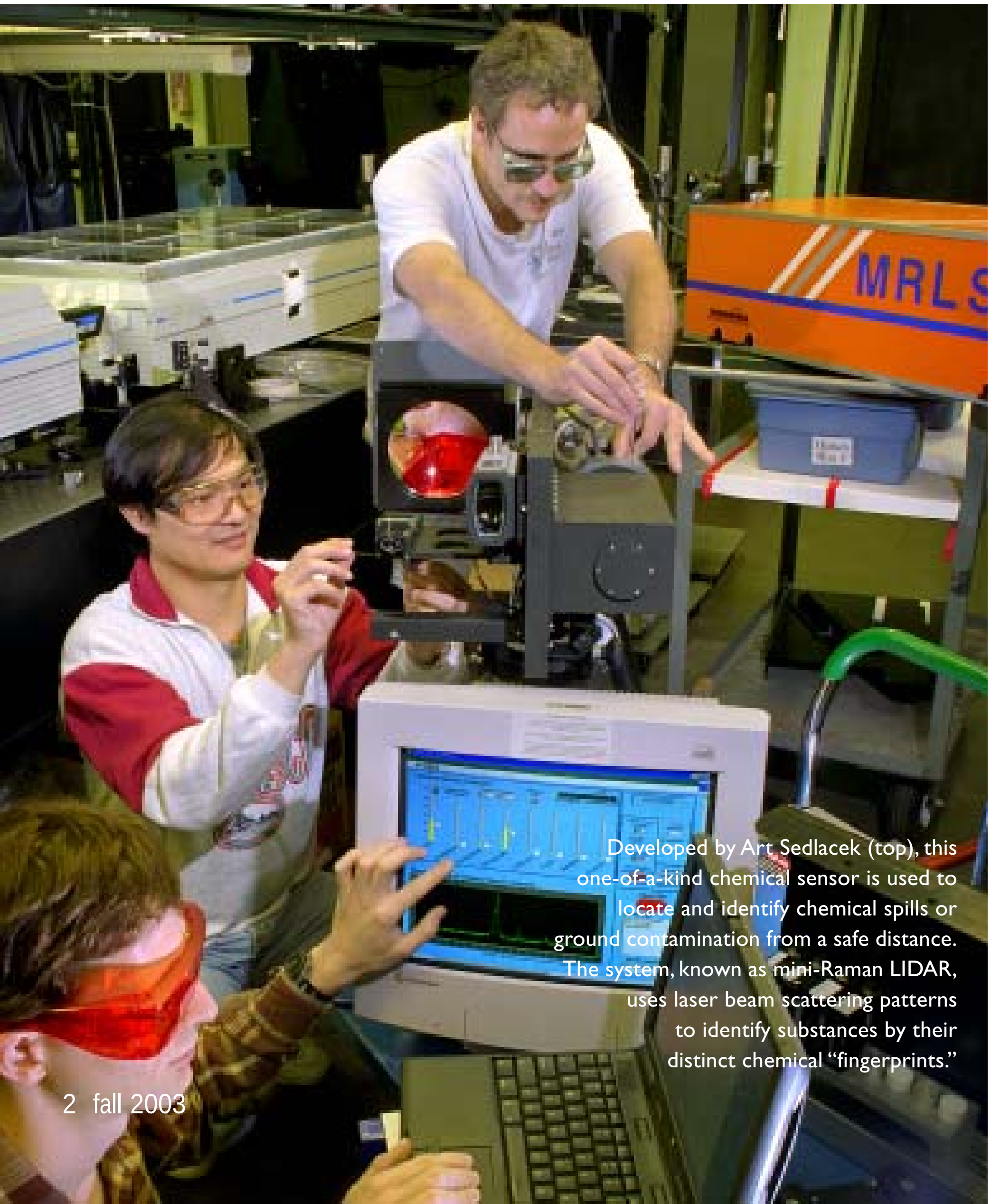
From safeguarding fissile materials to developing technology for detection of nuclear weapons, dirty bombs, toxic chemicals, biological pathogens, and conventional explosives, Brookhaven's homeland-security initiatives are focused on protecting the New York metropolitan area and our nation from future terrorist attacks.

BY PETER GENZER

Brookhaven Develops Science-Based Solutions

THE EIGHT PARALLEL PILLARS loom like some sort of post-modern Stonehenge, 20 feet tall and yellowish-orange in color. These steel towers, however, straddle a road encircling a former Long Island landfill, not a pastoral English meadow. Bristling with sophisticated electronic equipment, these pillars are radiation detectors: cutting-edge tools for the fight against terrorism that represent just one of Brookhaven Lab's current homeland-security initiatives.

"Here it comes now," says Carl Czajkowski of Brookhaven's Nonproliferation & National Security (N&NS) Department, pointing to a panel truck speeding down the road towards the detectors. As the vehicle passes between the pillars, multiple alarms sound in a nearby trailer, while computer screens display the type and energy of the radiation detected, and its position within the truck. The potential terrorists are stopped this time — but if only in a demonstration. For this purpose, "We put a tiny radioactive source inside the cargo area," discloses Czajkowski.



Developed by Art Sedlacek (top), this one-of-a-kind chemical sensor is used to locate and identify chemical spills or ground contamination from a safe distance. The system, known as mini-Raman LIDAR, uses laser beam scattering patterns to identify substances by their distinct chemical "fingerprints."

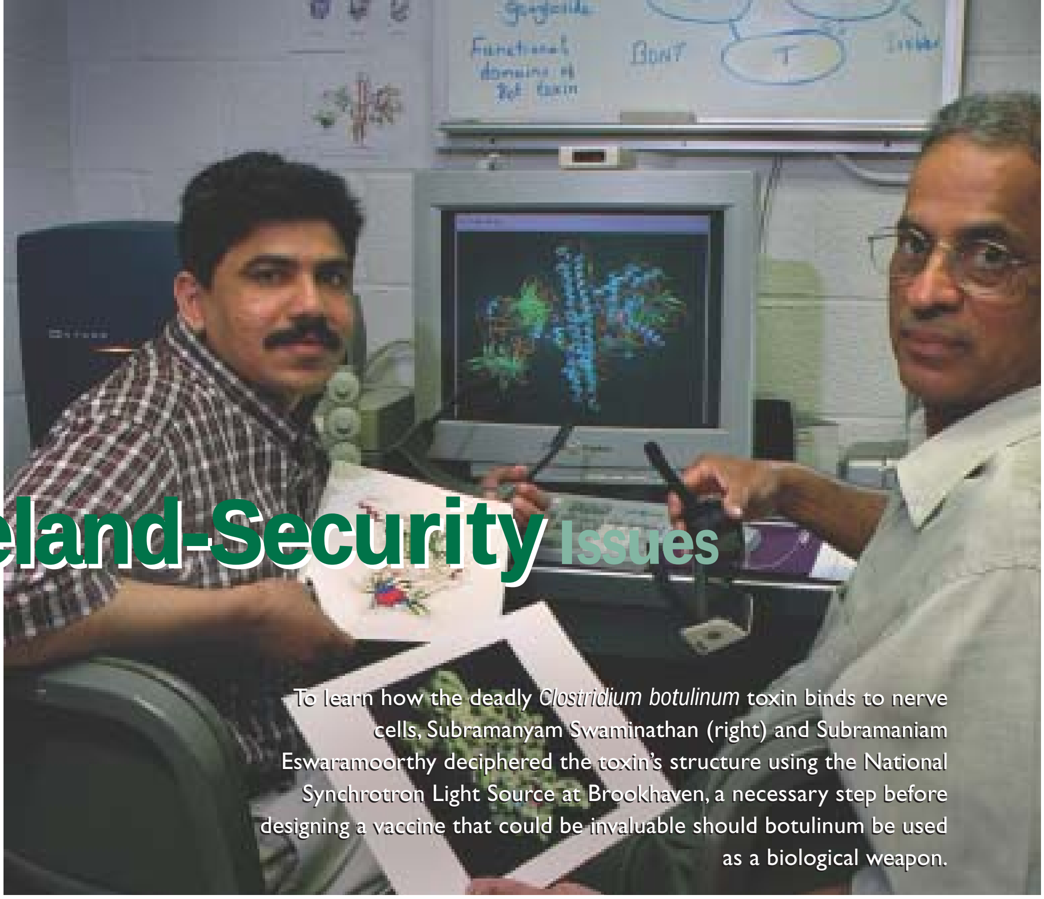
From safeguarding fissile materials to developing sensors and technologies for detection of nuclear weapons, dirty bombs, toxic chemicals, biological pathogens, and conventional explosives, the Laboratory's homeland-security initiatives are advanced, science-based solutions to help meet the challenges faced by those protecting U.S. national security interests both at home and abroad. Over the past two years, Brookhaven has been consolidating and refocusing its homeland-security programs while reaching out to local, state, and federal agencies to offer its assistance on a variety of issues.

