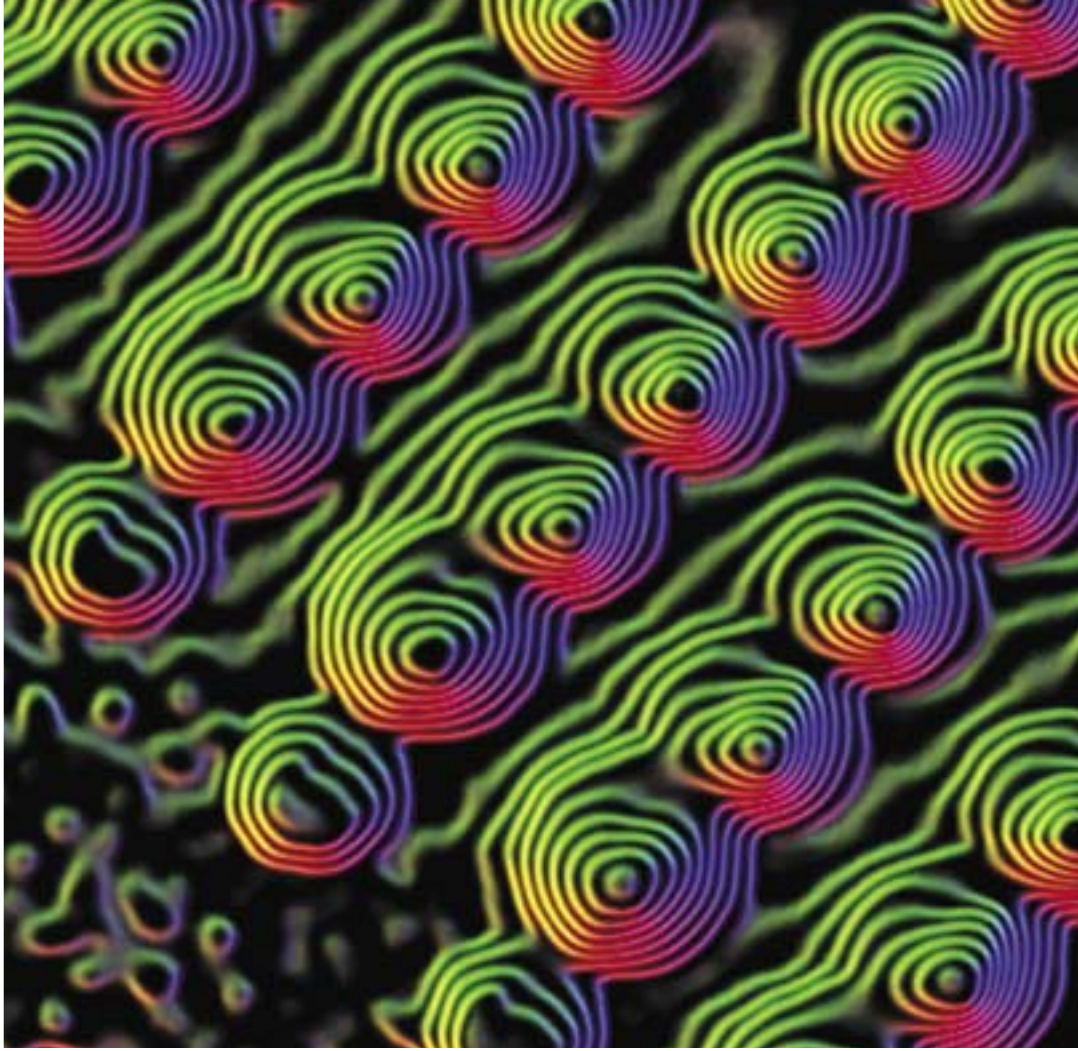

passion *for discovery*

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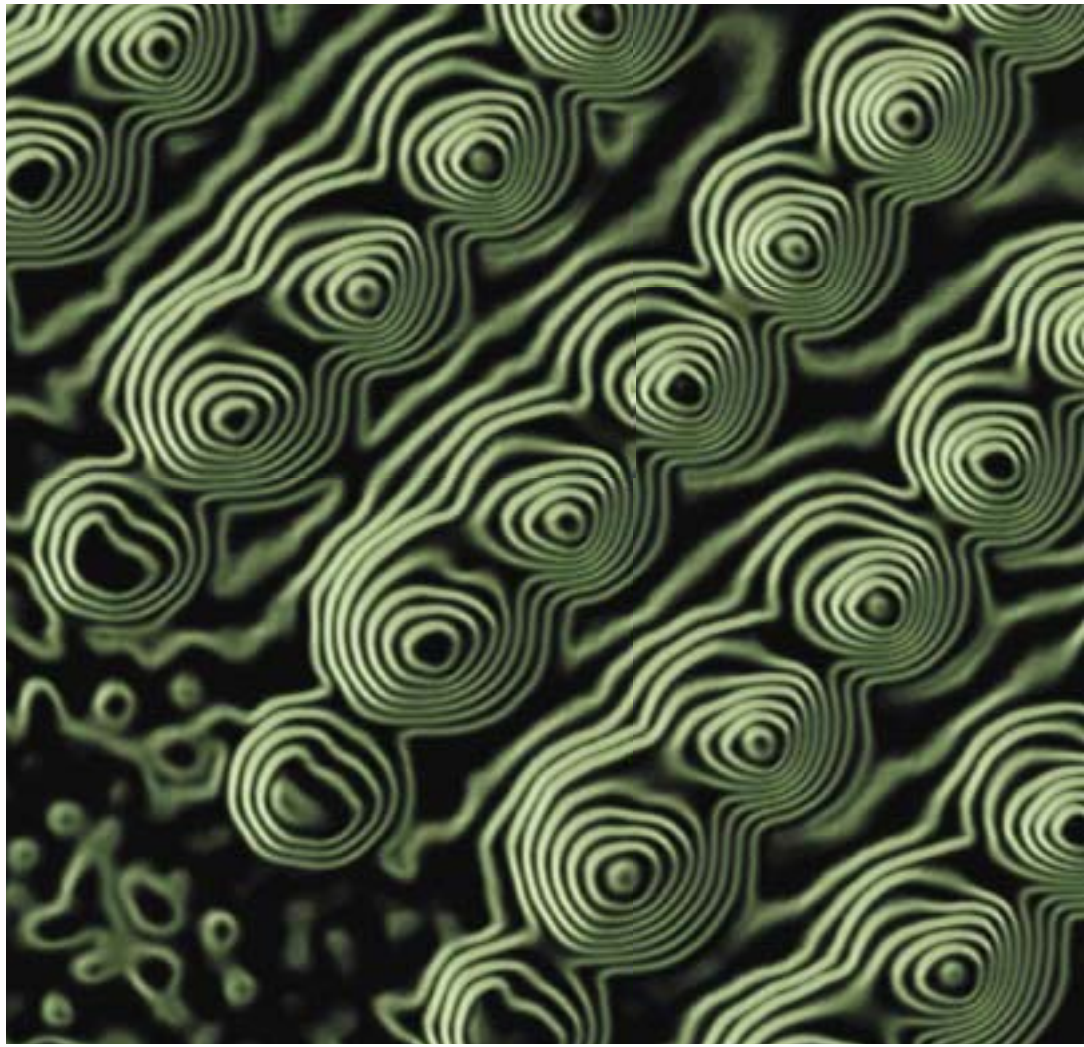
Cover photo: Map showing magnetic flux lines for nickel nanoparticles



passion *for discovery*

BROOKHAVEN
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Table of Contents

A *passion for discovery* is thriving at Brookhaven National Laboratory. Each year, close to 4,000 Laboratory, university, and industry scientists use Brookhaven's unique facilities to delve into the basic mysteries of physics, chemistry, materials, and biology. Brookhaven's researchers develop new technologies with applications ranging from energy to medicine, study humankind's impact on the environment, and serve our nation in national security arenas. Since its inception in 1947, the Lab has been home to six Nobel Prize-winning discoveries and countless other advances. Funded primarily by the Office of Science of the U.S. Department of Energy (DOE), the Laboratory houses large-scale instruments and facilities available nowhere else in the world. This booklet offers a glimpse at the spectrum of this research, highlighting the Lab's major programs and initiatives.

4 The Relativistic Heavy Ion Collider
Exciting Beginning, Compelling Future
Since 2000, this premiere physics facility has been colliding gold nuclei at nearly the speed of light, re-creating conditions of the early universe and offering deep insights into the fundamental forces and properties of matter. From its exciting beginnings, a startling new view of the early universe is emerging. Planned upgrades promise a compelling future through a richer understanding of the "perfect" liquid that pervaded the early universe, recently discovered at RHIC.

8 The National Synchrotron Light Source
A Beacon for Research
Each year, thousands of scientists from the U.S. and abroad perform experiments using Brookhaven's intense x-ray, ultraviolet, and infrared light source, the National Synchrotron Light Source (NSLS). Their studies span all scientific fields: from studies of the structure of proteins, to elucidating the properties of new materials, to understanding the fate of chemicals in our environment. A newer synchrotron known as NSLS-II, planned for completion in the next decade, will be the highest resolution light source in the world, expanding scientists' ability to probe structures at the nanoscale.

12 Center for Functional Nanomaterials
A Window into the Ultrasmall
Nanoscience — the study of materials on the order of billionths 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 will be 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
Brookhaven's research in the life sciences 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
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

24 Educational Programs
Investing in America's Future
More than 25,000 elementary and secondary school students and teachers — and several hundred college students and faculty members — come to Brookhaven Lab each year for visits to our Science Learning Center, science and engineering competitions, and opportunities to participate in world-class research alongside scientific mentors in our labs. These programs aim to ignite an interest in science and help maintain America's leadership in the world by training the next generation of scientists.

