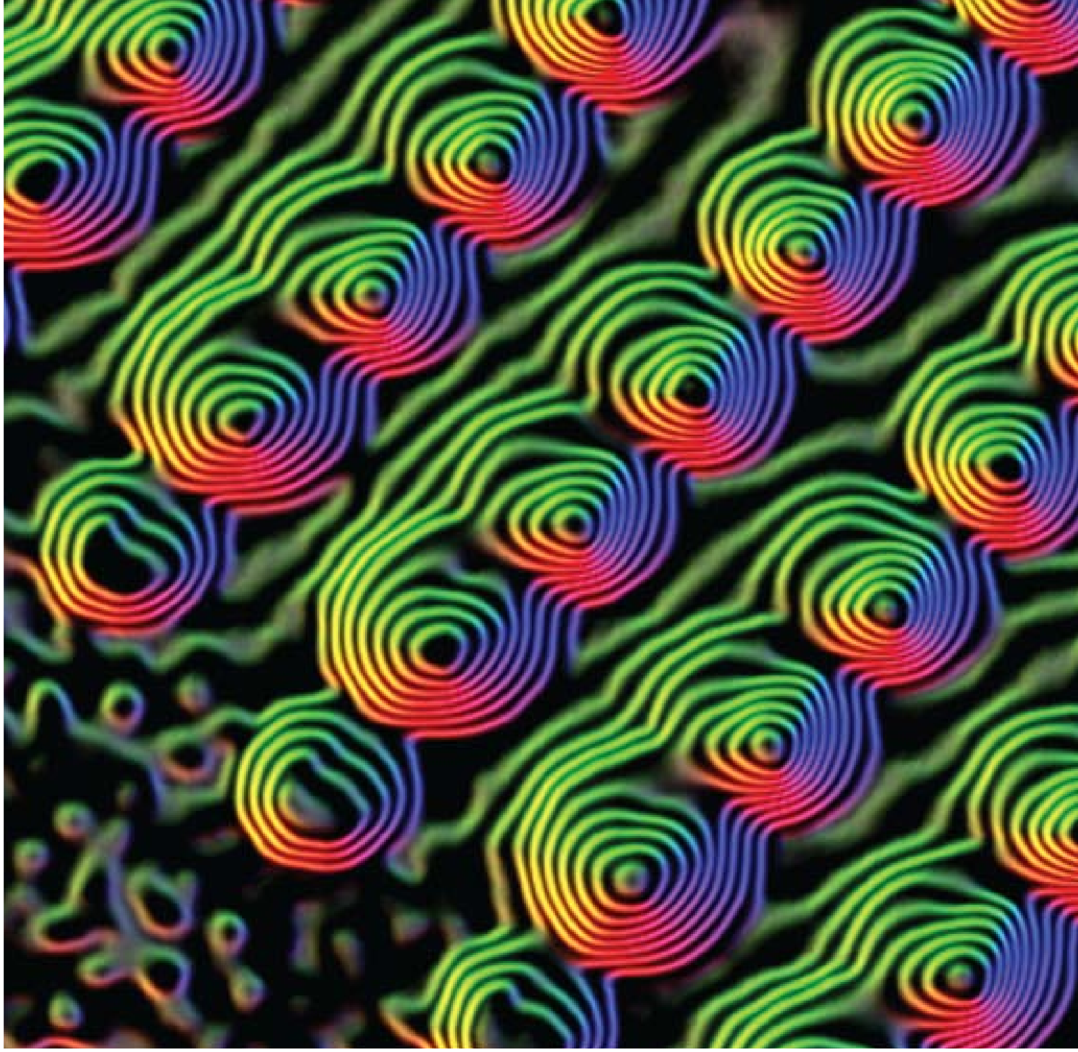

# passion

*for discovery*

BROOKHAVEN
NATIONAL LABORATORY

*Cover photo: Map showing magnetic flux lines for nickel nanoparticles*

# About Brookhaven

## Mission

Brookhaven National Laboratory's primary mission is to deliver science-based solutions to the nation's energy, environmental, and security needs. The Laboratory is noted for the design, construction, and operation of large-scale, cutting-edge research facilities that support thousands of scientists worldwide, its fundamental research into the nature of matter and materials and for biomedical and climate studies.

## Location

Upton, New York (on Long Island, 60 miles east of New York City)

## Funding

About $500 million, primarily from the U.S. Department of Energy (DOE)

## Management

Brookhaven National Laboratory is operated and managed for the U.S. Department of Energy's Office of Science by Brookhaven Science Associates, a limited-liability company founded by nearby Stony Brook University, the largest academic user of Laboratory facilities, and Battelle Memorial Institute, a nonprofit, applied science and technology organization.

## Staff

About 2,600 scientists, engineers, technicians and support staff; more than 5,000 guest researchers annually.

passion *for discovery*

BROOKHAVEN
NATIONAL LABORATORY

# Table of Contents

*A passion for discovery* is alive and well at Brookhaven National Laboratory, a multipurpose research institution established in 1947 for the peacetime exploration of science. Funded primarily by the Office of Science of the U.S. Department of Energy (DOE), the Laboratory houses large-scale instruments and facilities — some available nowhere else in the world. Each year, more than 4,000 Laboratory, university, and industry scientists use these facilities to delve into the basic mysteries of physics, chemistry, biology, materials science, energy, and the environment — and at the intersections of these disciplines. Six Nobel-Prize-winning discoveries and countless other advances have their origins at the Lab, with applications in fields as diverse as medicine and national security. This booklet offers a glimpse at the spectrum of this research, highlighting Brookhaven's major programs and initiatives:



Since 2000, this premiere nuclear physics research facility has been operating beyond expectation, colliding gold ions at nearly the speed of light to offer insight into the fundamental forces and properties of matter and a startling new view of the early universe. Planned upgrades promise a better understanding of the "perfect" liquid discovered at RHIC, and will also enable explorations into entirely new but complementary areas of physics.



Each year, thousands of scientists from the U.S. and abroad perform experiments using intensely bright beams of x-ray, ultraviolet, and infrared light at the National Synchrotron Light Source (NSLS). These studies span scientific fields from biology and physics to materials science, medicine, and more. A newer synchrotron known as NSLS-II, with design and engineering planning already underway, will be more than 10,000 times brighter than the NSLS, thus expanding scientists' ability to probe proteins, polymers, metals, and minerals to learn about their unique structures and properties.



Nanoscience — the study of materials on the order of a *billionth* of a meter — has the potential to bring about and accelerate new technologies in energy distribution, drug delivery, sensors, and industrial processes. Brookhaven's Center for Functional Nanomaterials is a hub for cutting-edge nanoscience studies aimed at solving energy problems through research on more efficient materials and practical alternatives to fossil fuels, including hydrogen-energy sources and improved solar-energy systems.

passion

*for discovery*


Office of Science
U.S. DEPARTMENT OF ENERGY
BROOKHAVEN NATIONAL LABORATORY

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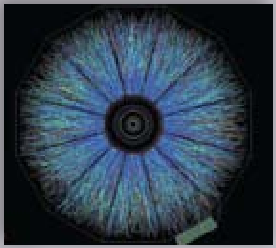
**16 Life Sciences**
From Molecules and Cells
To Medicine and Mother Nature
Research in the life sciences at Brookhaven Lab has a long and distinguished history and a promising future, including basic studies on DNA and proteins, molecular and cellular mechanisms, sophisticated imaging techniques, and biomedical and environmental applications based on this knowledge. These studies advance our understanding of the biological processes at work within and around us, offering many potential benefits to human health and society at large.