RADTEC: DETECTOR TEST FACILITY

At the nation's ports, airports, and border crossings, security is increasingly focused on the possibility that terrorists may illegally transport radioactive material into the country, for use as part of a conventional nuclear weapon or a "radiological dispersal device," which is more commonly called a dirty bomb. In response, state-of-the-art radiation detectors are being installed at key locations in an effort to intercept these materials before they can be used in an attack.

In cooperation with the U.S. Department of Homeland Security, the U.S. Department of Energy is drawing upon Brookhaven's expertise before field deployment of such radiation-detection equipment. "How we can help is by testing these instruments at RADTEC under

to National Homeland-Security Issues



To learn how the deadly *Clostridium botulinum* toxin binds to nerve cells, Subramanyam Swaminathan (right) and Subramaniam Eswaramoorthy deciphered the toxin's structure using the National Synchrotron Light Source at Brookhaven, a necessary step before designing a vaccine that could be invaluable should botulinum be used as a biological weapon.

controlled conditions that represent what is encountered in the field," explains Czajkowski.

RADTEC, or Brookhaven's Radiation Detector Testing and Evaluation Facility, is where off-the-shelf homeland-security technology developed by the government or industry can be assembled, operated, tested, and compared. Open for use by government and industrial technology developers, RADTEC defines the strengths and weaknesses of different types of detectors, and enables the comparison of detectors based on performance and ease of use. Analysis of RADTEC test results can be used to help develop the most comprehensive protection system using detectors in and around the New York metropolitan area.

In addition to collecting baseline data on various types of detectors, RADTEC staff is also offering training to city, state, and federal officials on operating and testing detectors, and interpreting test results. "After we complete testing," say Czajkowski, "these detectors will be deployed during field trials at New York and New Jersey facilities, such as bridge and tunnel toll plazas, shipping yards, and airport freight hangars."

DEVELOPING ADVANCED SENSORS

In addition to testing existing detectors, the Laboratory is also developing its own advanced sensors for detecting radiological, biological, and chemical materials. The most promising technologies under development at Brookhaven include:

- CADMIUM-ZINC-TELLURIDE-BASED SENSORS: detect gamma rays emitted by radionuclides of interest to terrorists, including cesium and cobalt. Unlike high-purity germanium detectors, which are expensive and must be kept chilled to function effectively, these work at room temperature and are compact and lightweight.
- LARGE-VOLUME XENON-BASED DETECTORS: are another type of room-temperature device used to detect and identify radioactive materials at transportation bottlenecks.
- HIGHLY SENSITIVE THERMAL NEUTRON CAMERAS: can locate fissionable radioactive materials from a substantial distance.
- ONE-OF-A-KIND CHEMICAL SENSOR: can, from a safe distance, locate and identify chemicals, such as those used in nerve gas, dispelled in the air or deposited on surfaces,

The Radiation Detector Testing & Evaluation Facility at Brookhaven

At RADTEC, radiation detectors sense the radioactive source carried within this panel truck

PURPOSE

To assemble, operate, and test commercial and government off-the-shelf technologies for use in homeland-security applications

SPONSOR

National Nuclear Security Administration, U.S. Department of Energy; and the U.S. Department of Homeland Security

FEATURES

- indoor workshop for protected assembly and calibration of advanced sensors before testing
- outdoor facility to imitate conditions likely to be seen in the field
- standardized data collection procedures to allow quantitative and qualitative comparisons of various detectors
- training available for equipment operators before off-site deployment

FACILITY USERS

U.S. industry, government agencies, and other laboratories

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www.bnl.gov/homeland/default.asp

using laser-scattering patterns to identify a substance's distinct chemical signature. In March 2003, the technology was licensed to the UTEK Corporation for further development.

- MOLECULAR FINGERPRINTER: could be useful for the early detection of biological attacks.
- ACCELERATOR-BASED, CARGO-SCANNING TECHNOLOGY: can detect nitrogen, which is found in many explosive materials.

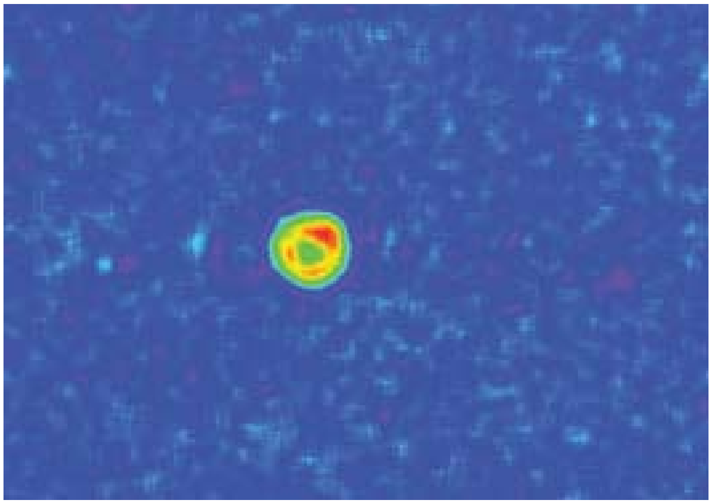
Brookhaven is also working with other New York and New Jersey agencies to determine what additional help is needed to prevent dangerous materials from entering the U.S. For instance, one solution involves deploying detectors as part of a sensor network to collect data from containers and ships, U.S. Customs and Coast Guard agents, dock-side cranes, truck and rail heads, and commercial trucks traveling Interstate 95.

A more ambitious Brookhaven program, called Urban Shield, would integrate data from hardened sensor networks that are deployed throughout a municipal area such as New York City and that provide on line data in real time. These sensor networks would employ a dense array of meteorological instrumentation, satellite products, and radiation detectors to identify and help track chemicals or radionuclides if accidentally or intentionally released, thereby providing real-time information that is crucial to emergency responders.

REGIONAL COUNTER-TERRORISM PLANNING

"For many political, economic, psychological, and technical reasons, New York City has been and continues to be a major target of terrorism," comments Paul Moskowitz of N&NS. "As a result of our proximity to New York City and our scientific and technical expertise and experience, Brookhaven is an invaluable counter-terrorism planning and implementation resource for the New York metropolitan area."

Over the years, the Laboratory has worked with city officials on issues of common interest, including spent nuclear-fuel transport, air and water pollution, and emergency services. Since September 11, 2001, Brookhaven has offered its assistance and been consulted on the counter-terrorism issue, as exampled by:



The Brookhaven-developed thermal neutron imaging camera can "see" radioactive materials, such as plutonium or the beryllium source pictured above, from a substantial distance.

- JANUARY 2002 CONFERENCE "Implications for Security of the Built Environment in New York City" co-sponsored by the Laboratory
- APRIL 2002 WORKSHOP "New York Metropolitan Region: Counter-terrorism and Infrastructure Assurance Technology Needs" co-sponsored by Brookhaven, and the U.S. Department of Energy's National Nuclear Security Administration, the Environmental Measurements Laboratory, the New York City Office of Emergency Management, and the U.S. Merchant Marine Academy
- 2002 DOE-FUNDED STUDY "Security of Radioactive Materials at Non-Reactor Sites in New York State" led by the Laboratory for the New York State Governor's Office of Public Security
- 2002 WORKSHOP "Urban Atmospheric Observatory" for New York City co-sponsored by Brookhaven and the Environmental Measurements Laboratory
- 2003 DOE-FUNDED STUDY, now ongoing and co-led by Brookhaven, of the vulnerability to terrorism of New York State infrastructure, such as bridges, tunnels, energy control systems, oil or gas pipelines, water supplies, and telecommunication systems.

> "Efforts to prevent the spread and use of weapons of mass destruction are not new, but, in light of September 11 and other recent world events, these efforts have never before seemed so important."
>
> JOSEPH INDUSI
> CHAIR OF NONPROLIFERATION &
> NATIONAL SECURITY DEPARTMENT

Through these and other efforts, Brookhaven has developed close working relationships with key regional authorities, private-sector partners, and academic institutions, including:

- New York City Office of Emergency Management
- New York State Office of Public Security
- Long Island Forum for Technology
- Northrop Grumman Corporation
- Symbol Technologies, Inc.
- Stony Brook University
- United States Merchant Marine Academy.