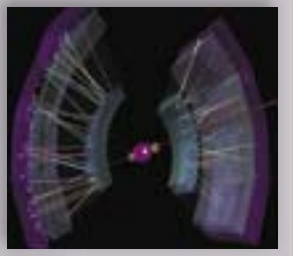
25 The Historical Perspective
Snapshots of Past Brookhaven Discoveries
Six Nobel Prizes — five in physics and one in chemistry — top the list of Brookhaven's past science highlights not covered elsewhere in these pages.

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.

STAR

PHOBOS

BRAHMS



PHENIX

Data images from the four detectors at the Relativistic Heavy Ion Collider.

The Relativistic Heavy Ion Collider

An Exciting Beginning and a Compelling Future

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory has taken its place among the world's premiere nuclear physics research facilities. Here, physicists are exploring the most fundamental forces and properties of matter and the early universe. Built and operated with funding from the U.S. Department of Energy's Office of Science, RHIC research offers insight into the entire spectrum of existence — from the subatomic to the cosmic, and from the beginning of time to the present and beyond.

Since 2000, the facility has been performing beyond expectations, producing discoveries that have captured worldwide attention from both scientists and the public. In doing so, RHIC research has shone a spotlight on U.S. leadership in science. And the exciting scientific output of RHIC has just begun.

Looking back

Like a giant "telescope" peering deep into the inner space of atomic nuclei, RHIC looks back in time to explore matter as it is thought to have existed fractions of a second after the birth of the universe. Inside the 2.5-mile-circumference particle accelerator, two beams of gold ions

The corkscrew grooves on Siberian Snake magnets help keep proton spins aligned, or polarized.

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"? A magnetic property of particles as basic as mass and electrical charge, spin is

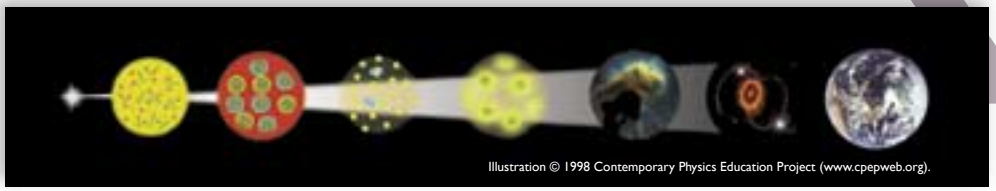
circulating at nearly the speed of light collide head on, releasing enormous amounts of energy.

Under these conditions, the quarks and gluons that make up protons and neutrons in ordinary atomic nuclei are expected to be free for a fleeting instant — just as scientists believe they were microseconds after the Big Bang, before joining together to form protons, neutrons, atoms, stars, planets, and people. Using sophisticated detectors known as BRAHMS, PHENIX, PHOBOS, and STAR, RHIC's researchers take "snapshots" of this early universe substance and study how it evolves.

Understanding matter at such a fundamental level will teach us about the forces that hold the universe and everything in it together. Earlier physics studies on the basic structure and properties of matter have yielded countless, unforeseen advances and many technologies we now take for granted — things like personal computers based on state-of-the-art electronics, medical tools that help diagnose and treat disease without surgery, and telecommunications devices that allow us to talk with friends and colleagues around the world using a device smaller than a human hand. Of course, no one can predict what, if any, practical applications the knowledge gained from RHIC will yield, but we'll never know unless we delve deeper into the mysteries of matter.

Liquid universe

Evidence to date suggests that RHIC's gold-gold collisions are indeed creating a new state of hot, dense matter, but one quite different and even more remarkable than had been predicted. Instead of behaving like a gas of free quarks and gluons, as was expected, the matter created in RHIC's heavy ion collisions appears to be more like a *liquid*.



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.

a particle's intrinsic angular momentum. 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 interactions of subatomic particles.

That evidence comes from measurements by the four RHIC detectors of unexpected patterns in the trajectories taken by the thousands of particles produced in individual collisions. Instead of dissipating randomly, as would be expected in a gas, the particles tend to move collectively in response to variations of pressure across the volume formed by the colliding nuclei. Scientists refer to this phenomenon as "flow," since it is analogous to the properties of fluid motion.

However, unlike ordinary liquids, in which individual molecules move about randomly, the hot matter formed at RHIC seems to move in a pattern that exhibits a high degree of coordination among the particles — somewhat like a school of fish that responds as one entity while moving through a changing environment. The scientists describe this as fluid motion that is nearly "perfect," because it can be explained by equations of hydrodynamics. In fact, the high degree of collective interaction and rapid distribution of thermal energy among the

The RHIC computing facility contains 3300 processors.

Crunching the Data

RHIC continues to push the development of ever more powerful computing technology to process and make sense of its enormous volumes of data. This shouldn't be a surprise considering that high-energy and nuclear physicists were the first to conceive of and develop a worldwide network of interconnected computers — precursor to today's World Wide Web — to speed the sharing and analysis of their work.

