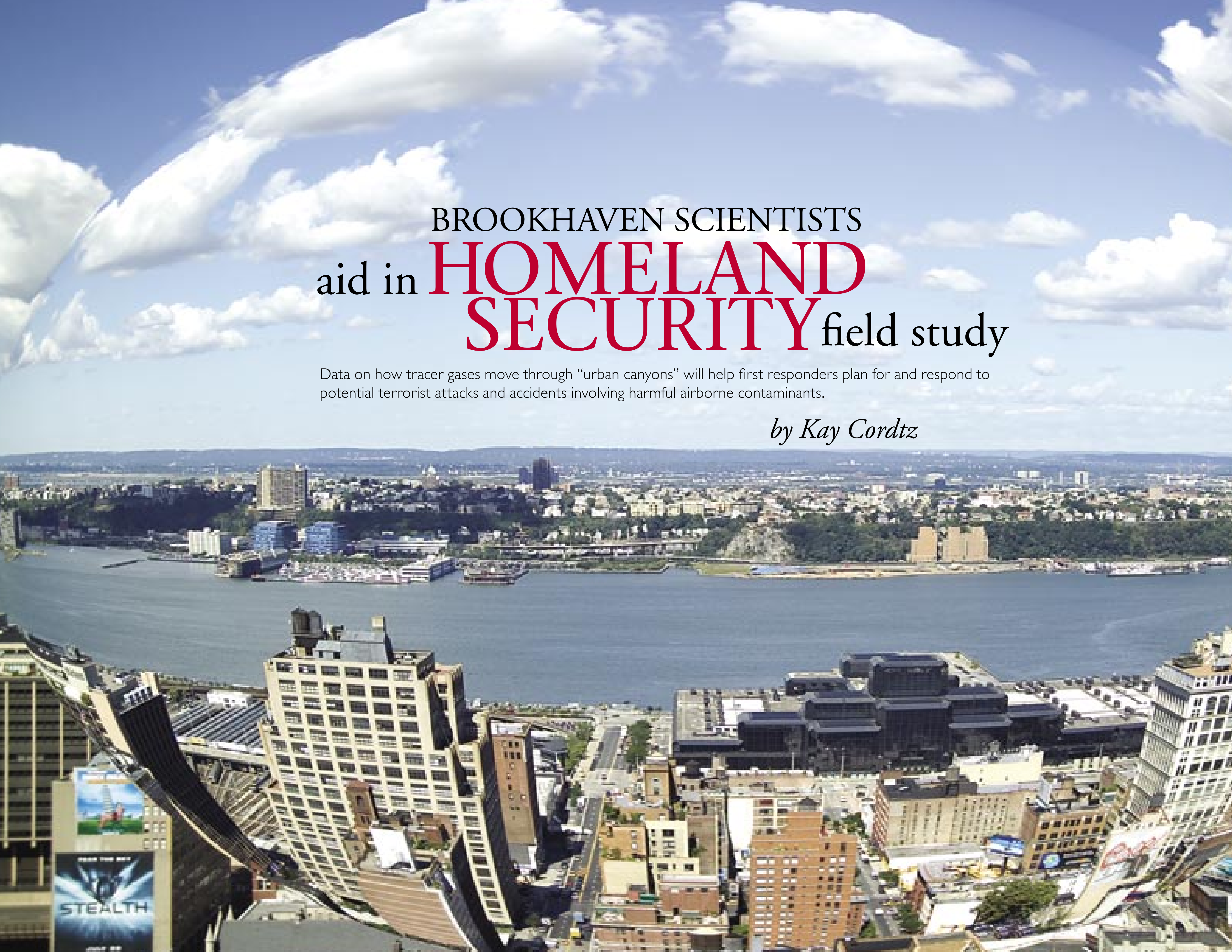
BROOKHAVEN SCIENTISTS aid in HOMELAND SECURITY field study

Data on how tracer gases move through "urban canyons" will help first responders plan for and respond to potential terrorist attacks and accidents involving harmful airborne contaminants.

by Kay Cordtz



Winter 2006

If an industrial accident or a terrorist act released dangerous contaminants into the atmosphere in New York City, the city's first responders would have to decide quickly whether people should shelter in place or be evacuated, and what evacuation routes should be considered. In the future they will be aided in making those decisions by information gathered during the New York City Urban Dispersion Program field studies, conducted in the city's urban canyons in March and August of 2005.