AT HOME AND ABROAD

While detecting and intercepting dangerous materials before entering the U.S. is crucial, securing these materials at the source is just as important.

So, overseas, Brookhaven scientists are working to safeguard nuclear materials in the former Soviet Union through the Laboratory's material protection, control and accounting cooperative program.

Designed to secure highly enriched uranium and other dangerous material stored at formerly secret sites across Russia and the other former Soviet states, program projects include:

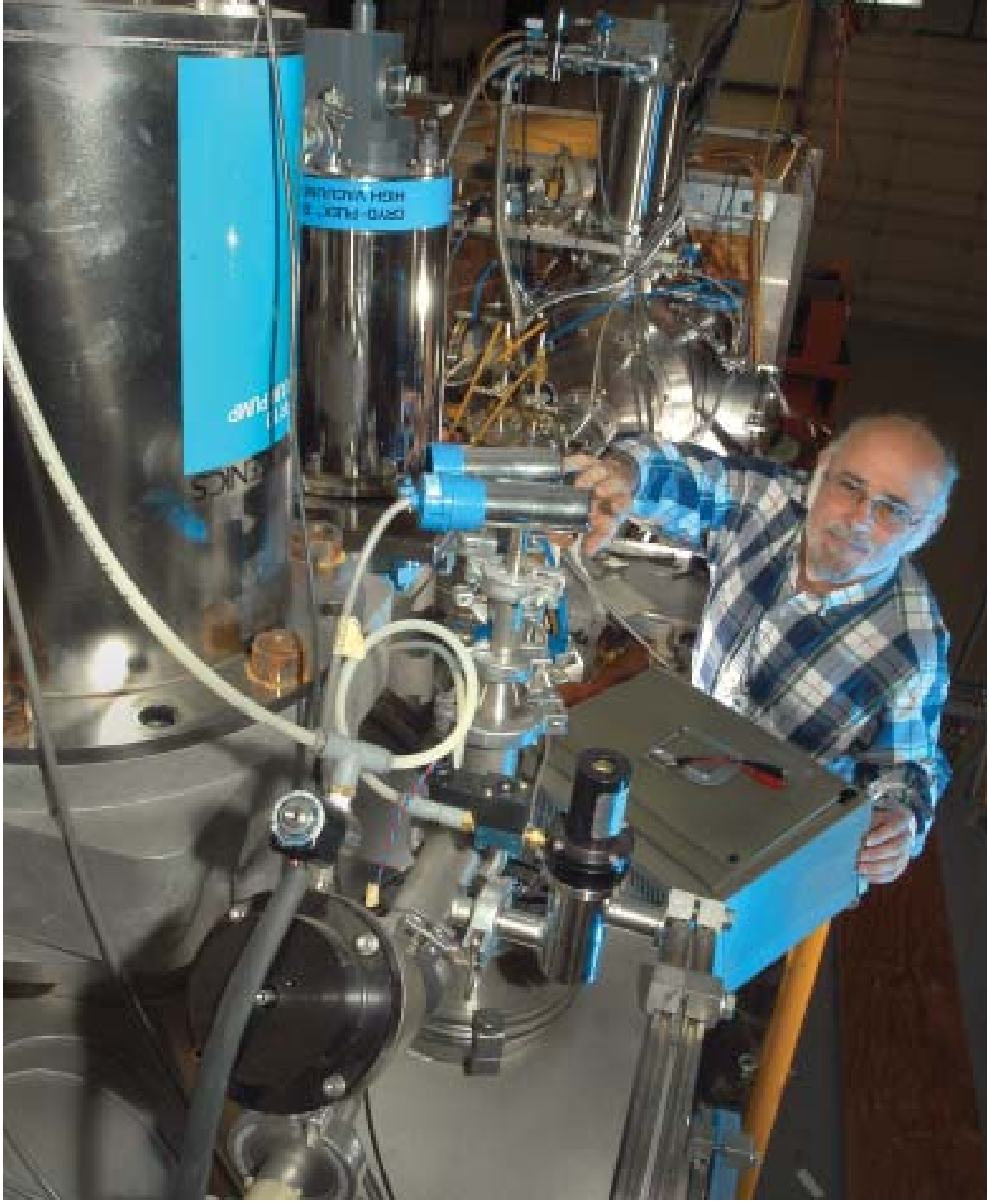
- upgrading and modernizing facilities used for the storage and disposal of nuclear materials
- providing re-training and job-placement help for the Soviet Union's former nuclear scientists
- building facilities to consolidate and convert highly enriched, weapons-usable uranium into low-enriched uranium suitable for use as nuclear reactor fuel
- installing operational monitoring systems at a variety of Russian facilities, including nuclear submarine bases

Introducing Nonproliferation & National Security

Joseph Indusi, chair of Brookhaven's Nonproliferation & National Security (N&NS) Department since 2001, knows that safeguarding nuclear material and preventing the proliferation of weapons is a deadly serious business. "We are entrusted with a job that is of utmost importance to the United States government," Indusi explains, "and we have a staff of experts who do that job well."

N&NS had its beginnings as what was called the Technical Support Organization, established in 1968 by the U.S. Atomic Energy Commission, a precursor of the U.S. Department of Energy. Today, N&NS's staff of 55 assists DOE and other agencies through five major programs:

- material protection, control & accounting: in cooperation with Russia, provides technical assistance in promoting enhanced safeguards and security for the protection of weapons-grade nuclear materials.
- nonproliferation and counter-terrorism: develops safeguards systems and arms-control verification methods to stem the spread and reduce the danger from nuclear, chemical, and biological weapons.
- international safeguards: provides technical oversight of safeguards projects for the International Atomic Energy Agency.
- infrastructure technologies: applies scientific and technical expertise to sustaining and securing infrastructure, including bridges and tunnels, electrical distribution systems, and energy-supply facilities.
- initiatives for proliferation prevention: supports nonproliferation of nuclear, chemical, and biological weapons by providing sustainable, non-weapons-related jobs to former Russian weapons scientists.



Lucian Wielopolski is developing a cargo-scanning technology that uses a particle accelerator to detect nitrogen and sodium found in many explosive materials.

- working with DOE's National Nuclear Security Administration to prepare and implement a strategy for securing and controlling radioactive sources of foreign origin that could be used in a "radiological dispersion device," which is also known as a dirty bomb.

"Most of the confirmed incidents of trafficking in radioactive or nuclear material involve material of Russian origin," explains N&NS Department Chair Joseph Indusi. "Since obtaining this material is the key to constructing a radiological dispersion device or nuclear weapon, it makes sense to try to safeguard these materials at the source, thereby preventing their transfer to terrorist groups or rogue states."

MORE INFORMATION

- funding: U.S. Department of Energy; U.S. Department of Homeland Security; National Institutes of Health; National Nuclear Security Administration; 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: Joseph Indusi, indusi@bnl.gov or (631) 344-2975
- Web: www.bnl.gov/homeland/default.asp

Because astronauts are spending more and more time in space, the National Aeronautics and Space Administration is working with Brookhaven and others here on Earth to learn about the possible risks to human beings exposed to space radiation. To study the radiobiological effects using proton and ion beams that simulate the cosmic rays found in space, a new $34-million NASA Space Radiation Laboratory was commissioned at Brookhaven this summer.

BY KAREN MCNULTY WALSH
AND MARSHA BELFORD

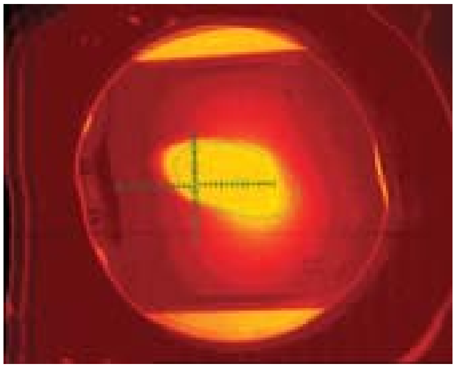

Seen in front of an image of a future NASA mission to Mars are scientists Marcelo Vazquez of Brookhaven's Medical Department and Betsy Sutherland of the Laboratory's Biology Department, who now perform their space-effects research at the NASA Space Radiation Laboratory at Brookhaven.

NASA Space Radiobiology Research

"TO BOLDLY GO WHERE NO ONE HAS GONE BEFORE"— the motto of the science-fiction saga Star Trek — could just as easily be the motto of America's real-life space explorers. Despite the recent Columbia shuttle tragedy, officials of the National Aeronautics and Space Administration (NASA) have a bold vision for future manned space exploration, which includes the completion of the International Space Station now under construction, and possible future missions to build a Moon outpost, explore near-Earth asteroids, and send astronauts to Mars.