During a recent RHIC run, the experiments collected a total of 675 Terabytes of data — enough to fill roughly 1 million compact discs. Much of these data will be analyzed on the more than 3300 processors at the RHIC Computing Facility (RCF). The RCF received data from the experiments at rates in excess of 200 Megabytes per second — equivalent to transferring the contents of a CD in 3 seconds — storing the data on tapes for later analysis.

particles, as well as the extremely low viscosity (or resistance to flow) in the matter being formed at RHIC, make it the most nearly perfect liquid ever observed.

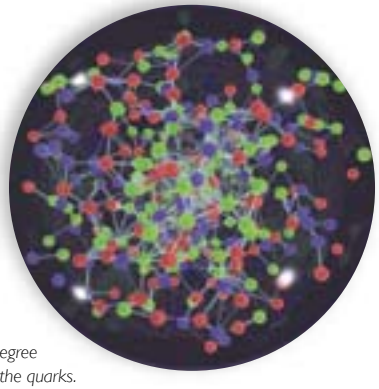
Moving forward

Planned upgrades to RHIC will expand the facility's reach for understanding this liquid phase of the early universe and allow researchers to investigate entirely new but complementary areas of physics.

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

Another upgrade, known as eRHIC, would add a high-energy electron ring to create the world's only electron-heavy ion collider. By colliding heavy nuclei with electrons at energies never before achieved in the laboratory, physicists expect to probe another new form of matter known as a color glass condensate — hypothesized to be the maximum density state that can be achieved by particles subject to the strong force.

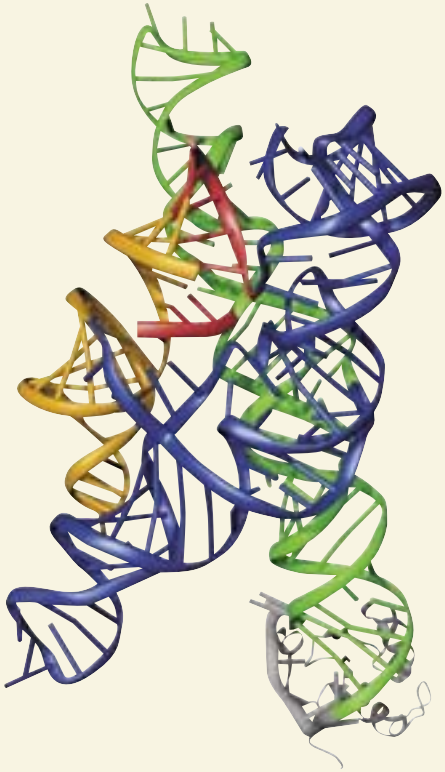
These upgrades exemplify RHIC's flexibility to explore the newest and most intriguing questions about the substructure of matter and the underlying mechanism by which mass is transformed into energy (or energy into mass) in accordance with Einstein's famous equation, $E=mc^2$. Perhaps this research will even ignite a spark in the mind of the next Einstein. ■



RHIC's "perfect" liquid: Green "force lines" represent a high degree of interaction and flow among the quarks.

To speed the analysis, RCF processors will at times be augmented by computing resources from collaborating sites around the world 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. The PHENIX experiment recently used Grid technology to transfer nearly 270 Terabytes of data to the RIKEN Institute in Japan. Additional data now stored at RCF will also be analyzed via the Grid.

RHIC research also demands computing power for theoretical calculations. Two new supercomputers, each capable of 10 trillion arithmetic calculations per second, will contribute to this task.



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, soils — 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 "beam lines" are located at many points around each ring. The beam lines, more than 80 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 — nearly 4,000 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, 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 2,300 guest researchers from approximately 400 universities, laboratories, and corporations.

About 60 percent of these researchers are from either the life or materials sciences, but

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, or to improve human health.

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

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.

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 700 papers each year, all stemming from experiments performed at the NSLS.

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.

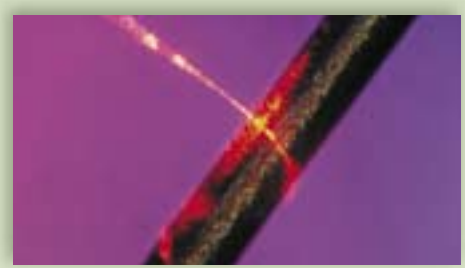
A bird's-eye view of the NSLS, which has been operating since 1982. The NSLS was the first of the "second generation" synchrotrons, built to take advantage of the phenomenon of synchrotron radiation by using it for research.

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.

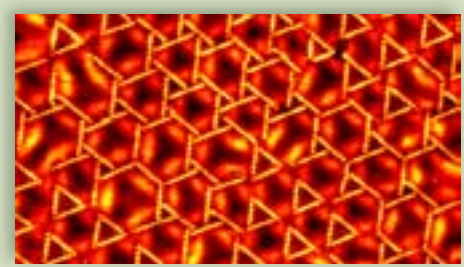
commissioning in 1982, today the practical limits of its performance have been reached. And while newer synchrotrons far surpass the performance of the present NSLS, no synchrotron anywhere in the world — either currently operating, under construction, or in design — will enable scientists to image and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

As a result, Brookhaven has proposed building 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, among others. 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.