**20 Environmental Sciences**
Understanding and Protecting Our World
Brookhaven scientists from a wide variety of disciplines are working to understand and protect our world on the global scale — for example, by studying global climate change, how to mitigate the impacts of human activity, and alternative energy sources — and, in the interests of national security, by working to prevent the spread of nuclear weapons and the misuse of radioactive materials. These programs have the common goal of maintaining a livable planet with safety and security for all.

**24 Education and Community**
Investing in America's Future
Over 30,000 pre-college students and teachers from the Long Island region, plus several hundred college students and faculty members from all over the country, come to Brookhaven Lab each year for programs including visits to our Science Learning Center, competition in an elementary school science fair, contests challenging students to build and test model bridges and magnetically levitated vehicles, and, of course, opportunities to participate in world-class research alongside scientific mentors in our labs. These programs aim to ignite an interest in science among the public and help maintain the nation's position of leadership in the world by training the next generation of scientists.

**25 The Historical Perspective**
Snapshots of Past Brookhaven Discoveries
Six Nobel Prizes — five in physics and one in chemistry — top the list of Brookhaven's past scientific achievements not covered elsewhere in these pages, followed by a range of significant contributions to our understanding of elementary particles and forces, radiation, superconductivity, energy sources, biochemistry, the brain, and more.



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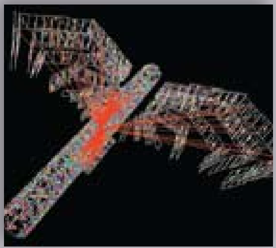

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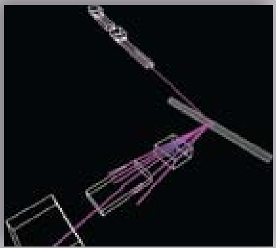

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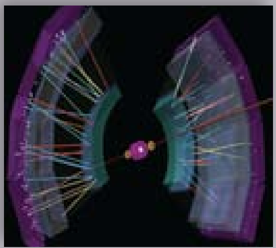


PHENIX

*Early data images from experiments at the Relativistic Heavy Ion Collider.*

# The Relativistic Heavy Ion Collider (RHIC)

## An Exciting Beginning and a Compelling Future

At the Relativistic Heavy Ion Collider (RHIC), a world-class particle accelerator at Brookhaven National Laboratory, physicists are exploring the most fundamental forces and properties of matter and the early universe, with important implications for our understanding of the world around us.

Operated with funding from the U.S. Department of Energy's Office of Science, the Relativistic Heavy Ion Collider (RHIC), was designed to recreate a state of matter thought to have existed immediately after the Big Bang some 13 billion years ago, and to investigate how the proton gets its spin and intrinsic magnetism from its quark and gluon constituents. Large detectors located around the 2.4-mile-circumference accelerator take "snapshots" of collisions between beams of particles — from protons to the nuclei of heavy atoms such as gold — to get a glimpse of the basic constituents of matter.

Understanding matter at such a fundamental level will teach us about the forces that hold the universe and everything in it together.

While no one can predict what, if any, practical applications that knowledge will yield, other, earlier physics studies on the basic structure and properties of matter have yielded countless, unforeseen advances and technologies we now take for granted — things like personal computers, medical instruments, and tiny hand-held cellular phones. The idea behind RHIC is simply to delve deeper into

## Supercomputing at RHIC

Since 2000, RHIC's detectors have taken digitized "snapshots" of billions of particle collisions – data-dense "pictures" that reveal details about the early universe and the fundamental properties of matter. Keeping up with the data and the theoretical calculations of quantum chromodynamics (QCD), the theory that describes nuclear particles' interactions, requires large-scale supercomputing. Designing the systems to meet these computing needs continues to push the evolution of technology in ways that may benefit us all — as did the development of the world wide web, first designed as a way for physicists to share data.

the mysteries of matter. In so doing, RHIC has become one of the world's premiere training grounds for young physicists.

## A perfect surprise

Already, RHIC research has captured worldwide attention and shone a spotlight on U.S. leadership in science.

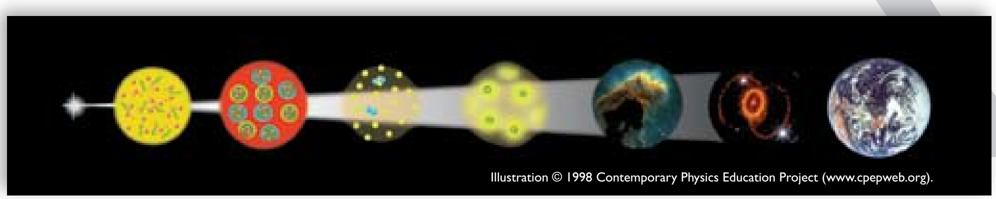
Scientists at RHIC had expected collisions between two beams of gold nuclei to pack enough energy and matter into a tiny space to recreate the extreme conditions of the early universe.

Under those conditions, it was thought that the smallest components of matter — the quarks and gluons that make up ordinary protons and neutrons — would exist freely in a gaseous state for a fleeting instant.

But instead of behaving like a gas of free quarks and gluons, the matter created in RHIC's energetic gold-gold collisions appears to be more like a *liquid.* And it's not just any liquid, but one with coordinated collective motion, or "flow," among the constituent particles.

The scientists describe this fluid motion as nearly "perfect" because it can be explained by the equations of hydrodynamics for a fluid with virtually no viscosity, or frictional resistance to flow. In fact, the high degree of collective interaction and rapid distribution of thermal energy among the particles, as well as the extremely low viscosity in the matter being formed at RHIC, make it the most nearly perfect liquid ever observed.

*(continued)*




*At RHIC, researchers look back in time to an instant just after the Big Bang (far left) to learn about how matter in the universe evolved.*

For data storage and analysis, RHIC physicists rely on a "farm" of 3,300 Linux processors and a super-fast robotic tape storage system at the RHIC/ATLAS Computing Facility (RCF/ACF). ATLAS is another new large-scale physics experiment located at the Large Hadron Collider accelerator complex at the European Center for Nuclear Research, or CERN.

RCF/ACF processors are at times augmented by computing resources from collaborating sites around the world, such as the Japanese RIKEN Laboratory, using the latest rendition of large-scale computer networking, known as the Grid. The Grid keeps track of all the networked computers, and distributes jobs among them at rates as fast as 2.4 gigabytes (GB) per second.

*(continued)*

*The RHIC/ATLAS computing facility contains 3,300 processors.*

## Moving forward

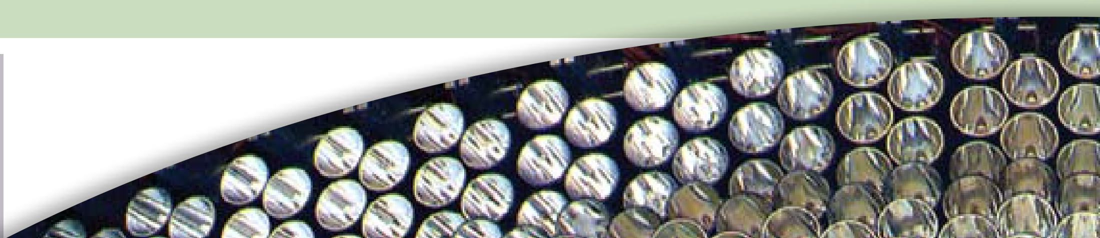
The stunning surprise that the early-universe matter created at RHIC behaves more like a liquid than a gas has enriched physicists' understanding of quantum chromodynamics (QCD), the theory that describes the interactions of the smallest known components of the atomic nucleus. But it has also raised compelling new questions about QCD.

These questions have prompted the need for the enhancement of RHIC to further the study of QCD both experimentally and theoretically. To address these questions, key improvements are planned for the RHIC facility. As part of a symbiotic research program using Brookhaven's new 100-teraflop Blue Gene supercomputer, known as New York Blue, and two 10-teraflop QCDOC (for QCD On a Chip) supercomputers, these upgrades will create a new QCD laboratory at RHIC unlike any research center in the world.