Such journeys hold exciting prospects for the advancement of science and the expansion of the human experience. But, for these ambitious plans to move forward, scientists first need a better understanding of how human space travelers will be affected by the harsh environment of space — which includes the presence of ionizing radiation — and how best to protect people in space from harm.

Since 1995, Brookhaven Lab's Betsy Sutherland and Marcelo Vazquez and their colleagues have been partners in this Earth-based quest for more knowledge about the effects of space radiation and their mitigation, using beams of heavy ions at what was the only U.S. accelerator for radiobiology research, Brookhaven's Alternating Gradient Synchrotron (AGS). This year, however, their research got a boost with the completion of a new, $34-million facility dedicated to NASA-funded space radiation-effects studies at the AGS Booster, now the best accelerator in America for these studies.


The profile of a heavy-ion beam (yellow spot) is shown on one of four fluorescing "flags" within the NSRL beam line. After tuning the beam, these flags are retracted so that the beam can be delivered unimpeded to experiments. Heavy ions were first sent down the NSRL beam line in winter 2002.

Jointly managed during the four-year construction by the U.S. Department of Energy's Office of Science and NASA's Johnson Space Center, the new facility — formerly called the Booster Applications Facility and now known as the NASA Space Radiation Laboratory (NSRL) — features a beam line dedicated to radiobiology research, as well as state-of-the-art specimen-preparation areas.

The NSRL became operational over three weeks this July, when over 75 experimenters from some 20 institutions from the U.S. and three other countries took part in what was the tenth running of heavy-ion beams at Brookhaven solely for radiobiology research. With the NSRL on line, instead of running only once or twice a year, radiobiology and physics experiments will be conducted three to four times per year, for three to four weeks per run.

Takes Off at New Brookhaven Facility

SPACE RADIATION

Given the low risk to public health on Earth and the limited time that astronauts have been spending in space, little research has been performed until recently on the consequences to human beings of exposure to ionizing radiation in space.

Radiation, in this sense, is a stream of particles, such as alpha and beta particles, electrons, neutrons, protons, heavy ions, x- and gamma rays, etc. Ionizing radiation is a stream of such particles that, when passing through a body like that of a human being, has enough energy to cause the atoms and molecules within that substance to lose or gain electrons, thereby acquiring a charge and becoming an ion. The higher the energy of ionizing radiation, the farther it will penetrate within the body.

By directly or indirectly ionizing and thus damaging the components of living cells, including the genetic material called DNA, ionizing radiation may cause changes in cells' ability to carry out repair and reproduction. Such radiation-induced changes may lead to mutations, which, in turn, may result in tumors, cancer, genetic defects in offspring, or death. If a dose of ionizing radiation is received over a shorter time period, then the more damage that it can cause.

Earth-bound human beings are shielded from harmful exposure to ionizing space radiation by the Earth's atmosphere and magnetic field. But astronauts on the Space Shuttle and the International Space Station fly above the magnetosphere. Although the spacecraft itself somewhat reduces radiation exposure, it does not completely shield astronauts from galactic cosmic rays, which are highly energetic heavy ions, or from solar particles, which primarily are energetic protons. By one NASA estimate, for each year that astronauts spend in deep space, about one-third of their DNA will be hit directly by heavy ions.

Since astronauts are spending longer and longer time in space on the International Space Station, they are receiving more exposure to ionizing radiation than astronauts on previous missions. If future space travelers venture beyond low-Earth orbit for new journeys to the Moon or Mars, for example, then they will be exposed to even higher space radiation doses.

ACCELERATING HEAVY IONS

Because one type of radiation, such as cosmic

The NASA Space Radiation Laboratory at Brookhaven

PURPOSE

To use beams of heavy ions provided by the Booster accelerator at Brookhaven to study the effects of simulated space radiation on biological and physical systems, with the goal of developing methods and materials to reduce the risk to human beings on prolonged space missions of the effects of ionizing radiation

SPONSOR

National Aeronautics and Space Administration (NASA)

PROJECT COST

$34 million over 4 years

OPERATING COSTS

$5 million per year

FEATURES

- beams of heavy ions with masses and energies similar to the cosmic rays encountered in space:
  - 1-billion electron volt (GeV)/nucleon iron-56
  - 0.3-GeV/nucleon gold-97
  - 0.6-GeV/nucleon silicon-28

A view of the front of the NASA Space Radiation Laboratory

- a new 100-meter transport tunnel and beam line to deliver the beam to a 400-square-foot shielded target hall for NASA-funded space-effects experiments
- a target hall connected to 4,560-square-foot support building, which includes five laboratories for biological, medical and materials experiments; specimen rooms; dosimetry room; and control rooms
- long-term user support provided by Brookhaven's Biology and Medical Departments
- heavy ions originate in the Tandem Van de Graaff accelerator and are injected into the Booster accelerator
- a resonant extraction system, which allows the removal from the Booster of broad and long pulses of heavy ions

Pictured inside the NSRL target room is Adam Rusek, who is checking the cabling of one of the four ion chambers used for beam imaging (black-framed objects) or dosimetry (blue-framed objects). Cutting off the beam from an experiment once the predetermined dose is reached, the computer-controlled dosimetry chambers ensure a dose accuracy within 0.5 percent.

FACILITY USERS

- NASA: headquarters, Johnson Space Center, NASA Specialized Center of Research and Training, National Space Biomedical Research Institute
- national laboratories and institutes: Brookhaven National Laboratory; Lawrence Berkeley National Laboratory; Medical Research Council, England; National Institute of Health, Italy
- universities: Case Western Reserve University; Colorado State University; Columbia University; Loma Linda University; New York University; Prairie View A&M University; The Johns Hopkins University; Texas A&M University; University Federico II, Italy; University of California, San Francisco; University of Maryland, Baltimore; University of Pennsylvania; University of Rome, Italy; University of Texas; University of Tokyo, Japan

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server.c-ad.bnl.gov/esfd/nsrl/index.html rays, can be reproduced by another type, such as iron, silicon, and gold heavy ions of the same energy, two of Brookhaven's accelerators — first the AGS and now the Booster — can serve as ground-based suppliers of particle beam for controlled radiobiological experiments.

From 1995 until this July, the AGS was the only accelerator in the United States capable of providing heavy ion beams at energies useful for space radiobiology research. So, for the past eight years, NASA-sponsored scientists have conducted experiments once or twice annually at the AGS, studying model organisms, cell and tissue cultures, and various materials bombarded with beams of iron, silicon, and gold ions at energies ranging from 0.6 to 10 billion electron volts (GeV) per nucleon.

Their goal has been to develop accurate estimates of radiation-associated risks to human beings in space, and to identify effective countermeasures for reducing those risks. So far, these studies have advanced the understanding of the molecular mechanisms by which radiation causes damage to the central nervous system. In quantifying these effects, radiobiology researchers have elucidated, for example, which types of damage to DNA are the most harmful.

NEW NASA FACILITY

Since the lowest energy ions that the AGS can produce have more energy than most space particles, the AGS is not the most ideal accelerator for radiobiology studies. To simulate the less-than-1-GeV energy spectrum of galactic cosmic rays and solar radiation better, NASA and Brookhaven have worked together since 1997, building a facility dedicated to space-radiation research at the Booster, which is the

MORE INFORMATION

- facility funding: National Aeronautics and Space Administration (NASA)
- research funding: NASA; National Space Biomedical Research Institute; Office of Biological & Environmental Research, Office of Science, U.S. Department of Energy
- paper: "BNL Accelerator-Based Radiobiology Facilities," First International Workshop on Space Radiation Research and 11th NASA Space Radiation Health Investigator's Meeting, May 28-31,2000, *Physica Medica*, 2001, vol. 17, supp. 1, pp. 26-29
- contacts: Derek Lowenstein, lowenstein@bnl.gov, (631) 344-4611; Betsy Sutherland, bms@bnl.gov, (631) 344-3380; Marcelo Vazquez, vazquez@bnl.gov or (631) 344-3443
- Web: server.c-ad.bnl.gov/esfd/nsrl/operations/index.html

> "NSRL is one of the stepping stones in the long road to deep space exploration by humankind."
>
> MARCELO VAZQUEZ

Meet Marcelo Vazquez and Betsy Sutherland

Like the ion beams used to bombard cell and tissue samples in their experiments, Marcelo Vazquez of Brookhaven's Medical Department and Betsy Sutherland of the Biology Department attack their research on space radiation with precision and intensity.