The field studies were part of the $10 million Urban Dispersion Program, sponsored by the U.S. Department of Homeland Security, the Defense Department's Defense Threat Reduction Agency, the Environmental Protection Agency (EPA), and the Department of Energy (DOE). Data gathered from the study will help improve existing models of how a gas or chemical release might move around Manhattan's tall buildings and canyons. Emergency management, law enforcement, and intelligence personnel use these models to plan for, train for, and respond to potential terrorist attacks and accidents involving harmful airborne contaminants.

"We are interested in how contaminants behave in very complicated urban canyon environments like New York City," said Paul Kalb of Brookhaven Lab's Environmental Sciences Department. "Anyone who's been to the city has observed that the flags on one side of the street may be blowing one way while those on the other side of the street are blowing in the complete opposite direction."

The March field study consisted of two days of detailed meteorological observations while scientists released a colorless, odorless, harmless "tracer" gas near Madison Square Garden. In six days of August experiments, the scientists released either perfluorocarbon (PFT) or sulfur hexafluoride at a number of outdoor locations. On several of those test days, small amounts of the gases were also released and tracked inside a Manhattan office building and in several subway stations.

"Many people may not realize that a few days of actual experimentation requires months of planning and preparation," said Brookhaven's John Heiser, the tracer team's principal investigator for the project. "Hundreds of samplers, thousands of sample

MEET THE STUDENTS

The UDP field studies offered a rare opportunity for hands-on training of future engineers and environmental scientists. During the March tests, Brookhaven's Office of Educational Programs (OEP) partnered with Brooklyn's New York City College of Technology (City Tech) and Medgar Evers College to recruit students to collect samples and assist in setting up equipment. Approximately 50 students from schools across the country were part of DOE-sponsored internship programs that included UDP fieldwork.

City Tech's Princilla Francis and Doniche Derrick from Medgar Evers College worked on both the winter and summer experiments. In March, both were stationed on street corners near the Madison Square Garden release points with handheld air samplers. At proscribed intervals, they would collect and record air samples. While both study periods featured extreme temperatures out on the Manhattan streets, most students who participated in both studies preferred the summer heat.

Students from schools across the country helped set up equipment on New York City streets and track tracer gases.

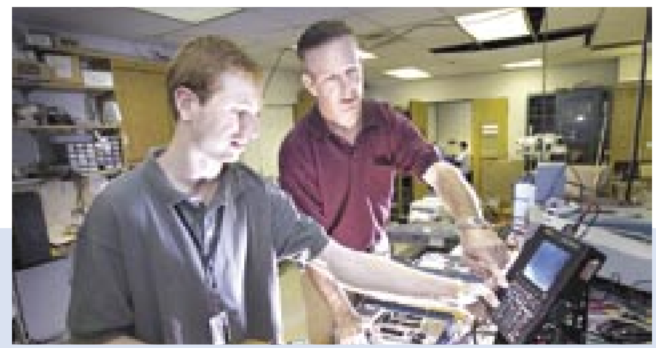
tubes, scores of approvals, in addition to the placement of meteorological equipment, route planning and many other details all require a massive, unseen effort by all involved."

"Everyone worked in perfect harmony and did so on a very tight schedule," he said, adding that he was impressed by the professionalism of the Brookhaven team. "I also enjoyed the spirit of cooperation shown to us by the various city, state, and federal agencies who assisted us."

On each study day, scientists and students tracked the winds and the dispersion of the colorless, odorless, and non-toxic gases with a variety of samplers, some located on rooftops, other placed in baskets attached to lampposts. Mobile air samplers were also carried by students positioned on street corners, and by EPA employees who walked along assigned routes, periodically capturing a sample of air from the invisible plumes. A DOE van equipped with state-of-the-art analytical equipment cruised the streets of the midtown area providing near "real-time" data on the plume location and concentration. Built and calibrated at Brookhaven, the van-mounted instrument was developed for Keyspan to locate leaks in underground pipes. At the end of each test day, the tracer team members dismantled all the equipment and collected samples for analysis back at the Lab.