Such high data-transfer rates will enable the RCF/ACF to process data from RHIC and ATLAS simultaneously. Brookhaven Lab is leading the U.S. arm of the international ATLAS collaboration, providing a large portion of the overall computing resources and operating as the central hub for storing and distributing ATLAS experimental data among U.S. collaborators.

At the same time, the QCD On a Chip (QCDOC) supercomputer at the RIKEN BNL Research Center (RBRC) is contributing another important element to RHIC physics. The RBRC was established at Brookhaven with funding from RIKEN to nurture a new generation of young physicists, particularly those focused on understanding the "spin" structure of protons at RHIC. This QCDOC machine is capable of performing 10 trillion arithmetic calculations per second, a speed necessary to perform the complex calculations of QCD.

These studies are augmented by another Brookhaven QCDOC machine, dubbed US QCDOC, designed and built with DOE



A near-term upgrade, known as RHIC-II, will increase the machine's luminosity, or collision rate, approximately 10-fold and improve the sensitivity of the detectors to record extremely rare processes — some of which occur in fewer than one in a billion collisions. These events will reveal detailed characteristics of the new form of matter.

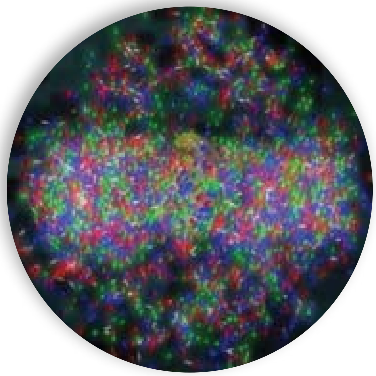
A longer-term upgrade, known as eRHIC, would add a high-energy electron beam to collide with either polarized protons or heavy ions at RHIC. With this powerful added dimension, physicists expect to probe another new form of matter locked deep inside ordinary nuclei, and further expand our ability to explore the newest and most intriguing questions about the substructure of the world around us.

## Spinning in another direction

In addition to investigating the primordial properties of the universe, some RHIC scientists are looking into another fundamental question of particle physics: What is responsible for proton "spin"?

Spin is a magnetic property of particles as basic as their mass and their electrical charge. While we routinely manipulate proton spins to look inside the body with magnetic resonance imaging (MRI), we do not understand the origin of the proton's spin.

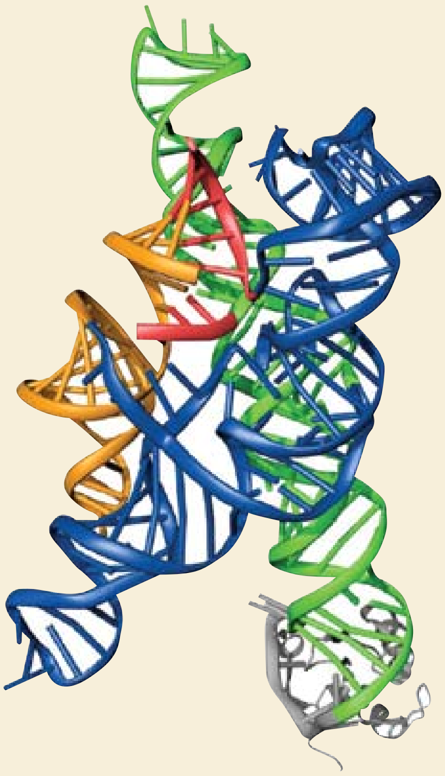
Using specialized magnets known as Siberian snakes to keep the spins of protons mostly aligned in the same direction, physicists at RHIC can collide beams of these "polarized protons" to examine the structure underlying the proton's spin. This research will offer further insight into the structure and interactions of subatomic particles.



*RHIC's "perfect" liquid*

Office of Science funding by a collaboration of Brookhaven Lab, Columbia University, IBM, the UKQCD collaboration in the United Kingdom, and RIKEN.

The architecture used in these QCDOC machines was the precursor to the Blue Gene architecture used in Brookhaven's newest supercomputer, New York Blue. This 100-terraflop machine was built by IBM and purchased by Stony Brook University with funding from New York State for installation at Brookhaven Lab. It is the fastest supercomputer in the world for general users, and will help interpret current RHIC data and model future runs at the collider.



*The structure of a segment of ribonucleic acid (RNA)*

# The National Synchrotron Light Source

## A Beacon for Research

Each year, thousands of scientists from the U.S. and abroad travel to Brookhaven's National Synchrotron Light Source (NSLS) to perform experiments using its bright beams of x-ray, ultraviolet, and infrared light. These researchers study proteins, polymers, metals, minerals — to name just a few examples — to learn about their unique structures and properties.

The NSLS, funded by the U.S. Department of Energy's Office of Science, produces light that cannot be generated in an ordinary laboratory, and therefore provides research opportunities that are not available at the scientists' home institutions. These studies span a spectrum of scientific fields: biology, physics, materials science, medical science, chemistry, nanoscience, and environmental science.

### A light factory

At the NSLS, making light begins with electrons, which are accelerated to nearly the speed of light by very powerful magnets in a circular particle accelerator known as a synchrotron. As the electrons zoom around this "storage ring," they emit light, called synchrotron light.

The NSLS features two storage rings. The x-ray ring produces high-energy x-rays, and the vacuum-ultraviolet ring produces ultraviolet, infrared, and low-energy x-ray light. To distribute the light for use in experiments, several "beamlines" are located at many points around each ring. The beamlines, about 65 in total, serve as light-beam "exit lanes," channeling the light from the storage ring to research end stations, where scientists use it to analyze their samples.

## Users at the NSLS

At Brookhaven National Laboratory, visiting researchers — more than 5,000 each year — are a vital component of the Lab's rich scientific community. They come from around the world to take advantage of the capabilities offered by Brookhaven's multiple user facilities, including the Relativistic Heavy Ion Collider, Alternating Gradient Synchrotron, Accelerator Test Facility, NASA Space Radiation Laboratory, Tandem Van de Graaf, and Center for Functional Nanomaterials.

The majority, however, come to Brookhaven to work at the NSLS. In fact, the NSLS is one of the busiest scientific facilities in the world, each year hosting more than 2,100 guest researchers from approximately 400 universities, laboratories, and corporations.

About 75 percent of these researchers are

## A giant microscope

The NSLS allows scientists to "see" the tiny molecular structures of many substances and specimens. With this capability, scientists at the NSLS have made many fascinating discoveries and are engaged in many ongoing projects. These include:

- Revealing a potential explanation for superconductivity, a little-understood phenomenon that may revolutionize computers and electronics
- Studying the chemical composition of bones, which may aid in the understanding of arthritis and osteoporosis
- Determining the structure of a section of RNA, which may lead to new ways to prevent or treat genetic disorders
- Using plants to clean up environmental contaminants, a technique known as phytoremediation
- Producing the first images of HIV, the virus that causes AIDS, attacking a human cell
- Determining a new way to use x-rays to study carbon nanotubes, tiny cylindrical carbon molecules with exceptional strength, conductivity, and heat resistance
- Studying how the structure and properties of various materials change when subjected to extreme high-pressure, high-temperature conditions

## Spotlight on life sciences

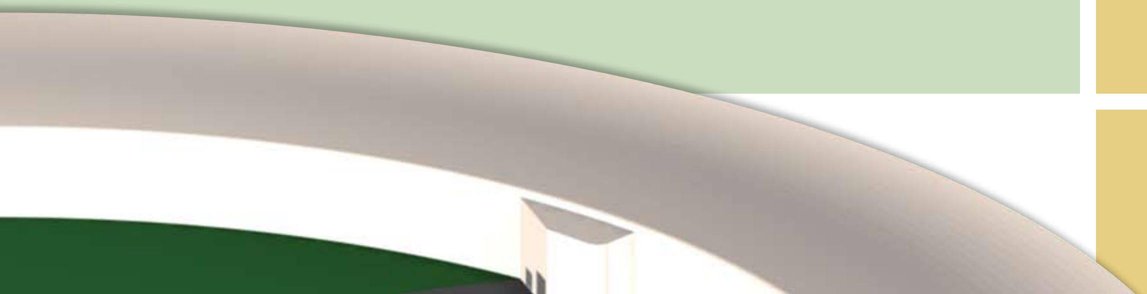
Scientists in the biological and medical sciences form the largest group of researchers at the NSLS, performing studies that aim to probe and understand the subtle inner workings of organisms and improve human health.