Vazquez — who became fascinated with the prospect of space travel when he was a young child — is most interested in how heavy ions affect nerve cells at the molecular and cellular levels. "We suspect that a gene called p53 may help to cause cell death after a cell is irradiated with heavy ions," explains Vazquez. "Once we determine the molecular pathways of cell damage, we will test certain chemicals to see if they can reduce or prevent the damage." He is also investigating the behavioral consequences of heavy-ion exposure in animal models.

Sutherland is assessing the ways in which radiation damages DNA, the body's genetic material, and which types of damage are most difficult for cells to repair. "We now have a technique to measure the damage and repair rates for different kinds of damage," comments Sutherland. "That knowledge

Astronauts such as this Shuttle mission specialist will be the beneficiaries of the radiobiology research now ongoing at the NASA Space Radiation Laboratory.

Preparing for his radiobiology research during a heavy-ion run, Marcelo Vazquez of Brookhaven's Medical Department checks a tissue culture flask containing neural stem cells.

lower energy pre-accelerator serving the AGS.

For all experiments using Brookhaven's accelerator-collider complex, ions originate in the Tandem Van de Graaff accelerator, while protons start at the linear accelerator. Beams are then transported to the Booster, where they are pushed to higher energies. Periodically, these beams are injected into the AGS for further acceleration, which, in turn, sends them on to the Relativistic Heavy Ion Collider (RHIC), the world's newest and largest accelerator for nuclear physics and polarized proton research (see story, page 10).

While RHIC is running, heavy ions or protons — either the same or a different beam than what is being collided within RHIC — can be accelerated or decelerated within the Booster, which then delivers the beam to the NSRL target room. There, Brookhaven researchers and other NASA-sponsored scientists irradiate a variety of biological specimens, tissues, and cells, as well as DNA in solution. In addition, other experimenters use industrial materials as samples, studying their suitability for space suits and spacecraft shielding.

In increasing knowledge of cosmic radiation effect on living beings and inert materials, NSRL studies may expand the understanding of the link between ionizing radiation and aging or neuro-degeneration, as well as cancer. In aiming to limit the damage to healthy tissue by ionization, NSRL research may also lead to improvements in cancer radiation treatments.

may help identify whether certain people are more susceptible to long-term problems, so might, therefore, run a greater risk of radiation damage during long-term space flight."

Adds Vazquez, "Our findings may not only help to determine if future space missions will be safe and devise ways to protect astronauts, but may also improve certain radiation treatments."

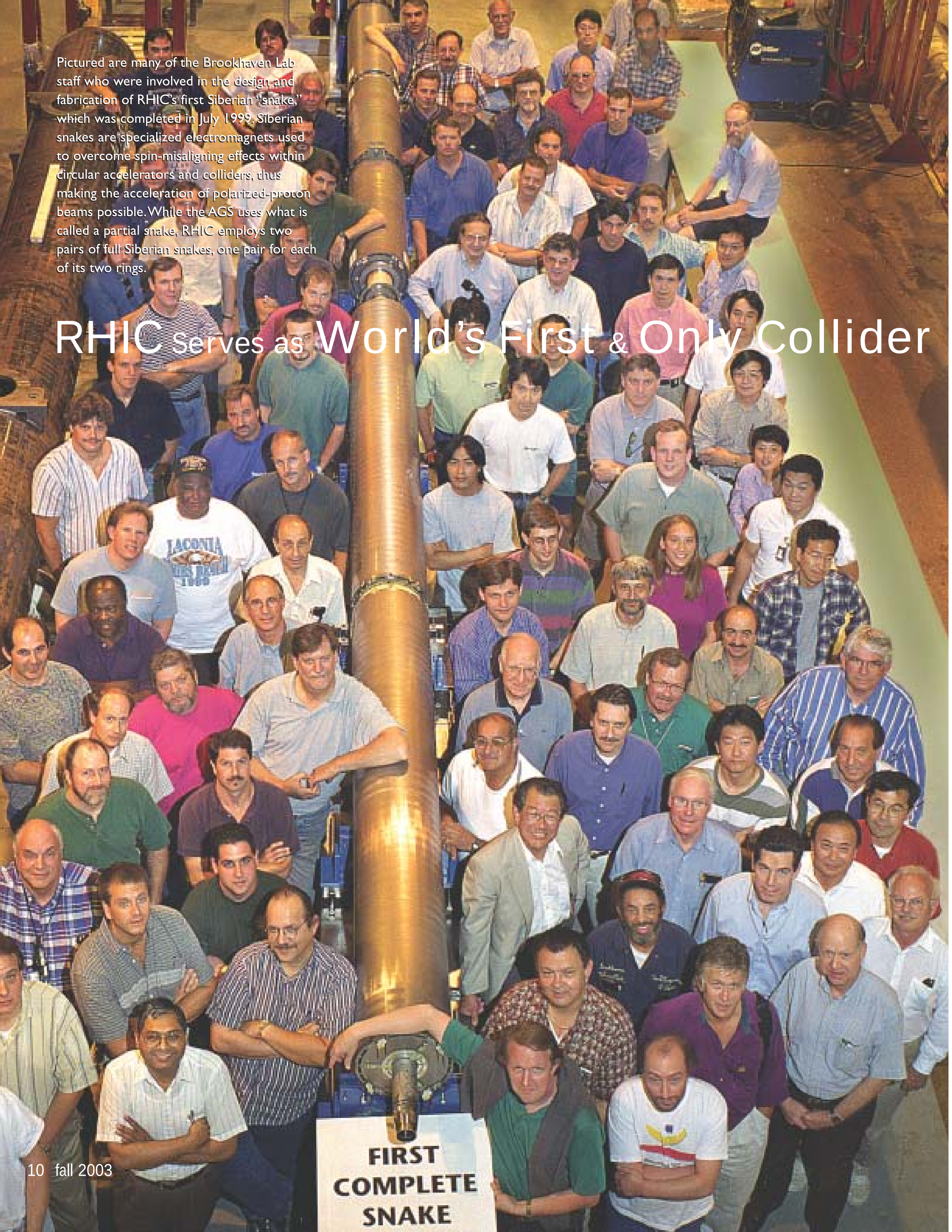
Vazquez serves as the Brookhaven experimental liaison in the Medical Department for the NSRL research program and is also associate leader of the radiation effects team of the National Space Biomedical Research Institute.

Marcelo Vazquez earned an M.D. and Ph.D. from the National University of La Plata, Argentina, where he was born and raised. After conducting post-doctoral research at Uppsala University in Sweden, he served as a research scientist at Columbia University before coming to Brookhaven in 1995.

Betsy Sutherland earned a B.S. and M.S. in biology from Emory University and a Ph.D. in radiation biology from the University of Tennessee. She completed her post-doctoral work at the Walter Reed Research Institute and the University of California, Berkeley. She served on the faculty at the University of California, Irvine, until 1977, the year she came to Brookhaven Lab.

Sutherland was awarded the 1985 Ernest Orlando Lawrence Memorial Award by the U.S. Department of Energy for her work on a DNA repair enzyme. She is currently chair of Brookhaven's Scientific Advisory Committee for Radiobiology.

> "The major challenges for research at the NSRL are to uncover the risks of radiation to space travelers and to develop countermeasures that allow the safe, long-term presence of human beings at the Space Station and beyond."
>
> BETSY SUTHERLAND



Pictured are many of the Brookhaven Lab staff who were involved in the design and fabrication of RHIC's first Siberian "snake," which was completed in July 1999. Siberian snakes are specialized electromagnets used to overcome spin-misaligning effects within circular accelerators and colliders, thus making the acceleration of polarized-proton beams possible. While the AGS uses what is called a partial snake, RHIC employs two pairs of full Siberian snakes, one pair for each of its two rings.

RHIC Serves as World's First & Only Collider

As the world's first and only collider of spin-polarized protons, the Relativistic Heavy Ion Collider is being employed to investigate a fundamental question about an important particle and a universal property: What is responsible for the "spin," or intrinsic angular momentum, of the proton? While data from this spring's run are being analyzed, unexpected results from RHIC's first spin-physics run are generating great interest.

BY MARSHA BELFORD

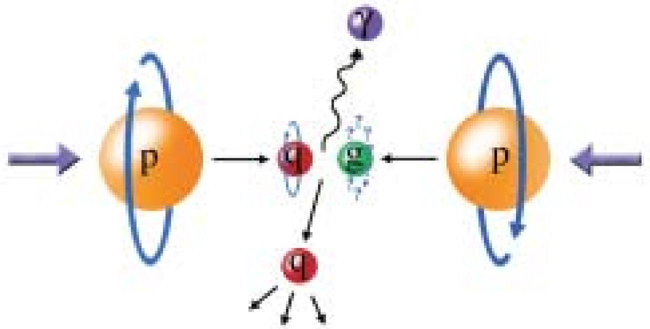
# of Polarized Protons for 'Spin' Physics

FOR THE SECOND TIME SINCE ITS COMMISSIONING IN 2000 as the world's highest energy, heavy-ion collider, the Relativistic Heavy Ion Collider (RHIC) took a break from colliding gold ions in the attempt to recreate the conditions of the early universe — to serve again as the world's first and only collider of spin-polarized protons.