R. Michael Reynolds and his team from the Earth Science Systems Division provided precise meteorological measurements.

"Computer models on many scales and with resolutions ranging from kilometers down to one meter will be evaluated with the meteorological and dispersion data we



"March was beyond freezing," said Francis. "Luckily there was a Chinese restaurant on my corner where I could warm up between sample periods."

Derrick, who grew up in St. Vincent and the Grenadines, now hopes to earn a Ph.D in environmental chemistry.

"The Urban Dispersion Program helped me with my career goals because I see myself doing similar research in the future."

"We really appreciated the assistance that the student volunteers provided, said Paul Kalb. "While it was a learning experience for them, their help in deploying and collecting samples enabled us to significantly enlarge the amount of data collected."

One student in the summer internship program made a significant contribution to the refinement of the technology used in the study. John Cornwell of Duke University developed an enhanced base component for the Brookhaven Atmospheric Tracer Sampler (BATS), used to actively sample released

Far left: Doniche Derrick, who is studying environmental science at Medgar Evers College in Brooklyn. Middle: tracking the progress of the experiment on a Manhattan street. Above: John Cornwell from Duke University with mentor Ray Edwards.

provide here," Reynolds said. "It is essential that our meteorological data is as good as it can be, because once a model is shown to replicate our measurements, it can be applied with greater confidence to the entire neighborhood."

Additional tests are scheduled for the spring of 2006. These experiments will add to the team's knowledge of how weather conditions affect air dispersion. Previous field studies were conducted in Salt Lake City in 2000 and Oklahoma City in 2003.

More information is available at http://urbandispersion.bnl.gov/index.stm

perfluorocarbon tracer (PFT) by pumping air through adsorbent-filled tubes. Under the supervision of his mentors, John Heiser and Ray Edwards of the Environmental Sciences Department, Cornwell helped develop a cost-effective replacement for the electronic control system previously used in the BATS, an integral part of the Lab's PFT technology.

Cornwell first discovered Brookhaven when he entered the Lab's bridge building contest while a senior at Huntington High School. He began working on the BATS project as a summer intern at Brookhaven last year. An electrical engineering and computer science major, he plans a career in robotics, which uses similar control and feedback systems as the ones he designed for the BATS.

"At school, I build things but they're all pretty trivial and have been done a thousand times," Cornwell said. "It was nice to do something important."

"One of our objectives at the Office of Educational Programs is to educate the next generation of scientists and engineers," said OEP's Noel Blackburn.

Above left: Brookhaven scientists collect data from the roving van. Above right: City Tech student Princilla Francis monitors a PFT release.

MULTIPLE AGENCIES COLLABORATE TO PREPARE FOR DISASTER

Funded by the Department of Homeland Security, with additional support from the Defense Threat Reduction Agency of the Department of Defense and the Department of Energy, the Urban Dispersion Program's March fieldwork was coordinated by DOE's Pacific Northwest National Laboratory (PNNL) through the New York City Office of Emergency Management. The primary field efforts were accomplished by Brookhaven National Laboratory, with support from PNNL, the U.S. Environmental Protection Agency, the U.S. National Weather Service, Stony Brook University, Harvard University, and Stevens Institute of Technology. For the August studies, the collaborator list grew to include Argonne National Laboratory, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, two divisions under National Oceanic and Atmospheric Administration Air Resources Laboratory, and the Naval Research Laboratory.

Perfluorocarbon tracer being dropped through a syringe onto a screen where a fan will release it into the air.

At Brookhaven, all three divisions within the Environmental Sciences Department collaborated on the project.

"Our ability to field multidisciplinary teams of scientists and technicians to support a field exercise is one of the Department's strengths, a strength that sets us apart from many other scientific institutions", said department chair Creighton Wirick. "The Urban Dispersion Program is an example of what we do best."

Jerry Allwine, a staff engineer at PNNL, coordinated the efforts of all the laboratories and agencies. "Success of the large field studies conducted in New York City were critically dependent on the professional and open collaboration of all participants," Allwine said.

TURNING OFF ALCOHOL ABUSE

Studies of brain circuits and neurotransmitters in "alcoholic" animals suggest new ways to modulate drinking, offering hope that such treatments may one day help human alcoholics overcome their addiction.

by Karen McNulty Walsh

"*Stopping* alcohol abuse will never be as easy as turning on or off a 'switch,'" says Panayotis (Peter) Thanos, a neuroscientist at the U.S. Department of Energy's (DOE's) Brookhaven National Laboratory. "But understanding the brain's reward circuits and finding ways to modulate them could play a role in developing successful treatments."