Many of these researchers investigate protein structures, leading to fascinating (and often beautiful) protein "snapshots" that reveal the intricate mechanisms of cell functions and can form the foundation for developing drugs and treatments for disease. For example, in 2003, NSLS researcher Roderick MacKinnon of The

*Roderick MacKinnon, a visiting researcher at the NSLS, shared the 2003 Nobel Prize in Chemistry for work explaining how one class of proteins helps to generate nerve impulses.*

from either the life or materials sciences, but many also conduct research in chemistry, geosciences and ecology, and applied science and engineering. The remaining users perform research in optical, nuclear, and general physics, or other fields.

All told, these user scientists publish, on average, more than 800 papers each year, all stemming from experiments performed at the NSLS.



Rockefeller University won the Nobel Prize in Chemistry for determining the atomic structure of a cell-membrane protein that allows ions to pass in and out of cells. His work opened a doorway to understanding the mechanism of ion channels, which are responsible for all nerve and muscle signals in the body.

In another set of experiments, scientists are using a combination of ultraviolet and infrared light to study the structures of proteins involved in creating the characteristic "plaques" and "tangles" that form in the brains of Alzheimer's patients.

Additionally, NSLS scientists have developed a new imaging technique to see cartilage and other soft tissues better than any other method. The technique provides more detailed images than other techniques, such as magnetic resonance imaging (MRI) and ultrasound, and imparts a lower x-ray dose than conventional x-rays. It is a promising method for detecting breast cancer and may provide an alternative to mammography.

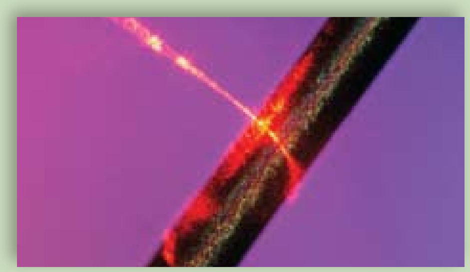
*A bird's-eye view of the NSLS, which has been operating since 1982. The NSLS was the first of the "second generation" synchrotrons, built to take advantage of the phenomenon of synchrotron radiation by using it for research.*

## A bigger, brighter NSLS

As the boundaries of scientific discovery have expanded, many researchers are looking for additional capabilities beyond those that can be provided by the NSLS or, indeed, by any other synchrotron in the world. To take their research to the next level — to see even smaller, subtler details of their samples — they need more intense, better-focused beams of light. Although the NSLS has been continually updated since its

## Seeing the Very Small

The NSLS-II facility will allow scientists to "see" deep into material samples, revealing extremely tiny details – even down to the billionth-of-a-meter level. These abilities will make NSLS-II a key complement to Brookhaven Lab's Center for Functional Nanomaterials.



*At left, a nanowire is wrapped around a human hair. Nanowires are one example of the type of interesting and useful materials that scientists at NSLS-II and the CFN will study. Nanowires have the potential to miniaturize and improve the performance of many devices, possibly leading to a new generation of ultrafast computers, improved magnetic storage media, advanced chemical detectors, and even biosensors to detect disease.*

*This view of the NSLS experimental floor shows four aluminum-foil-wrapped beam lines. Why foil? For light to travel down the beam lines properly, they are heated to "bake" away molecules attached to their inner walls. Just as with baked potatoes, the foil helps keep the beam pipes hot.*

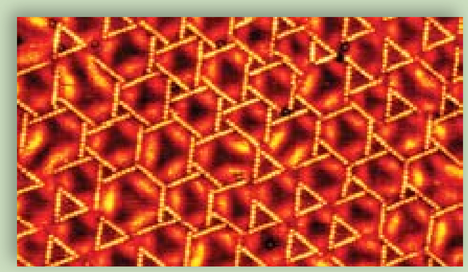
commissioning in 1982, today the practical limits of its performance have been reached. And while newer synchrotrons far surpass the performance of the present NSLS, no synchrotron anywhere in the world — either currently operating, under construction, or in design — will enable scientists to image and characterize materials down to billionth-of-a-meter (nanometer) resolution.

As a result, Brookhaven expects to build a replacement for the present NSLS — NSLS-II. NSLS-II will be a state-of-the-art, world-leading synchrotron that will produce brighter light than any other synchrotron in the world.

Like an extremely powerful microscope, NSLS-II will provide scientists with the world's finest capabilities for x-ray imaging. Its superior capabilities will reinforce U.S. scientific leadership, giving researchers here a competitive advantage in numerous scientific fields, which, in turn, will benefit our nation's economy.

The unique characteristics of NSLS-II will enable scientists to explore the "grand challenges" they face in developing new materials with advanced properties. It will lead to significant advances in condensed matter and materials physics, chemistry, and biology — advances that will ultimately enhance national security and help drive the development of abundant, safe, and clean energy technologies.

Moreover, NSLS-II will have broad impact on a wide range of disciplines and scientific initiatives, including the National Institutes of Health's structural genomics initiative, the U.S. Department of Energy's Genomes to Life initiative, and the federal nanoscience initiative. It is expected to be an important complement to Brookhaven's Center for Functional Nanomaterials (CFN), as researchers will be able to produce nanomaterials at the CFN and analyze their structures and properties right next door at NSLS-II.