Physicists use RHIC in this fashion to investigate a fundamental question about an important particle and a universal property: What is responsible for proton "spin"? A magnetic property of particles as basic as mass and electrical charge, spin is a particle's intrinsic angular momentum. In spin-polarized proton beams, most of the protons are spinning in the same direction. By colliding beams of polarized protons at RHIC , physicists can examine the structure underlying the proton's spin.

To turn RHIC into the world's first and only collider capable of accelerating and colliding high-energy, spin-polarized protons took many years, much hardware, a dedicated staff, and a partnership with RIKEN, the Japanese Institute of Physical and Chemical Research (see sidebar, page 12).

While the second RHIC run of polarized protons (p↑p↑) was conducted over eight weeks this spring, unexpected results from the collisions of polarized protons during the first run in fall-winter 2001-02 are generating great interest within the international spin-physics community.



In this diagram representing the head-on collision of a quark (red ball) from one proton (orange ball) with a gluon (green ball) from another proton with opposite spin, spin is represented by the blue arrows circling the protons and the quark. The blue question marks circling the gluon represent the question: Are gluons polarized? Ejected from the collision are a shower of quarks and a photon of light (purple ball).

From two separate experiments, spin physicists have discovered that there are large asymmetries in the production of two different particles resulting from the inelastic collisions of unpolarized protons with vertically spinning, or transversely polarized, protons. When the polarized protons' spin points up, many more of these particles emerge to the left side of the beam than to the right. When the beam spin is down, the direction of the asymmetrical particle production is also reversed, so more particles emerge to the right than the left.

"In addition to RHIC's remarkable success in its first year as a polarized proton collider, it is exciting that the spin-physics experiments have already seen such large asymmetries," comments Brookhaven senior physicists Gerry Bunce, who leads the RHIC spin collaboration. "This is the beginning of a new and unique program probing proton spin structure."

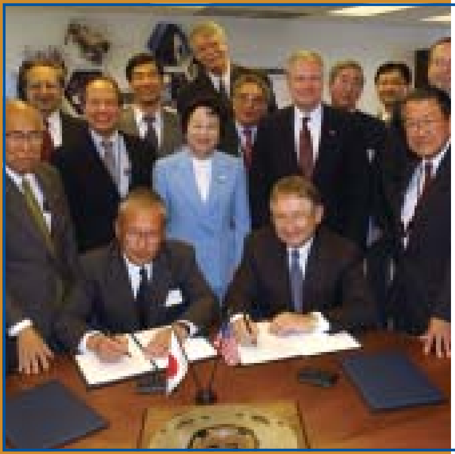
Meanwhile, another RHIC p↑p↑ experiment, called pp2pp, has also produced results from the first run, but from its analysis of data from elastic collisions. The purpose of the pp2pp experiment is to understand how spin affects how protons scatter elastically, like billiard balls, via the nuclear, or strong, force, which is one of the four fundamental forces in nature. Analysis of pp2pp's first run data has produced the first measurement of what is called the nuclear slope parameter b at the highest proton-proton collision energy so far.

SPIN 'CRISIS'

The spin "crisis" in high-energy physics began in 1988, when it was first discovered that, contrary to expectation, the spin of the quarks inside the proton do not account for all or even very much of the proton's spin. As it has been learned since from accelerator-based experiments with polarized protons at lower energies, quark spin only accounts for one quarter of the proton's spin.

The remaining three-quarters of a proton's spin may be carried by particles called gluons, which bind quarks inside the proton, or by something called orbital angular momentum, or by both. If it is discovered that gluons do carry proton spin, then this knowledge may lead to an understanding of why quarks and gluons are confined within the proton and the neutron, which are the main constituents of the atomic nucleus and are collectively known as nucleons.

As RIKEN BNL Research Center Director and Nobel laureate T.D. Lee explains: "The shape of a nucleon is defined by the spreading of an infinite number of 'soft' gluons. Each of these gluons possesses an integral spin, which can be readily excited because of the confinement property of Quantum Chromodynamics. Hence, spin physics offers us the unique opportunity to measure the proton's shape."



> “The research performed at the RIKEN BNL Research Center exemplifies the international nature of science, while advancing our understanding of the universe’s most basic matter.”
>
> T.D. LEE,
> NOBEL LAUREATE AND
> RIKEN BNL RESEARCH CENTER DIRECTOR

To uncover what fraction of proton spin is carried by gluons, physicists at RHIC just completed experiments during the second p↑p↑ run using two beams of longitudinally polarized protons, which allow quarks in one proton beam to probe the spin of gluons in the opposing beam (see diagram, page 11).

When quarks and gluons in longitudinally polarized beams collide, what is observed is the creation of photons and other particles, which emerge in groups called jets. The rates at which jets and photons are produced depend upon the spin of the incident beams. If both beams have the same spin direction, then the rates of particle production are expected to be higher than when the beams have the opposite spin. But whether or not that expectation is met will be determined by the now ongoing analysis of the second run’s data.

MEASURABLE & LARGE ASYMMETRIES

During the first run, experimenters on the PHENIX and STAR experiments used especially built detectors to look for spin asymmetries as a way to monitor spin direction when transversely polarized beams collided. After analyzing the first p↑p↑ run’s data, the scientists were surprised to find is that not only were the asymmetries measurable, but they are also large.

With the polarized proton beam’s spin up, PHENIX physicists detected 20 percent more neutrons produced to the left than the right following glancing collisions, in which the opposing proton beams barely hit. This asymmetry had not been seen before by accelerator-based experiments collecting data at lower energies and is not yet understood.

Meanwhile, STAR observed twice as many particles called neutral pions emerging to the left than to the right as a result of hard, head-on collisions of an unpolarized beam with a spin-up polarized beam. Although this asymmetry is just as large as what has been seen from much lower energy accelerator experiments, it is nonetheless a surprise that has also not yet been explained.

With the results of the first run to be explained and those of the second run under analysis, Bunce foresees another five or more years work ahead of the p↑p↑ program: “Along the way, we will look for violations of mirror symmetry from the weak interaction, to measure the spin direction of the anti-quarks within the proton. And, in ten years or so, to learn more about the spin structure of the proton and the nature of the strong interaction governing quarks and gluons, we hope to be colliding polarized protons with high-energy polarized electrons, in an alternative configuration of RHIC that we call e-RHIC. ”

MORE INFORMATION

- funding: Japanese Institute of Physical and Chemical Research; and Division of Nuclear Physics, U.S. Department of Energy
- paper: “Prospects for Spin Physics at RHIC,” Annual Review of Nuclear and Particle Science, volume 52, 2002, pp. 525-75
- contacts: Gerry Bunce, bunce@bnl.gov or (631) 344-4771; Thomas Roser, roser@bnl.gov or (631) 344-7084
- Web: www.agsrhichome.bnl.gov/RHIC/Spin/

The RIKEN BNL Research Center

Established in 1995 by RIKEN, which is the Japanese Institute of Physical and Chemical Research, and headed by Nobel laureate T.D. Lee, the RIKEN BNL Research Center at Brookhaven is home to some 25 experimenters and theorists from around the world who are performing research centered on the heavy-ion and spin physics of the Relativistic Heavy Ion Collider. In addition, RIKEN’s contributions to the spin-physics program have included much of the hardware needed to collide polarized protons at RHIC, plus a spin-physics detector for the PHENIX experiment.

PURPOSE

To perform research in spin physics, lattice quantum chromodynamics, and relativistic heavy-ion physics

SPONSOR

RIKEN, the Institute of Physical and Chemical Research, Japan

FEATURES

- 0.6-teraflop QCDSP supercomputer, the world’s 12th fastest; construction of a new, 10-teraflop QCDOC supercomputer
- Siberian snakes and spin rotators for colliding polarized protons
- muon arm of the PHENIX detector to study polarized quarks and anti-quarks, and gluon polarization

STAFF

- approximately 25 experimenters and theorists
- 2-year post-doctoral and 5-year fellowship appointments

WEB ADDRESS

www.bnl.gov/riken

Accelerating & Colliding High-Energy Polarized Protons at RHIC

As a collider of high-energy, high-luminosity polarized protons, the Relativistic Heavy Ion Collider (RHIC) is uniquely enabling physicists to study the spin structure of the proton, with the goal of understanding the contribution of gluons and antiquarks to proton spin, and verifying spin effects in perturbative Quantum Chromodynamics and parity violation in W and Z particle production.