His research — funded by the Office of Biological and Environmental Research within DOE's Office of Science, the National Institute on Drug Abuse, the National Institute on Alcohol Abuse and Alcoholism (NIAAA), and others — shows that he's on to something. Through brain-imaging and behavioral studies in animals, Thanos and his colleagues have demonstrated that a variety of brain receptors play a role in excessive drinking — and that changing the levels of these receptors or their ability to send pleasure/reward signals can drastically affect drinking behavior.

"These studies improve our understanding of the mechanism or mechanisms of alcohol addiction and strengthen our hope that these methods might one day be developed into treatments to help people addicted to alcohol," Thanos said.

The pleasure of dopamine

One of the first brain chemicals Thanos' group investigated was the neurotransmitter dopamine. Many studies have shown that alcohol, like all addictive drugs, increases the brain's production of dopamine, which sends a strong reinforcing signal of pleasure and reward.

Over time, however, the brain responds to this constant dopamine stimulation by "down-regulating," or decreasing, the number of a particular type of dopamine receptors — nerve cell proteins to which the neurotransmitter must bind to send the pleasure signal. Alcoholics then may drink more and more to try to override this blunted pleasure response. And people with initially low levels of these dopamine receptors (known as D2 receptors) might be particularly prone to abuse alcohol or other drugs.

If this is true, Thanos hypothesized, then perhaps increasing the level of D2 receptors would decrease drinking.

Thanos and his group tested the idea by delivering the gene for D2 receptors directly into the brains of rats that had been trained to drink large quantities of alcohol. This "gene therapy" temporarily increased the rats' levels of D2 receptors and turned heavy drinkers into light drinkers, and rats who initially drank less into near teetotalers.

"These studies improve our understanding of alcohol addiction and strengthen our hope that these methods might one day be developed into treatments to help people addicted to alcohol."

"When you see a rat that chooses to drink 80 to 90 percent of its daily fluid as alcohol, and then three days later it's down to 20 percent, that's a dramatic drop in alcohol intake — a very clear change in behavior," Thanos said.

This same approach also worked to decrease alcohol consumption/preference in rats with a genetic preference for drinking very high levels of alcohol, and in genetically engineered transgenic mice with varying levels of dopamine D2 receptors.

Receptor blockade

In another study, Thanos' group tested the idea that blocking the activity of a different kind of dopamine receptor (D3) in rats with a genetic preference for alcohol might reduce the rats' feelings of pleasure in response to drinking — and therefore decrease the amount they drank. This time they used a drug that binds to the D3 receptor, preventing dopamine from binding.

The highest doses did indeed decrease the amount of alcohol the animals drank, supporting the idea that such a D3-receptor blockade could possibly be used as a treatment.

Most recently, Thanos has tried this receptor-blocking strategy using a drug that binds to and blocks the brain's cannabinoid receptors, known as CB1. These brain receptors are directly involved in triggering the reinforcing properties of marijuana and were hypothesized to also play a role in stimulating reward pathways in response to alcohol.

Neuroscientist Panayotis (Peter) Thanos (above) tests laboratory animals' preference for alcohol and how much they imbibe in cages set up with two bottles: one with regular drinking water and one with a winelike concentration of alcohol.

When given a choice between alcohol (at a concentration approximately equivalent to that of wine) and water, mice with normal levels of CB1 receptors showed more of a preference for and drank more alcohol than mice with moderate or no CB1 receptors. After receiving the CB1-blocking drug, the mice with normal and moderate levels drank significantly less alcohol than before the treatment.

These studies suggest new strategies that might be employed in the fight against alcohol abuse in humans, a condition that affects more than 11 million people in the U.S. alone. They may also offer ways to combat other addiction problems.

MEET PETER THANOS

Peter Thanos traces his interest in dopamine back to a psychology class on the brain and behavior, which he took while an undergraduate at Queen's University in Canada. Intrigued by the relationship between brain chemistry and behavior, he volunteered to work in the lab with his professor and got hooked on research.