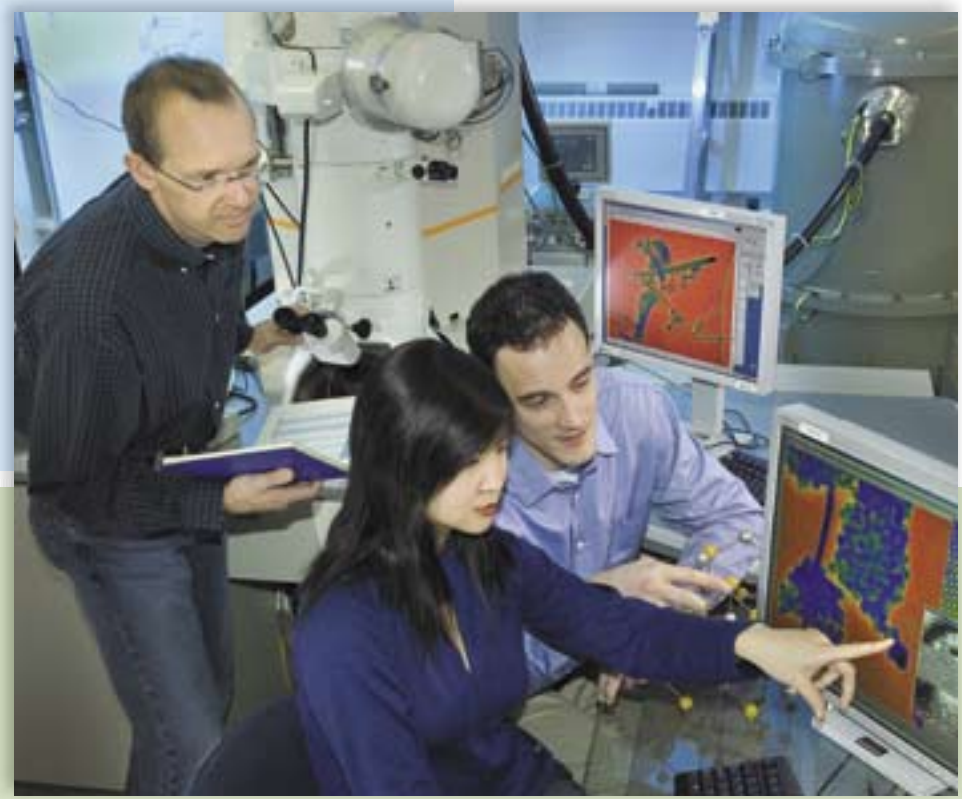
At left, "dancing triangles" are formed by sulfur atoms on a layer of copper, which in turn rests upon a base, or "substrate," of ruthenium. Scientists at NSLS-II and the CFN will study this type of configuration to understand how one metal behaves on top of another, and how sulfur atoms affect that 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

A Window into the Ultrasmall

Nanoscience is the synthesis and study of structures on the scale of atoms, or a billionth of a meter. Materials that are a few microns, or millionths of a meter, in size are currently employed in today's technology, but materials 1,000 times smaller are now being investigated and their potential applications are being explored.

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



Still early in its development, nanoscience has the potential to bring about and accelerate new technologies in energy distribution, drug delivery, sensors, and industrial processes.

In October 2005, the Laboratory held a groundbreaking ceremony for Brookhaven's Center for Functional Nanomaterials (CFN), one of five Nanoscale Science Research Centers to be built at Department of Energy national laboratories. The 94,500-square-foot state-of-the-art laboratory/office facility is expected to attract an estimated 300 researchers

from the Northeast annually, and will be a hub for cutting-edge nanoscience studies.

The CFN will provide researchers with state-of-the-art capabilities to fabricate and study nanoscale materials. Functional materials are those which exhibit a predetermined chemical or physical response to external stimuli. The CFN's focus is to achieve a basic understanding of how these materials respond when in nanoscale form. Nanomaterials offer different chemical and physical properties than bulk materials, and have the potential to form the basis of new technologies.

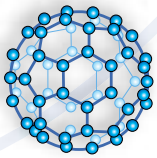
The overarching research goal of the CFN is to help solve the U.S.'s energy problems by exploring materials that use energy more efficiently and by researching practical alternatives to fossil fuels, such as hydrogen-based energy sources and improved, more affordable solar energy systems.