To do all this, certain RHIC accelerator physics challenges had to be met in the production, acceleration, storage, and collision of polarized protons (p↑ p↑), while maintaining and being able to measure the percentage of beam polarization. These were no easy tasks, as spinning protons act like tiny magnets, which must be bent and focused by the magnets making up the four accelerators within the RHIC complex.

“The level of beam polarization is extremely important, since the accuracy of spin related asymmetry measurements made by the polarized proton experiments goes proportionally with polarization or the square of polarization, so every percent of polarization is significant,” explains Thomas Roser, who heads the accelerator division of Broookhaven’s Collider-Accelerator Department, which is responsible for RHIC operations.

The proof that these challenges were met are in the records of RHIC’s first two runs as the world’s first and only p↑p↑ collider: During RHIC’s first run, from November 2000 through January 2001, approximately 25 percent polarization was maintained at a beam energy of 100 billion electron volts (GeV). During RHIC’s second p↑p↑ run, from April through May 2003, spin polarization was increased to about 40 percent at the same beam energy.

NOVEL ACCELERATOR HARDWARE

These world-record accomplishments were made possible by partnering with RIKEN, which is the Japanese Institute of Physical and Chemical Research (see sidebar, page 12), and the advanced development and deployment of five novel types of accelerator hardware:

- **OPPIS:** is an optically pumped, polarized-ion source that produces a direct current beam of 1-milliampere negative hydrogen ions (H^-) with 75 percent polarization in 200 microsecond pulses at a repetition rate of 7.5 hertz (Hz). This corresponds to a polarized proton beam of 4×10^{11} after the H^- beam is accelerated through a radio-frequency quadrupole and the 200 million-electron-volt linear accelerator, and strip-injected into the 1.5 GeV booster. After acceleration within the booster, the beam is then transferred to RHIC’s injector, the Alternating Gradient Synchrotron (AGS).

In the control room is the staff of accelerator physicists who are responsible for the successful collision of polarized protons at the Relativistic Heavy Ion Collider.

- **PARTIAL & FULL SIBERIAN SNAKES:** are chains of vertical and horizontal dipole magnets or a single solenoid magnet, originally invented in Novosibirsk in the late 1970s. They are used to overcome spin-misaligning magnetic effects, called depolarizing spin resonances, within circular accelerators and colliders, such as, respectively, the AGS, and RHIC itself. With a corkscrew-like design that causes the polarized particles to have a snake-like trajectory, Siberian snakes work by rotating the beam’s spin direction, thus keeping the spin precession frequency constant.

Accelerating polarized protons since 1984, the AGS now employs a partial Siberian snake, which is a 2-tesla, 2.3-meter-long solenoid non-superconducting, or warm, magnet module located in the 110 straight section. This 5-percent snake rotates the spin by 9 degrees, which, in conjunction with a spin flipper, is sufficient to avoid most beam depolarization up to the required RHIC transfer energy of approximately 25 GeV.

Not having the space limitations of the AGS, RHIC utilizes two pairs of full Siberian snakes, one pair for each of its two rings, with one snake located at 3 o’clock, the other at 9 o’clock in each ring. Each 100-percent Siberian snake consists of four 4-tesla, 2.4-meter long superconducting, 360-degree-twist helical dipole magnet modules able to rotate the spin by 180 degrees to counteract depolarizing resonances.

- **SPIN FLIPPERS:** are radio frequency ac dipole magnets used to produce oscillating magnetic fields, which not only work to minimize depolarizing resonances in conjunction with the partial Siberian snake in the AGS, but also allow the polarization direction to be reversed during a store in RHIC. To cause a full, 180-degree flip of the spin, these dipoles produce a strong, artificial spin resonance excited coherently for the entire beam. The AGS spin flipper is a 100-kHz, 20-Gauss-meter warm vertical dipole. Located at IP4 and common to both beams, RHIC’s spin flipper is a 40-kHz, 100-Gauss-meter dipole.
- **P-C CNI POLARIMETER:** employs proton-carbon elastic scattering in the Coulomb nuclear scattering region (p-C CNI) to measure beam polarization. With one located at C15 in the AGS and one within RHIC’s IP12 region, each p-C CNI polarimeter employs an ultra-thin carbon ribbon as the target for p-carbon elastic scattering. To identify the recoil carbon ions, which arrive out of time with the prompt background from the target, silicon strip detector measure simultaneously the particles’ energy and time of flight. With minimal beam perturbation, the p-C CNI polarimeters work accurately, with 5 percent relative error, and quickly, within 1 minute in RHIC and 5 minutes in the AGS.

REACHING DESIGN POLARIZATION

For the next p↑p↑ run in 2004, the intermediate goal is to increase beam polarization to 50 percent at 100 GeV. In 2005-06, the polarization is expected to reach the design goal of 2×10^{11} protons per bunch with 70 percent at 250 GeV. To reach the intermediate and design goals, polarization losses occurring within the AGS will be overcome by replacing the existing partial solenoidal Siberian snake with helical versions that can avoid more of the depolarizing spin resonances.

The first substitution will be a 5-percent, or 9-degree, 1.5-tesla warm helical magnet assembly, which is now being built in Japan by RIKEN and is expected to be delivered this fall. The helical magnet will avoid the coupling depolarizing resonances that the present solenoid snake produces. The ultimate partial snake for the AGS will be a superconducting helix that is five times stronger. The 25-percent, or 45-degree, 3-tesla superconducting helix is now being constructed within Brookhaven’s magnet division, with commissioning scheduled for 2005.

Anatoly Zelenski is pictured with the optically pumped, polarized-ion source that he designed and built for spin physics at RHIC.

Despite the myriad of discoveries using the super bright beams provided by the National Synchrotron Light Source at Brookhaven Lab and other light sources around the world, researchers who use synchrotron light would always welcome even more brilliant and revealing beams.

Toward this end, NSLS accelerator physicists and other staff are developing a novel combination of a synchrotron and a laser: the world's only free-electron laser that produces intense deep ultraviolet light through a process called high-gain harmonic generation.

When the DUV-FEL is complete, it will present many new scientific opportunities for its users in the fields of chemistry, condensed-matter physics, geology, materials science, and more.

BY PATRICE PAGES AND MARSHA BELFORD

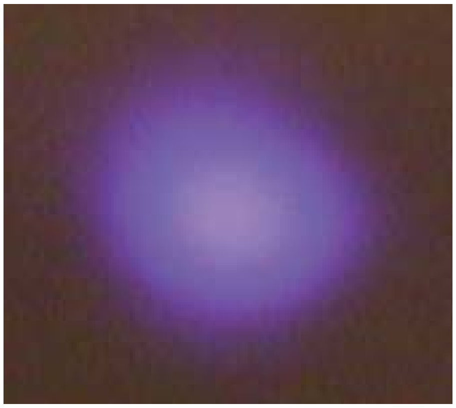
Next-Generation Light Source Development

BECAUSE SUPER BRIGHT BEAMS of x-ray, ultraviolet, and infrared light are produced at the National Synchrotron Light Source (NSLS) at Brookhaven Lab, more than 2,500 guest researchers from nearly 500 universities, laboratories, and corporation go there each year, to perform experiments to reveal the structure and function of a range of physical materials and biological specimens.

Despite the myriad of discoveries with synchrotron light around the world, however, researchers would always welcome ever more brilliant and revealing beams.

In looking for a next-generation light source, accelerator physicists at Brookhaven and elsewhere have been researching methods to increase intensity and take even more advantage of other characteristics of light. Toward this end, NSLS accelerator physicists and other staff are combining the advantages of lasers and those of synchrotrons into a new source of super bright light — by developing what is called a free-electron laser (FEL).

Brookhaven's FEL research has been ongoing since its beginning in the 1980s at the Laboratory's Accelerator Test Facility (ATF). Since the 1990s at the NSLS, this research has been focused on one particular FEL. This device produces very intense deep ultraviolet (DUV) light through a process called high-gain harmonic generation (HGHG), a technique that was first proven at the ATF in 2000. Today, Brookhaven's DUV-FEL is just one of a handful of FELs worldwide designed to produce ultraviolet light. Not only does the Brookhaven device produce the brightest FEL light, but it is also the only in the world using the HGHG process.