As he continued his studies, he became aware of the groundbreaking research linking dopamine with addiction going on at Brookhaven Lab using positron emission tomography (PET) by Nora Volkow, Gene-Jack Wang, and Joanna Fowler. After completing his Ph.D. at Eastern Virginia Medical School, he went to Stony Brook University to work with researchers who, in collaboration with the Brookhaven neuroimaging group, were beginning to develop the new microPET technology for small-animal studies. He joined the Lab as a neuroscientist in 1999.

As a member of the Lab's Center for Translational Neuroimaging at BNL and NIAAA Laboratory of Neuroimaging, he has been instrumental in assessing and using microPET in addiction research. Thanos' Behavioral Neuropharmacology Lab has conducted proof-of-principle experiments to demonstrate microPETs usefulness as a research tool to complement a variety of different behavioral studies in rodents.

He's also made a point of extending the research opportunity he had as a student to three or four undergraduate students each semester — and sometimes more in the summer. "Even if students have had no prior research experience," he says, "they can produce great work. The key is to find the students who are motivated and interested."

With many of these students going on to medical school, graduate school, dental and veterinary schools, it's clear that Thanos' ability to spot and spark that motivation pays off for the students as well as their mentor.

When not at the lab, Peter enjoys spending time with his wife, Renie, and daughter Kiki. With a wink, Thanos says Kiki has already expressed interest in doing a pre-school science project in a few years!

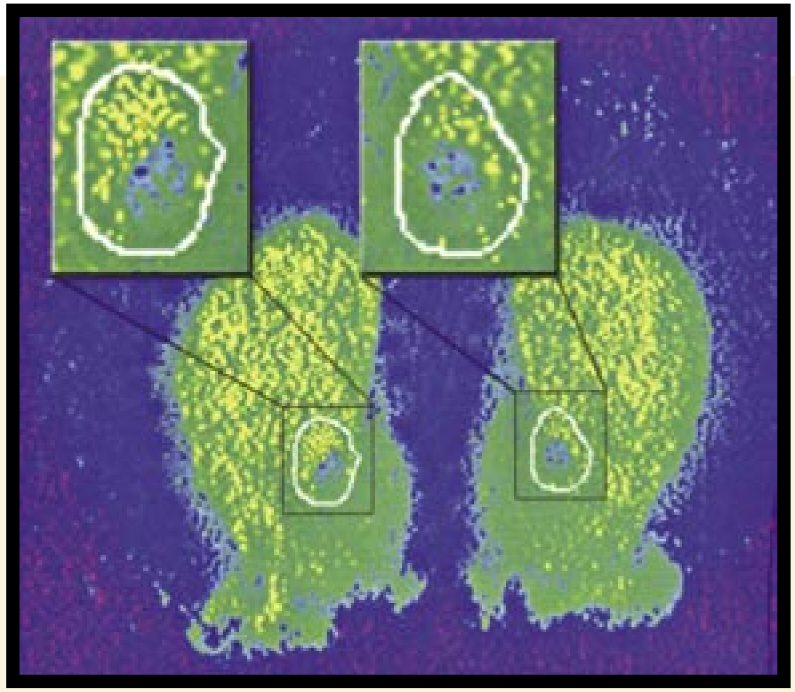
For more information: Peter Thanos, (631) 344-7364 or thanos@bnl.gov

BRAIN IMAGES LINK BEHAVIOR, BIOCHEMISTRY

An essential element in pointing the way to new treatment strategies for alcoholism and other addictions is the brain-imaging research that reveals the underlying biochemistry of addictive disorders. The images obtained using techniques such as positron emission tomography (PET) and magnetic resonance imaging (MRI) allow researchers to measure levels of various chemicals — drugs, neurotransmitters, or their receptors, for example — and study how these biochemical variables correlate with behaviors such as excessive drinking or drug-seeking behavior.

These brain-imaging techniques are a direct outgrowth of the Department of Energy's long-term support of basic physics research: Both MRI and PET owe their existence to insights gained by physicists building particle accelerators and detectors for investigations into the fundamental nature of matter and energy. MRI relies on detecting differences in how protons in various tissues bend and relax in magnetic fields, while PET detects positrons, a type of radioactive subatomic particle, emitted by certain radioactive isotopes. Chemists can attach these isotopes to chemicals of interest — for example, a chemical that binds to dopamine receptors — to produce radioactively labeled "tracers" detectable by the PET scanner. Radiotracers can also be used to monitor the levels of neurotransmitters or receptors in tissue samples using a technique known as autoradiography.