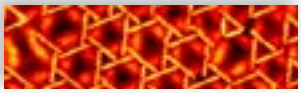
Under that energy banner, CFN studies will focus on three key areas:

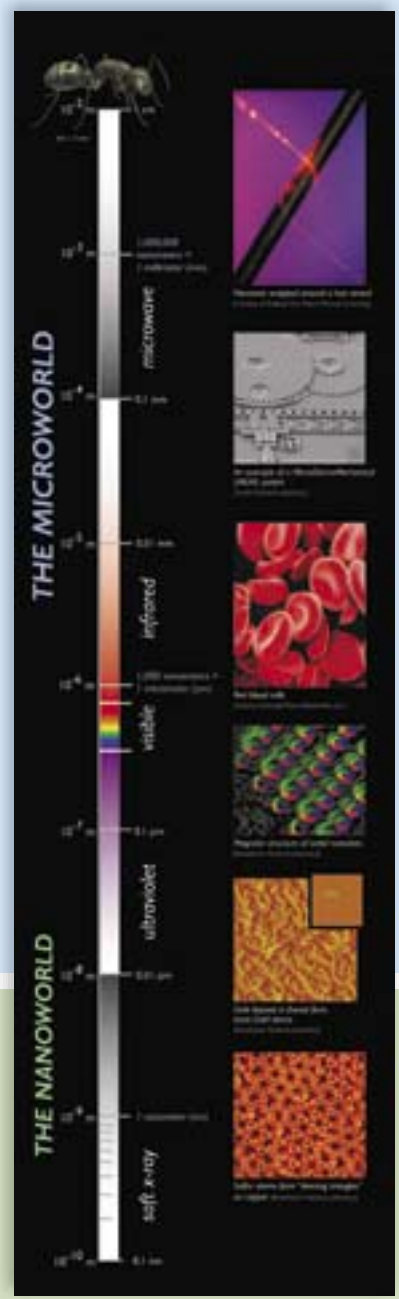
- nanocatalysis, the acceleration of chemical reactions using nanoparticles
- biological and soft nanomaterials, such as polymers and liquid crystals, where specialized design will lead to new functions
- nanoelectronic materials, for unprecedented control of the electron that will lead to new communication and energy control devices

Nanocatalysis

Nanocatalysis uses tiny structures, a few billionths of a meter in dimension, to speed up chemical reactions essential to modern life.







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

Metal-containing nanoparticles are indispensable ingredients in industrial chemical production and energy-related processes.

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 chemical transformations on nanoscale objects.

Biological and soft nanomaterials

Biological and soft nanomaterials include polymers, liquid crystals, and other relatively "squishy" materials that fall into a state between solid and liquid. Nanoscience has allowed understanding and engineering of soft materials properties that mimic those of conventional "hard" materials, yet are lighter, cheaper, transparent, and biocompatible.

One focus of soft nanomaterial research is on the structure and behavior of soft matter deposited onto "nano-patterned" interfaces– surfaces that contain features, such as ridges or grooves, that are a few to several nanometers in dimension. This work will help scientists learn and control how materials transfer forces and electric charge, and how these properties are influenced by the surface on which the film is grown. Such research may lead to flexible computer or television displays. CFN scientists will study liquid crystals, which can self-organize into ordered nanoscale structures. Liquid crystals have applications in many areas, such as television and computer liquid-crystal displays (LCDs) and information storage.

Electronic nanomaterials

Research will focus on understanding how electric charge and magnetism move and interact within nanomaterials. Nanomaterials have characteristics, such as very small one- or two-dimensional geometries, that make them appropriate for advanced electronic applica-

Hydrogen Research

Scientists are investigating ways to combine hydrogen research with nanoscience to find innovative solutions to energy problems. To develop efficient hydrogen batteries and fuel cells for powering cars, homes, and businesses, materials that can store and release a lot of hydrogen are a necessity. Recently, the DOE stated that any such materials slated for use by 2015 must have certain properties – they must be cheap, safe to handle, and have high reactivity rates and storage capacities. At Brookhaven, scientists are attempting to meet that challenge by studying metal hydride compounds, which release hydrogen when reacted with a catalyst. With the DOE

tions. Nanoscale electronic materials research is expected to renovate the energy storage and distribution network in the U.S., as well as transform the electronics industry, producing circuits that are both extremely small and fast.

At the CFN, scientists will focus on studying how electrons transfer between diverse materials. In particular, the properties of carbon nanotubes will be studied. Carbon nanotubes are cylindrical carbon molecules typically a few nanometers wide and up to millions of nanometers long. Carbon nanotubes possess exceptional electric and structural properties for their size, making them attractive for many applications. It has been demonstrated by CFN scientists that a single nanotube can emit ultraviolet light when a voltage is applied across it, creating the world's first electrically controllable light emitter.

The energy-efficient CFN facility will occupy nine square acres and house 150 people. The state-of-the-art building is expected to be completed by 2007, and will attract an estimated 300 researchers from the Northeast annually.

guidelines in mind, they are looking for materials that hold nine percent hydrogen by weight (a relatively large amount) and are reusable.

One of the roadblocks toward the practical use of hydrogen as fuel is finding a hydrogen source that doesn't produce a lot of waste. Natural gas, oil, and coal are good sources, 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.