An image of ultraviolet light with a wavelength of 266 nanometers that was recently generated by the Deep Ultraviolet Free-Electron Laser.

Ultimately, the DUV-FEL will generate sub-picosecond pulses of deep ultraviolet light with a wavelength of 88 nanometers (nm) having a peak intensity that is 10 million times greater and pulses that are up to 1,000 times shorter than light produced by a synchrotron. The goal of this work, however, is to develop an intense source of light with even shorter wavelength light: highly penetrating, or "hard," x-rays.

When ready for users, the DUV-FEL will be employed by chemists, condensed-matter physicists, geologists, materials scientists, and other researchers to do experiments that cannot be performed at present. This research will complement the work done at the NSLS's two synchrotrons.

"Because it will be able to reveal the fine details of atomic interactions inside materials and the very fast motion of molecules in chemical reactions with a precision unequaled so far, the very intense, coherent light produced by the DUV-FEL will be a powerful new scientific tool," explains Brookhaven accelerator physicist Li Hua Yu, who is leading the Laboratory's DUV-FEL effort.

Pictured in the control room of the Deep Ultraviolet Free-Electron Laser (DUV-FEL) at the National Synchrotron Light Source are some of those involved in the research and development of this novel device, including the leader of the high-gain, high harmonic DUV-FEL experiment, Li Hua Yu (right).

Focused on Deep Ultraviolet Free-Electron Laser

LASER VERSUS SYNCHROTRON

What do bar-code scanners, CD and DVD players, dental drills, fiber optic telecommunications, metal cutting and welding, cornea surgery, and tattoo removal have in common? They all use lasers.

Unlike light coming from a more common source such as a light bulb, laser light is intense and has special properties. It is highly monochromatic, meaning that light produced by a laser essentially has one wavelength, or color; it is collimated, meaning that laser light is concentrated in a narrow beam; and it is coherent, meaning the emitted photons are in step, or in phase, with each other in time and space.

Since the 1958 discovery of the process called light amplification by the stimulated emission of radiation, which was first postulated by Albert Einstein, lasers have made possible the development and commerce in billions of dollars of consumer goods, medical devices, industrial equipment — and scientific tools. Because of an inherent limitation, however, lasers cannot produce ultra-short wavelength light below 100-200 nm.

Very intense ultraviolet light is produced by one of the two synchrotrons at the NSLS, as well by other such accelerator-based light sources. Within a synchrotron, x-ray, ultraviolet, and infrared light is emitted as electrons are raced in a circular orbit to near the speed of light. In addition to intensity and its broad spectrum, synchrotron light has many special features: it is collimated, polarized, and pulsed; and it has a broad spectrum, so synchrotron light can be tuned to a particular wavelength.

An FEL such as Brookhaven's is combining the intensity and coherence of laser light with the broad spectrum of synchrotron light. But, as Yu explains, the intensity of DUV-FEL light surpasses that of a synchrotron because of coherence.

HOW COHERENCE WORKS

In a synchrotron or an FEL, electrons accelerated to near the speed of light are sent through devices called wigglers, which force the electrons to oscillate. The more the electrons are sent back and forth by a series of magnetic fields with alternating directions, the more intense the light that is generated.

In a synchrotron, this very intense light is emitted by electrons randomly, or incoherently, as a jumble of waves. In the DUV-FEL, however, intense light is produced by all the electrons coherently, or in the same time phase. The reason that light from the DUV-FEL is up to 10 million times more intense is its coherence. "Coherence is as if, instead of having a group of people sing the same song at different times, they sing it in unison," says Timur Shaftan, an accelerator physicist also working on the DUV-FEL.

The electrons within an FEL can "sing in unison" in one of two ways: either by HGHG or by what is called self-amplified spontaneous emission (SASE). Through SASE, electrons interact with light emitted by their fellow electrons, creating small groups of electrons. "Within each group, the electrons sing in unison, but the songs between any two groups are out of sync," explains Adnan Doyuran, a post-doctoral student on the DUV-FEL project.

Through the HGHG process, the electrons interact with light produced by a laser. This interaction also produces groups of electrons, but, "This

> “Using HGHG as the basis for Brookhaven’s FEL research and development is exciting not only because of its immediate usefulness in a fourth generation source of intense, highly coherent deep ultraviolet light, but also because of its potential to be extended to much shorter wavelengths, including hard x-rays.”
>
> LI HUA YU

time, not only is each group a united ‘choir,’ but all groups also ‘sing’ together,” adds Henrik Loos, another DUV-FEL post-doc. It is this “super choir” of electrons that emits light many times more intense than that generated by the SASE process, which is why the DUV-FEL project members chose HGHG over SASE.

USING THE DUV-FEL

To take advantage of the DUV-FEL’s particular wavelength of intense, coherent, and pulsed light, three Brookhaven scientists, among others, have submitted proposals to use this new source:

- **PHYSICAL CHEMIST ARTHUR SUITS** is interested in using the DUV-FEL to perform light-induced dissociation of atoms in hydrocarbons, which will reveal details of their molecular structure and bonding. “The DUV-FEL is really ideal for our experiments,” says Suits. “The information we hope to gain using it would be impossible to obtain by other means.”
- **PHYSICIST LOUIS DIMAURO** plans to use the DUV-FEL’s short and highly intense light pulses to study the interaction of matter with intense, short-wavelength light. “This tool will open up many new areas of research in fundamental and applied science,” comments DiMauro.
- **PHYSICAL CHEMIST MICHAEL WHITE** intends to use the DUV-FEL to study chemical reactions that occur on the

Gathered are many of the staff of the National Synchrotron Light Source who contributed to the research and development of the DUV-FEL. They are standing along side the DUV-FEL’s linear electron accelerator (background, left), with the laser system (background, center) behind them, and radiation shielding and the device’s shielded amplifier in front of them.

Meet
Li Hua Yu

In 1999, Senior Physicist Li Hua Yu became known in the accelerator physics field for having led the experiment that showed for the first time how a process called high-gain harmonic generation could be used to generate extremely bright infrared light with a very powerful laser, called a free-electron laser (FEL).

Since then, Yu and his collaborators have been refining this FEL so that, beginning in 2002, it has been generating intense ultraviolet light for the study of materials and chemical reactions at the atomic level.

The author of more than 50 scientific publications and 21 conference proceedings, Yu is the 1989 recipient of one of the 100 awards given annually by R&D magazine to the inventors of the top technologies of the year. He was recognized for developing what is called a real-time, harmonic closed-orbit feedback system, designed to stabilize the orbits of the electron beams circulating at nearly the speed of light within the two synchrotrons at the National Synchrotron Light Source (NSLS) at Brookhaven.

Yu earned his B.S. in physics from Jilin University, China, in 1970, and an M.S. and a Ph.D. in physics from Stony Brook University in 1980 and 1984, respectively. Part of the NSLS accelerator physics staff ever since, he has moved up the ranks, obtaining tenure in 1992 and his present title in 2000.

The Accelerator Test Facility at Brookhaven

PURPOSE

To provide high-brightness beams and high-powered lasers for experiments in advanced accelerator and light-source science.

DUV-FEL ACHIEVEMENT

- 1999: high-gain harmonic generation proof of principle experiment

SPONSOR

Office of Science, U.S. Department of Energy

FEATURES

- 4.5-MeV electron gun with world's lowest emittance
- 70-MeV linear accelerator,
- two high-power lasers synchronized to the electron beam
- four beam lines

FACILITY USERS

- nine U.S. institutions, including UCLA, STI-Optronics, and Columbia University
- five international institutions in Japan, Russia, and Taiwan

WEB ADDRESS

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

> surfaces of materials, for which the product yields are low or where the gaseous products are particularly difficult to detect. Says White, "In the long term, the DUV-FEL will produce very short pulses that, in real time, will provide new information on surface processes."

For Yu and his collaborators, these proposals show that, as with the development of earlier generations of light sources, many new scientific opportunities for DUV-FEL users from many fields will present themselves as a result of the opportunity to use this latest generation source of light.

"The scientific use of the DUV-FEL will be the best reward for all of us and the culmination of a lot of hard work and dedication by the scientists, engineers, and technicians who have worked on this project," concludes NSLS Associate Chairman for Accelerators James B. Murphy.

MORE INFORMATION

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- **paper:** "High-Gain Harmonic Generation Free-Electron Laser," Science, August 11, 2000, volume 289, pp. 932-934
- **contact:** Li Hua Yu, lhyu@bnl.gov or (631) 344-5012
- **Web:** http://nslsweb.nsls.bnl.gov/nsls/org/AccPhys/SDL/HGHG266nm.htm

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