Using PET and MRI scanners for both human and small-animal studies, scientists at Brookhaven's Center for Translational Neuroimaging are poised to make critical discoveries linking biochemical changes to behaviors such as drug addiction.



Injecting the gene for dopamine D2 receptors into the left side of this rat's brain increased expression of dopamine D2 receptors (yellow and blue dots in inset) on that side compared with the right side, which did not receive the "gene therapy." Increasing dopamine receptor numbers may help treat alcoholism.

These physics-derived tools have helped researchers detect the changes that occur in neurotransmitters and receptor levels in response to drug use and abuse. For example, in one of Brookhaven neuroscientist Peter Thanos' gene-therapy experiments, he used autoradiography to confirm that injected genes for dopamine D2 receptors were indeed expressed, or used to increase receptor numbers, in the brains of his experimental rats. And using a "microPET" scanner developed specifically for studies in rodents, Thanos demonstrated the technique's ability to measure subtle differences in dopamine receptor levels between genetic strains of mice.

Using PET and MRI scanners for both human and small-animal studies, scientists at Brookhaven's Center for Translational Neuroimaging are poised to make critical discoveries linking biochemical changes to behaviors such as drug addiction, and translate this knowledge into successful new treatment strategies.

ALCOHOLISM affects more than 11 million people in the U.S. alone.

following nature's lead

SCIENTISTS *seek* *better* CATALYSTS

Theoretical investigations of a bacterial enzyme by Brookhaven Lab scientists have revealed a catalytic complex with higher predicted chemical reactivity than that of industrial catalysts currently in use. This research sparks hope for cleaner, more efficient hydrogen production.

by Karen McNulty Walsh

Theoretical investigations of a bacterial enzyme by Brookhaven Lab scientists have revealed a catalytic complex with higher predicted chemical reactivity than that of industrial catalysts currently in use, sparking hope for cleaner, more efficient hydrogen production.

"We wanted to establish how the biological system works, and then compare it with materials currently used in industry for these chemical processes — and we found that the biological system is indeed better," said Brookhaven chemist Jose Rodriguez. "The challenge now is whether we can reproduce this more efficient system for use in an industrial setting."

Added former Brookhaven biochemist Isabel Abreu, "We are learning from nature what is working in nature, and then trying to use that for the design of other processes."

The complex studied is a particular configuration of iron and sulfur atoms and the surrounding amino acids in an enzyme isolated from *Desulfovibrio desulfuricans*, a bacterium that can live in sulfur-rich environments without oxygen. The specific chemical function of the iron-sulfur complex in this bacterial enzyme is not yet known, but similar complexes of iron and sulfur play an important role in many enzymes, catalysts, and sensors.

Earlier studies by Abreu and coworkers suggested that, unlike iron-sulfur complexes found in other proteins, which are usually bound to four surrounding cysteine amino acids, the iron-sulfur complex from *D. desulfuricans* appeared to have only three bound cysteine neighbors.

"This opened up the possibility of interesting chemical properties," Abreu said.

Rodriguez and Abreu's first step was to use "density functional calculations" to establish if a structural model previously proposed by Abreu for the three-cysteine configuration was theoretically stable enough to exist in nature, and then to investigate how that structure might influence the reactivity of the iron-sulfur complex. In agreement with the predicted model, they found that the three-cysteine structure was indeed stable, leaving the iron-sulfur complex — located in a surface pocket of the bacterial enzyme — exposed on one side.

Next, the scientists tested the theoretical chemical reactivity of the complex with a variety of reactants important in either the production of hydrogen or the control of air pollution. Finally, they compared those results with the reactivity of other iron-sulfur-complex catalysts, including those that are currently used for these catalytic processes in industry.

"Our calculations predict that this particular unit should be four to five times more reactive than the catalysts currently used, which is very significant," Rodriguez said. "With this structure, the key is that you have an open side of the molecule to bind things and do chemistry because it is missing one cysteine neighbor. You can make it react with other things."

"We wanted to establish how the biological system works, and then compare it with materials currently used in industry for these chemical processes—and we found that the biological system is indeed better."

The next challenge will be to see if the scientists can use the enzyme or synthesize a mimic of its cysteine-iron-sulfur center – an engineering project on the nanoscale (i.e., measured in billionths of a meter).