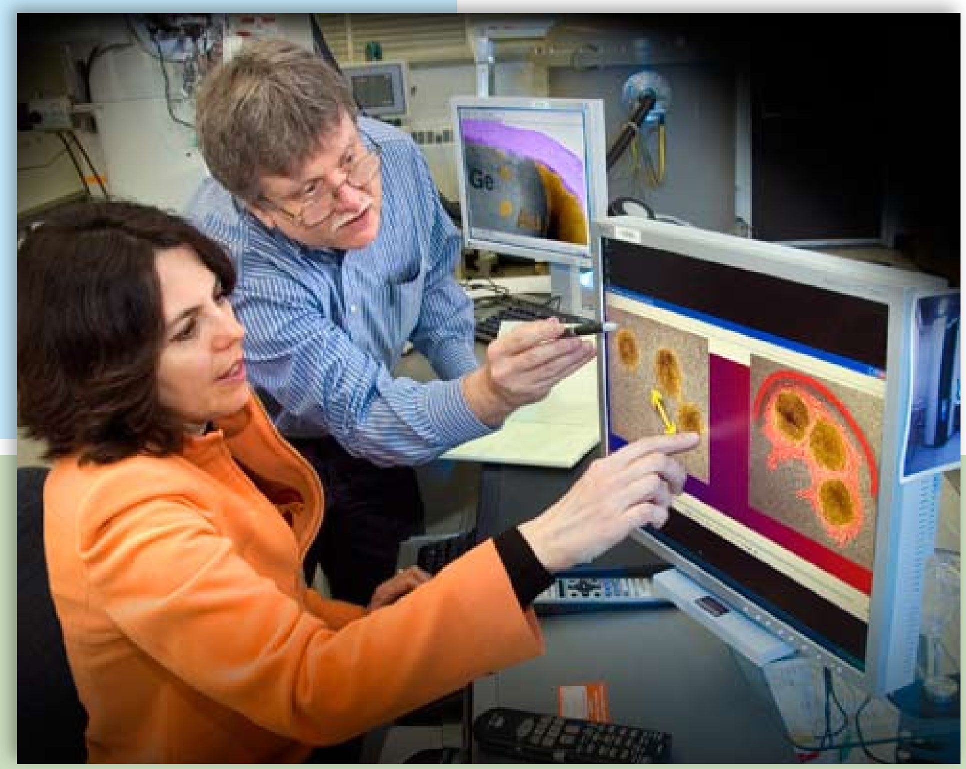


*At left, "dancing triangles" are formed by sulfur atoms on a layer of copper, which in turn rests upon a base, or "substrate," of ruthenium. Scientists at NSLS-II and the CFN will study this type of configuration to understand how one metal behaves on top of another, and how sulfur atoms affect that interaction. Layered metals are often used as catalysts, such as those that clean pollutants from automobile exhaust in catalytic converters. Copper on ruthenium may make a particularly good model catalyst.*

# Center for Functional Nanomaterials

## Science for Discovery at the Ultrasmall

Nanoscience is the synthesis and study of structures with atomic-scale sizes, or about a billionth of a meter (nanometer). Although still part of a nascent area of research, nanostructure materials have the potential for creating or accelerating new technologies across fields as diverse as energy, electronics, medicine, and industrial processes.




*CFN researchers will use advanced probes and new fabrication techniques to study materials at nanoscale dimensions.*

The Center for Functional Nanomaterials (CFN) at Brookhaven National Laboratory was inaugurated in 2007. Built and supported by the U.S. Department of Energy (DOE), the CFN is one of five Nanoscale Science Research Centers located at national laboratories. This 94,500-square-foot user-oriented science facility will be a hub for cutting-edge nanoscience and is expected to attract an estimated 300 researchers annually from the northeastern United States and other parts of the world.

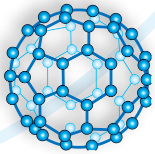
The CFN provides scientists with state-of-the-art capabilities for fabricating and studying nanometer-scale functional materials. Nanomaterials can possess chemical and physical properties different from those of their larger-scale, bulk counterparts. Understanding and enhancing nanomaterial functions is of capital importance, as it is these properties that ultimately enable practical applications.

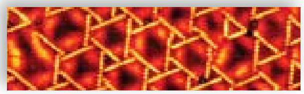
The scientific directions of the CFN are primarily aligned with our national challenges in energy. Nanostructured materials may enable energy-efficient processes and devices for alternatives to fossil fuels, such as efficient catalysts, fuel cells, photovoltaic (solar cell) elements, or solid-state lighting. Research programs in the CFN focus on three key areas:

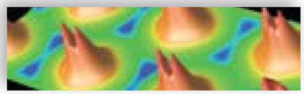
- Nanocatalysis, which helps accelerate chemical reactions using nanoparticles
- Biological and soft nanomaterials, such as biomolecules and polymers, in which specialized designs can mimic nature and lead to new functions
- Electronic nanomaterials, whose optical and electronic properties can be enhanced for incorporation into efficient energy-conversion devices

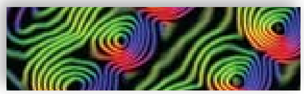
## Nanocatalysis

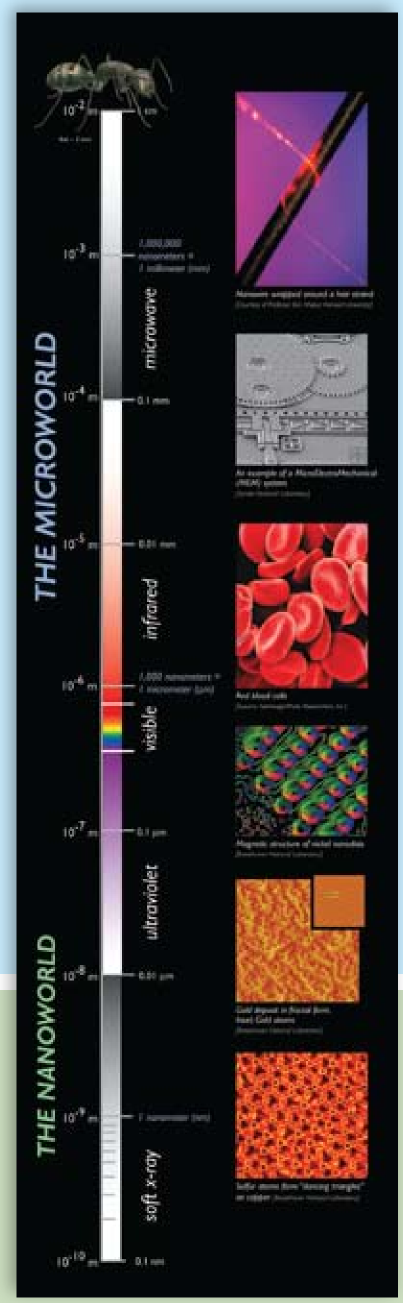
Nanocatalysis uses tiny structures, a few nanometers in size, to speed up chemical reactions essential to modern life. Metal-containing nanoparticles are indispensable ingredients in industrial chemical production and energy-related processes. For instance, fuel cells for powering












electric vehicles use bi-metallic particles of platinum and ruthenium to catalyze the conversion of chemical energy into stored electrical energy. These particles are less than 100 nanometers in size and make up only a few percent of the catalyst's weight, yet they provide the active sites where chemical reactions take place.

CFN scientists are now developing new experimental and theoretical tools to image and understand chemical reactions activated by such nanoparticles.

## Biological and Soft Nanomaterials

Soft nanomaterials include polymers, liquid crystals, and other relatively "squishy" materials that fall into a state between solid and liquid, whose properties can be engineered to replicate those of conventional "hard" materials, yet are lighter, transparent, cheaper, and, in some cases, biocompatible.

Of current interest is the development of methods that mimic nature to assemble hybrid nanosystems consisting of inorganic and biological components that maintain biofunctionality. Such nano-engineered systems will find applications in advanced optical, magnetic, and electrical devices that require the placement of nano-objects with high precision. To achieve this, scientists are developing novel ways to biofunctionalize nanoparticles and nanotubes with DNA and proteins.

Using the advanced facilities available at the CFN, scientists are devising ways to use biomolecules as scaffolds, or "guides," to build two- or three-dimensional arrays of organized nano-objects, and they are learning how cooperative effects among those objects can be used in applications.

## Electronic Nanomaterials

At the nanoscale, materials can exhibit electrical and optical characteristics that are not present at macroscopic dimensions. For instance,

# Hydrogen Research

Scientists are investigating ways to combine hydrogen research with nanoscience to find innovative solutions to energy problems. To develop efficient hydrogen fuel cells for powering cars, homes, and businesses, materials that can store and release a lot of hydrogen are a necessity.

To be practical, these materials must be cheap, safe to handle, and have both a high reactivity rate and storage capacity. At Brookhaven Lab, scientists are addressing this challenge by studying metal hydride compounds, which release hydrogen when they react with a catalyst. With DOE guidelines in mind, these researchers are looking for materials that hold nine percent

*Scientists at the CFN will study materials at nanoscale dimensions, 1000 times smaller than a human hair.*

electronic mobility is enhanced drastically in certain nanomaterials. In others, the emission or absorption of light is improved significantly by small size. These novel properties give electronic nanomaterials the potential for strongly impacting the performance of energy-conversion devices.