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

Lab scientists have conducted research on carcinogenesis, using a fish model sensitive to light-induced melanoma. These fish are the only useful model for human melanoma.

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 the 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 — a process that establishes the very identity of cells and, when gone awry, sometimes triggers conditions like cancer.

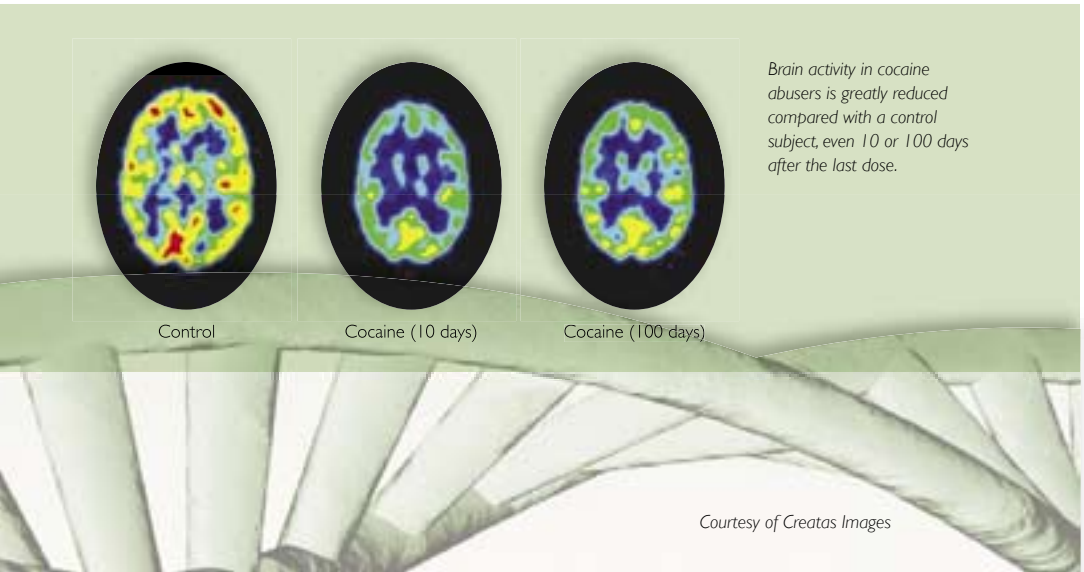
Puzzling proteins

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 and computational methods to understand how they 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 against botulism and Lyme disease.

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. For example, in one Brookhaven effort, 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. 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



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

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 proteins known as enzymes that are 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.

Brookhaven biologists study everything from DNA to proteins and other macromolecules.

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. Magnetic resonance imaging (MRI) allows scientists to visualize brain anatomy at high resolution, allowing the study of site-specific brain function and neurochemistry over time.

With PET and MRI facilities for studying both humans and small animals, Brookhaven researchers can analyze a real-world population, and also test hypotheses triggered by those human studies — and potential treatments —

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.

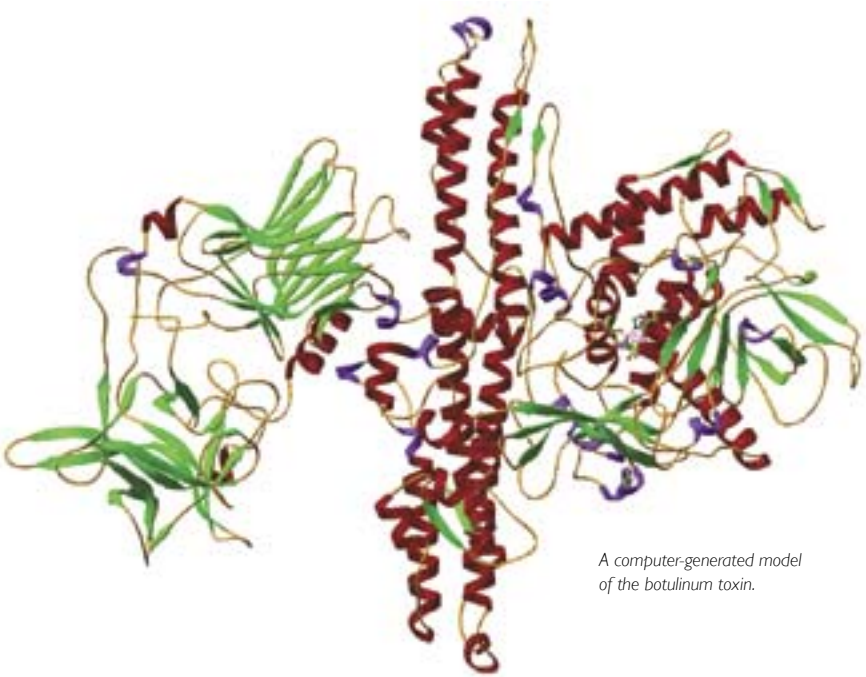
The Brookhaven Linac Isotope Producer creates a variety of radioisotopes — radioactive forms of ordinary chemical elements — that can be used alone or incorporated into "radiotracers" for use in nuclear medicine research or for clinical diagnosis and treatment.

in controlled animal models. In an effort to eliminate the effects of anesthesia used in many animal studies, Brookhaven scientists are even 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 the radiation encountered on long-term missions to the Moon or Mars. These studies on cell and tissue cultures and small animals will help assess risks and design preventive measures.