"Even if we can't use this exact enzyme, then maybe we could create other molecules or particles with this type of structure using synthetic methods," Abreu said.

This type of work – synthesizing, studying, and fine-tuning the properties of nanoscale catalytic systems – will be a major research focus at Brookhaven Lab's Center for Functional Nanomaterials (CFN), currently under construction (see below).

"Once you have the nanoparticles, you can do the testing with the catalytic reactions," Rodriguez said. "Then, if they work the way the theory predicts, you have something that is really useful."

The research was funded by the Office of Basic Energy Sciences within the U.S. Department of Energy's Office of Science. The CFN at Brookhaven Lab is one of five nanoscience research centers being constructed and funded by DOE's Office of Science.

Brookhaven Lab's Center for Functional Nanomaterials (CFN),

ENERGY SOLUTIONS AT THE NANOSCALE

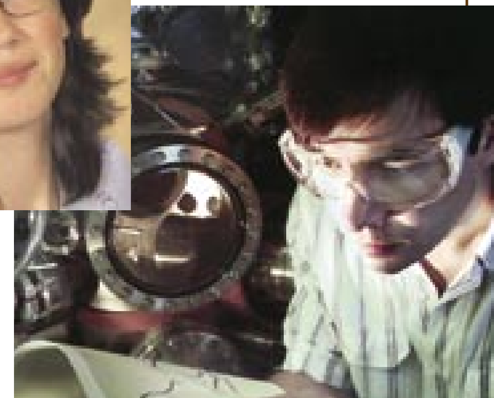
The overarching research goal of the Brookhaven Center for Functional Nanomaterials (CFN) is to help solve our nation's energy challenges by exploring materials that use energy more efficiently and by researching practical alternatives to fossil fuels, such as hydrogen-based energy sources and improved, 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; and **nanoelectronic materials,** for unprecedented control of the electrons that will lead to new communication and energy control devices.

1. **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.

2. **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.

3. **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.



Isabel Abreu, Jose Rodriguez, and students working in the chemistry lab.

MEET JOSE RODRIGUEZ AND ISABEL ABREU

Born and raised in Venezuela and Portugal, respectively, both Jose Rodriguez and Isabel Abreu traveled a long way in the name of science to become successful researchers, following their passion for chemistry to Brookhaven National Laboratory.

Rodriguez' research career began at Simon Bolivar University in Caracas, Venezuela, where he received bachelor's degrees in chemistry and chemical engineering, and then a master's degree in theoretical chemistry. From there, he made the long trip to Indiana University in Bloomington, Indiana, to earn a Ph.D. in physical chemistry. His research next brought him to Texas A&M University for postdoctoral work and then, finally, to Brookhaven, where he joined the Lab's scientific staff in 1991.

As Rodriguez settled in at Brookhaven, Abreu began her bachelor's degree in biochemistry at the Universidade de Lisboa in Lisbon, Portugal, finishing in 1996. She completed her Ph.D. in biochemistry at the Universidade Nova de Lisboa in 2002. Then, she crossed the Atlantic to become a postdoctoral researcher at Brookhaven, where she worked from 2003 until mid-2005 (she is currently a postdoctoral fellow at The Rockefeller University in New York).

While at the Lab, Rodriguez and Abreu collaborated on several projects, investigating the catalytic properties of nanoparticles and metal-compound surfaces and comparing them with those of biological enzymes. They co-wrote three scientific papers on catalysis.

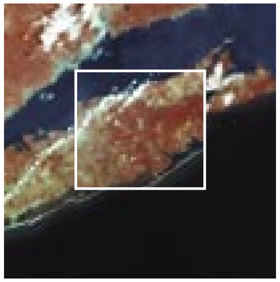
"We are learning from nature."

In his own work, Rodriguez often uses synchrotron-based techniques, such as the tools available at the National Synchrotron Light Source (see article page 18), to study catalytic materials. At Rockefeller, Abreu is using a model plant genetic system to investigate how, at the molecular level, plants perceive and respond to changes in their environment, such as droughts.

When not studying catalyic activity, Rodriguez takes part in plenty of physical activity, participating in baseball, soccer, and football. He also enjoys music and literature. Now working and living in the big city, Abreu says she doesn't have much free time, but, when she can, she likes to go to New York's many museums and theaters.