The CFN program emphasizes the preparation of nanomaterials and understanding their opto-electronic properties to create both individual nanostructures and organized assemblies. Developing nanomaterial assemblies is important, for example, for use in large-area energy conversion devices.

*The energy-efficient CFN facility occupies nine square acres and will house 150 people. The state-of-the-art building was completed in 2007, and will attract an estimated 300 researchers from the Northeast annually.*

hydrogen by weight (a relatively large amount) and are reusable.

One of the roadblocks to the practical use of hydrogen as fuel is finding a hydrogen source that does not produce much waste. Natural gas, oil, and coal are good sources of hydrogen, but the reaction process is very wasteful, producing enough carbon monoxide (CO) to eventually "poison" the catalyst and stop the reaction entirely. Brookhaven scientists are working on new catalysts that would lower the CO poisoning rate, allowing the fuel cell to function longer. This research may help lead to practical fuel cells that can power cars for days instead of hours.

# Life Sciences

## From Molecules and Cells to Medicine and Mother Nature

Research in the life sciences at Brookhaven National Laboratory has a long and distinguished history and a promising future, including basic studies on DNA and proteins, molecular and cellular mechanisms, sophisticated imaging techniques, and biomedical and environmental applications based on this knowledge. Funded by the U.S. Department of Energy's (DOE) Office of Science, the National Institutes of Health, and other agencies, these studies advance our understanding of the biological processes at work within and around us, offering many potential benefits to human health and society.

*Researchers analyze data to understand how drugs affect the brain.*

### The language of life

All of the machinery within living cells operates according to the principles and language of biochemistry. Therefore, understanding the complex interactions of molecules is essential to understanding life.

Many DOE scientists, including researchers at Brookhaven, have made enormous advances in decoding the "dictionary" of this molecular language — the DNA-based genetic code that governs the actions of every cell. As part of the effort to learn how to read and make sense of the language, Brookhaven researchers have also developed many methods to produce and study the proteins encoded by genes. Proteins are the cellular workhorses that carry out genetic instructions and help cells communicate with one another.

One technique developed at the Lab enables the production of large quantities of specific proteins, such as would be needed for large-scale research or applications in industry and medicine. Another scans the entire genome to identify sites where so-called regulator proteins bind to turn particular genes on or off. This process establishes the very identity of cells and, when gone awry, sometimes triggers conditions like cancer.

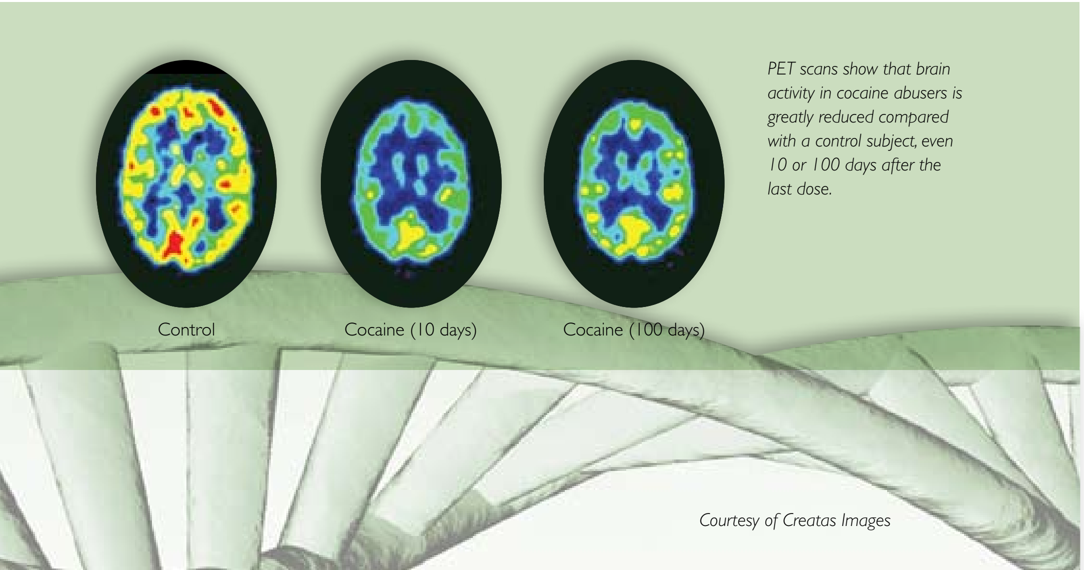
### Puzzling proteins

To understand how proteins carry out certain tasks and look for ways to stop disease-causing proteins, Brookhaven scientists are using high-intensity x-rays and a cryo-electron microscope to decipher these molecules' three-dimensional atomic structures, as well as computational methods to understand how the proteins become active. These techniques have, for example, helped researchers identify how AIDS and common-cold viruses bind to and infect human cells, and identify targets for new vaccines. Brookhaven scientists have also engineered combination proteins from the bacteria that cause Lyme disease for use in diagnostic tests and improved vaccines.

Structural analysis of the complex proteins located within cellular membranes, another Brookhaven focus, could lead to more effective drug delivery and even ways to use biological systems to clean up or otherwise mitigate environmental damage.

### Talking about plants

Studies of genes, proteins, and molecular interactions in plants have a host of potential real-world applications. One primary interest is the development of plant species for the efficient production of sustainable biofuels. In another effort, Brookhaven researchers have mixed plant-dwelling bacteria with pollutant-digesting soil-dwellers to yield a new bacterial strain that can break down pollutants while living in the roots of plants.




*PET scans show that brain activity in cocaine abusers is greatly reduced compared with a control subject, even 10 or 100 days after the last dose.*

*Courtesy of Creatas Images*

This approach has the potential to greatly increase the ability of certain plants to soak up and degrade contaminants in soil, a strategy known as phytoremediation. Similar efforts may improve plants' ability to soak up carbon dioxide from the atmosphere, thereby helping to control the greenhouse effect.

Another plant project seeks ways to boost production of useful plant products (for example, plant oils) by using genetic methods to "tune up" the enzymes responsible for making these products. Increasing the efficiency of these enzymes or helping them evolve new functions could lead to the production of more healthful plant oils or the use of plants as a renewable resource for the kinds of industrial raw materials we now derive from petroleum.

*Studies of plants may lead to new raw materials for industrial processes.*

## Translation, please

Translating molecular and cellular knowledge to an understanding of more complex life processes, diseases, and even human behavior has been a huge challenge. Brookhaven is home to a spectrum of sophisticated imaging tools that aim to bridge this gap.

For example, positron emission tomography (PET) scanning shows neurotransmitter proteins sending signals from brain cell to brain cell, and how these vital communication networks are affected by drugs of abuse, eating disorders, other diseases, and normal aging. Brookhaven scientists have been instrumental in developing the radiotracers used with PET. In fact, a Brookhaven-developed radiotracer, a form of glucose called 18-FDG, is now routinely used for cancer diagnosis in almost every PET center in the world. Magnetic resonance imaging (MRI) allows scientists to visualize brain anatomy at high resolution,

## Brookhaven Facilities for Life Sciences Research

**The National Synchrotron Light Source** generates high intensity x-ray, ultraviolet, and infrared light for probing the structures and inner workings of biological molecules.

**The Center for Translational Neuroimaging** includes two large-scale (human) PET scanners, a high-field MRI camera, and smaller-scale micro PET, micro MRI, and micro computed tomography (CT) scanners for complementary small-animal studies.