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 cancer survival rates and minimize debilitating side effects.



A computer-generated model of the botulinum toxin.

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, allowing for cell-culture and small-animal studies 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 their effect 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.

Brookhaven scientists also participate in the Atmospheric Radiation Measurement (ARM) program, a key contributor to national and

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.

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 Carbon Dioxide (CO_2) 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, CO_2-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 systems to elevated carbon dioxide.

Brookhaven's Tracer Technology Center uses perfluorocarbon tracers (PFTs) to study a wide range of atmospheric processes, indoor air quality, identification of gaseous and liquid leak pathways, and most recently, the fate and transport of contaminants that might be released in complex urban canyon environments.

Environmental research and technology is conducted to characterize and remediate hazardous, radioactive and mixed wastes – from basic science through development and deployment of cleanup technologies. Basic research focuses on fate and 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. Still early in its development, nanoscience has the potential to bring about and accelerate new technologies in energy distribution, drug delivery, sensors 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.

Under that energy banner, CFN studies will focus on three key areas: nanocatalysis, biological and soft nanomaterials, and nanoelectronic materials. Nanocatalysis uses tiny particles, a few billionths of a meter in dimension, to speed up chemical reactions essential to modern life. Metal-containing nanoparticles are essential ingredients in industrial chemical production and energy-related processes. Biological and soft nanomaterials include polymers, liquid crystals,

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.

and other relatively "squishy" materials that fall into a state between solid and liquid.

Nanoscience has allowed understanding and engineering of soft materials properties that mimic those of conventional "hard" materials, yet are lighter, cheaper, transparent and biocompatible. Nanoelectronic materials research will focus on understanding how electric charge and magnetism move and interact within nanomaterials. Nanomaterials have characteristics, such as very small one- or two-dimensional geometries, that make them appropriate for advanced electronic applications. Research on nanoscale electronic materials is expected to renovate the energy storage and distribution network in the U.S. as well as transform the electronics industry, producing circuits that are both extremely small and fast.

Brookhaven Lab's energy scientists are also working to advance alternative energy technologies, which will offer energy solutions without the carbon dioxide-increasing effects of fossil fuels. Researchers are examining the potential of biodiesel, a biodegradable, nontoxic, renewable 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 in ways that will be both useful and difficult for terrorists and others seeking nuclear materials to exploit.

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.

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 highly enriched uranium and leads the development and deployment of safeguards operational monitoring systems such as CCTV systems activated by personnel movement and vault access door alarms at Russian nuclear facilities.

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

The International Safeguards Project Office provides technical oversight and management of over $15 million per year in technical support and equipment for improving International Atomic Energy Agency (IAEA) safeguards.

To slow the transfer of weapons knowledge to rogue states or terrorist groups, Brookhaven's 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.

Educational Programs

Investing in America's Future

More than 25,000 elementary and secondary school students and teachers, and several hundred college students and faculty members, come to Brookhaven National Laboratory each year for programs offering hands-on science and invaluable career experience. This educational outreach is just one reason the Lab was honored with the Long Island Workforce Builders' Award in 2004.

Brookhaven Lab offers learning opportunities for students of all ages:

- The Science Learning Center, active nearly every day of the year, hosts dozens of schools for students to experience hands-on inquiry-based science related to Lab research.
- Thousands more elementary students compete each year in local school science fairs, with winners at each grade level entered in the Brookhaven National Laboratory Elementary School Science Fair.
- Middle school students compete in the Magnetic Levitation (MagLev) Vehicle Contest, in which they design, construct and test a magnetic levitation vehicle.
- High school students can participate in research experiences, or compete in a regional Science Bowl and/or Brookhaven's Bridge Building Competition, in which students design and build basswood bridges that must hold thousands of times their weight to come out winners.
- To help our future workforce transition from being students to scientists, the Lab offers research internships for undergraduate, graduate, and postdoctoral students and faculty in scientific fields.

Thousands of students come to Brookhaven each year for hands-on science and research experience.

One of Brookhaven Laboratory's educational goals is to establish strong collaborations with colleges and universities in our region. One example is when several dozen students from the New York City College of Technology and Medgar Evers College participated in the March 2005 Urban Dispersion Program in New York City, assisting atmospheric researchers studying the movement of tracer gases in urban winds. The Laboratory also has ongoing collaborations with Hofstra and Stony Brook Universities, New York University, and the Dowling College Center for Minority Teacher Development and Training.

For more information on these programs and others, visit www.bnl.gov/scied.

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