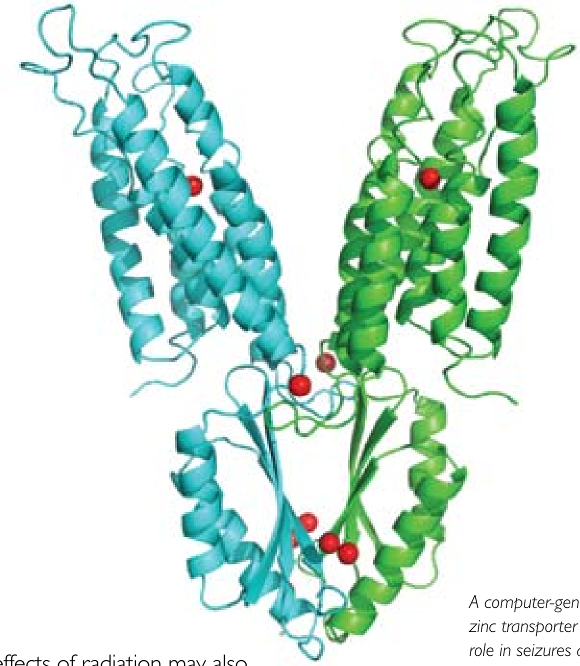
**The Brookhaven Linac Isotope Producer** creates a variety of radioisotopes — radioactive forms of ordinary chemical elements — that can be used alone or incorporated into "radiotracers" for nuclear medicine research or for clinical diagnosis and treatment.

allowing the study of site-specific brain function and neurochemistry over time.

With PET and MRI facilities for studying both humans and small animals such as rodents, Brookhaven researchers can analyze a real-world population, and also test hypotheses — and potential treatments — triggered by those studies. Brookhaven scientists are also developing a "mobile" PET scanner for imaging fully alert animals.

## Miscommunication

Another important arm of life sciences research investigates how external factors sometimes disrupt the language of life by damaging DNA or interfering with cells' ability to repair such damage. A large collaborative effort with the National Aeronautics and Space Administration (NASA) examines the biological effects astronauts might experience as a result of radiation encountered on long-term missions to the Moon or Mars. These studies will help assess risks and design protective measures.



*A computer-generated model of a zinc transporter protein, which plays a role in seizures and type-2 diabetes, and may also be relevant in the production of biofuels.*

Studies on the effects of radiation may also help scientists improve the use of radiation in the treatment of diseases like cancer, a prime example of normal cellular communication gone awry. Enhancing radiation treatments so that only diseased cells are affected while normal cells are spared could increase survival rates and minimize side effects.

**The Scanning Transmission Electron Microscope** investigates the intricate details of biological beings from bacterial cells to humans.

**The Cryo-Electron Microscope** offers scientists another way to decipher the structures of proteins.

**The NASA Space Radiation Laboratory** produces beams of radiation similar to those that would be encountered by astronauts on long-term missions to help assess risks and test protective measures.

# Environmental Sciences

## Understanding and Protecting Our World

Scientists from a wide variety of disciplines are working to understand and protect our world on the global scale by studying global climate change, how to mitigate the impacts of human activity, and alternative energy sources — and, in the interests of national security, by working to prevent the spread of nuclear weapons and the misuse of radioactive materials. These programs have the common goal of maintaining a livable planet with safety and security for all.

### From the clouds to the earth

Global climate change is one of the most pressing and controversial issues facing our world today. Brookhaven National Laboratory scientists from a wide variety of disciplines work on aspects of this problem ranging from forecasting its effects to advancing technologies that may slow or reverse its progress.

Atmospheric scientists conduct field studies with aircraft and surface measurements to examine how aerosol pollutants form, grow, and move, and examine their effects on Earth's energy balance and climate. Regional studies in the United States have focused on how these pollutants affect climate and air quality as they spread from their points of origin into the atmosphere and over the oceans.

*Researchers and students used Brookhaven tracer technology to study the dispersion of airborne contaminants in New York City. At right, one of a variety of instruments deployed to track the winds.*

Brookhaven scientists also participate in the Atmospheric Radiation Measurement (ARM) program, a key contributor to national and international research efforts related to global climate change. At sites on the U.S. Southern Great Plains, the North Slope of Alaska, and in the Tropical Western Pacific, ground-based remote sensing instruments take continuous field measurements of interactions between clouds and radiative feedback processes in the atmosphere.

Back on the ground, the Free Air CO2 Enrichment (FACE) program provides a technology to modify the microclimate around growing plants to simulate climate change conditions at diverse sites across the country and around the world. Typically, carbon-dioxide (CO2) enriched air is released from a circle of vertical pipes into large plots of growing plants such as wheat and cotton, and stands of pine trees. The program provides a window on the future, offering researchers a realistic assessment of long-term responses of intact ecosystems to elevated carbon dioxide.

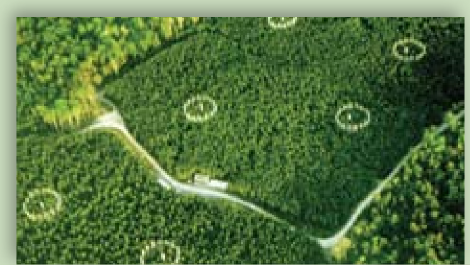
Brookhaven's Tracer Technology Center uses perfluorocarbon tracers (PFTs) to study a wide range of atmospheric processes and indoor air quality to identify gaseous and liquid leak pathways and, most recently, to monitor the fate and transport of model "contaminant" releases in complex urban-canyon environments.

Environmental research and technology is conducted to characterize and remediate hazardous, radioactive, and mixed wastes. Basic research focuses on the transport of contaminants in the environment at the molecular scale using state-of-the-art techniques at Brookhaven's National Synchrotron Light Source. Treatment technologies for contaminants such as mercury, and decontamination technologies for removal of contaminants from surfaces and soil have been developed and licensed for commercial application.

## Exploring Energy Alternatives

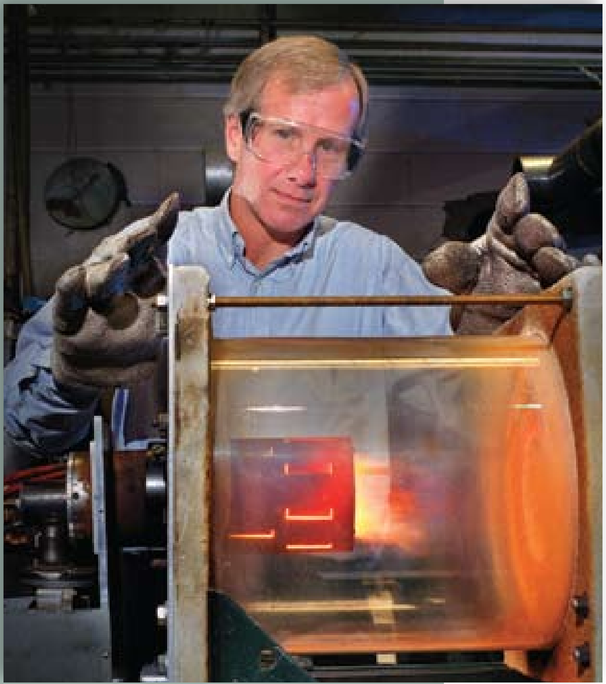
Brookhaven's Center for Functional Nanomaterials (CFN) will be a hub for cutting-edge nanoscience studies aimed at addressing our nation's energy challenges. Still early in its development, nanoscience has the potential to bring about and accelerate new technologies in energy distribution and industrial processes. The overarching research goal of the CFN is to help solve the U.S.'s energy problems by exploring materials that use energy more efficiently and by researching practical alternatives to fossil fuels, such as hydrogen-based energy sources and improved, more affordable solar-energy systems.

Brookhaven Lab's energy scientists are also working to advance alternative energy technologies, which will offer energy solutions with less global impact than fossil fuels. Researchers are examining the potential of biodiesel, a biodegradable, nontoxic, renew-



*Scientists study large plots of growing plants exposed to $CO_2$-enriched air to predict future effects of elevated carbon dioxide.*

*The Brookhaven-developed fan-atomized oil burner offers improved fuel- and air-mixing for better performance.*



able fuel made from new or used vegetable oils or animal fats. The "biofuel" can be used in diesel-powered vehicles, and can also be used for home heating in a standard oil-fired furnace or boiler.

Concerns about greenhouse gases and global climate change have also revitalized interest in nuclear energy technologies. Brookhaven Lab is a leader in the Advanced Fuel Cycle Initiative, which will allow for the reprocessing of spent nuclear material in reactors instead of burying it in a repository. Scientists are finding ways to recycle the material that will be both useful and difficult for terrorists and others seeking nuclear materials to exploit.

Brookhaven Lab also serves many user communities with its National Nuclear Data Center, which collects, evaluates, and disseminates nuclear physics data for basic nuclear research and applied nuclear technologies.

## Promoting Nuclear Safety, At Home and Around the World

The Nonproliferation and National Security Department at Brookhaven Lab plays a key role in preventing the spread of nuclear weapons and the misuse of radioactive materials through its many programs supported by the Department of Energy, the Department of Homeland Security, the Department of State, and other federal agencies.

The largest program provides funds for Brookhaven scientists to collaborate with Russian colleagues to help secure nuclear materials through upgrades to special nuclear materials accounting, protection, and control systems. In addition, Brookhaven plays a major role in supporting the conversion and consolidation of

## Tracking Radioactive Materials

To support the detection of illicit movement of radioactive and nuclear materials, Brookhaven maintains and operates the Radiation Detector Testing and Evaluation Center (RADTEC) for the Department of Homeland Security. This set of facilities tests and evaluates commercially available and certain laboratory prototype radiation detectors for portal monitoring (at bridges, tunnels, and other transportation choke points) as well as hand-held search detectors. In addition, research and development efforts are under way to build and test advanced radiation detector systems capable of identifying and locating radioactive materials with a single detector. Advanced radiation detectors will find use at maritime ports, major roadways, and waterways, and for searches of buildings and vehicles. Brookhaven also works on the international level to develop response plans and train authorities to respond to incidents involving radioactive materials.

highly enriched uranium, and leads the development and deployment of monitoring systems such as closed circuit TV activated by personnel movement and vault-access door alarms at Russian nuclear facilities.

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The Lab also conducts research in developing international safeguards approaches for critical nuclear facilities such as uranium enrichment plants. In past work, Brookhaven developed innovative concepts such as safeguard seals and short-notice random inspections.

The International Safeguards Project Office provides oversight and management of technical support and equipment for improving International Atomic Energy Agency safeguards.

To slow the transfer of weapons knowledge to rogue states or terrorist groups, a Brookhaven program has successfully placed scientists from the weapons programs of the former Soviet Union into non-weapons work supporting commercial product development.

*Brookhaven plays a key role in preventing the spread of nuclear weapons and the misuse of radioactive materials.*

*Advanced radiation detectors are both developed and tested at Brookhaven for the Department of Homeland Security.*

# Education and Community

## Investing in America's Future

Educational programs sponsored by Brookhaven National Laboratory serve the nation by helping to educate and train future scientists and engineers. Over 30,000 pre-college students and teachers from the Long Island region, plus several hundred college students and faculty from all over the country, come to Brookhaven each year for programs offering hands-on science experiences and invaluable career training.

Brookhaven Lab serves many communities, from its neighbors to international users to the agencies and officials that oversee the Laboratory. To ensure that the Lab is responsive to all concerns, Brookhaven works to increase awareness and understanding of its operations, as well as to involve its many stakeholders appropriately in decisions that may concern their values or quality of life.

- The Department of Energy's (DOE) college and university programs, such as the Science Undergraduate Laboratory Internship, offer student appointments for spring, summer, and fall terms. Participants work side-by-side with Brookhaven's scientific and professional staff to gain research experience in chemistry, physics, engineering, biology, nuclear medicine, applied mathematics, high- and low- energy particle accelerators, and nanoscience.

- The DOE Academies Creating Teacher Scientists program provides three consecutive years of multi-week summer research experience and professional development for science, mathematics, and technology teachers. Participating teachers receive a stipend, housing allowance, travel expenses, and funds to support professional development and classroom equipment.

- Brookhaven sponsors contests and competitions to stimulate student interest in the sciences. Winning teams from the high school and middle school regional science bowl competitions advance to the DOE National Middle School Science Bowl and DOE National High School Science Bowl.

- Brookhaven's Office of Educational Programs (OEP) serves as a liaison between educational institutions around the country and the Laboratory's scientific staff to build collaborative opportunities. A consortium of historically black colleges and universities, for example, has worked with National Synchrotron Light Source research staff to introduce students and faculty to the facility, with the aim of developing research and employment opportunities at DOE facilities.


- The Open Space Stewardship Program, initiated by OEP, supports more than 50 teachers and hundreds of students as they conduct research on public lands in their neighborhoods. This community, government, and school partnership provides an opportunity for students to interact with researchers, government officials, and environmental managers while conducting research activities.

For more information on educational programs, visit http://www.bnl.gov/education. For more information on Brookhaven's community outreach and involvement efforts, visit www.bnl.gov/community

## Brookhaven's Nobel Prizes

**2003 Chemistry:** For membrane-protein studies beginning in 1998, some at the NSLS, which help explain how nerve cells send signals.

**2002 Physics:** For discovery begun in 1967 of solar neutrinos, proving that fusion powers the sun.

**1988 Physics:** For the 1962 discovery at the AGS of the muon neutrino.

**1980 Physics:** For the 1963 discovery at the AGS of "CP violation," which helps explain why matter predominates over antimatter in the universe.

**1976 Physics:** For the 1974 discovery at the AGS of the J/psi particle.

**1957 Physics:** For a theory known as parity conservation.

## Science Highlights

Precision measurements of the "spin" of the muon differ from theory and may offer new in-sight into "new" physics "beyond the Standard Model."

Physicists observe "once-in-a-trillion" predicted decay of subatomic kaon — one of the keys to understanding the universe's most elemental forces and building blocks — twice.

Discovery of "left-handedness" of neutrino particles.

Mystery of too few solar neutrinos discovered, then resolved with discovery that neutrinos change type as they journey from sun to Earth.

First use of calculation methods for solving problems in Quantum Chromodynamics (QCD), the theory of strong interactions among quarks.

Discovery of various subatomic particles: top quark, charmed lambda, omega-minus, long neutral kaon, sigma-zero, and sigma-minus.

Application of superconducting materials for power transmission and magnetically levitated trains.

Discovery of and investigations into mechanisms of high-temperature superconductors.

Development of new materials for less toxic and longer lasting batteries.

Investigations into more effective ways to harness solar energy.

Studies to authenticate artwork and historical documents, including oldest playable flutes and map of "New World."

Development of fuel- and money-saving devices for oil burners.

Engineered bacteria capable of digesting pollutants and purifying fossil fuels.

Development of asbestos-"digesting" foam to mitigate danger while preserving flame-retardant properties.

Discovery of link between salt and hypertension.

First use of L-dopa to treat Parkinson's disease.

Pioneered use of radiotracer now used in 85 percent of world's nuclear medicine procedures, including heart, kidney, lung, liver, spleen, and bone scans.

First synthesis of human insulin.

Developed radiotracer now used in heart stress tests around the world.

Investigations of new methods for treating cancers and cancer-related pain.

Uncovered relationship between sun's ultraviolet (UV) rays and cancer — and usefulness of sunscreen.

Developed foremost PET radiotracer used to diagnose cancer, brain disease, psychiatric illness, and heart disease.

Investigations of promising treatment for addiction.

# The Historical Perspective

## Snapshots of Past Brookhaven Discoveries