For more information: Jose Rodriguez, (631) 344-2246 or rodrigez@bnl.gov

The primary research goal of the Brookhaven Center for Functional Nanomaterials is to help solve our nation's energy challenges.



A "PERFECT" LIQUID at RHIC

Evidence to date suggests that gold-gold collisions at the Relativistic Heavy Ion Collider (RHIC) are creating a new state of hot, dense, matter different and even more remarkable than had been predicted.

by Karen McNulty Walsh

Above: RHIC, 2.4 miles in circumference, is visible as the tiny circle on this satellite image of eastern Long Island.

Since 2000, the Relativistic Heavy Ion Collider (RHIC) has been performing beyond expectations. Built and operated with funding from the U.S. Department of Energy's Office of Science, RHIC has produced 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 "microscope" peering deep into the inner space of atomic nuclei, RHIC also effectively serves as a "telescope," looking 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 circulating at nearly the speed of light collide head on, developing enormous energy density in a tiny volume.

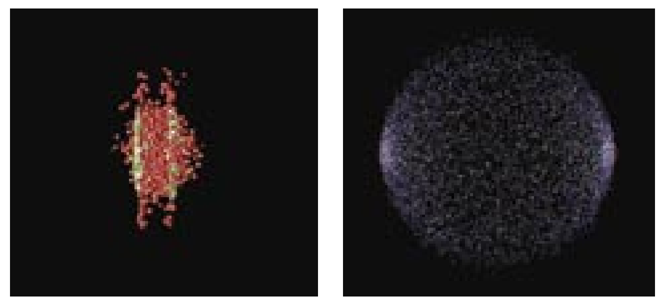
Under these conditions, the quarks and gluons that make up protons and neutrons in ordinary atomic nuclei are expected to be free for a fleeting instant — just as scientists believe they were microseconds after the Big Bang, before joining together to form protons, neutrons, and eventually, atoms, stars, planets, and people. This is much farther back in time than any telescope surveying the sky will ever be able to reach. 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.

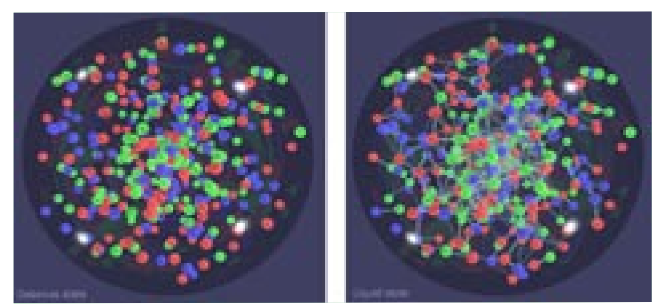
Liquid universe

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.

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.



At nearly the speed of light, two gold ions flatten and collide (far left). The energy of the collision creates a spray of new particles (near left) with trajectories and other characteristics that offer clues about the state of matter created on impact.



RHIC was expected to create a gaseous state of free-flowing quarks (near right), but the matter created behaves more like a liquid with a high degree of interaction and collective motion, or "flow," represented by the force lines between quarks (far right).

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. It fact, the high degree of collective interaction and rapid distribution of thermal energy among the 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 and fundamental questions about the substructure of matter.

Special magnets with a corkscrew-like design, known as Siberian Snakes, regularly flip the spins of protons during RHIC spin experiments to keep the protons in the beam aligned, or polarized.

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 RHIC’s most recent run, the experiments collected a total of 675 Terabytes of data — enough to fill roughly 1 million compact discs. Much of this 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.

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. Known as QCDOC machines, for quantum chromodynamics (QCD) on a chip, these supercomputers perform the complex calculations of the theory that describes the interactions of quarks and gluons and the force that holds atomic nuclei together.

SPINNING IN ANOTHER DIRECTION

In addition to investigating the primordial properties of the universe, 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 a particle’s intrinsic angular momentum. Using specialized magnets known as Siberian Snakes to keep the spins of protons aligned, physicists at RHIC can collide beams of these “polarized protons” to examine the structure underlying the proton’s spin. This research will address a decades-old mystery about what constituents or dynamics inside the proton account for its spin. RHIC is a unique tool for attacking this deep puzzle and the answers will provide important new insights into the structure and interactions of subatomic particles.

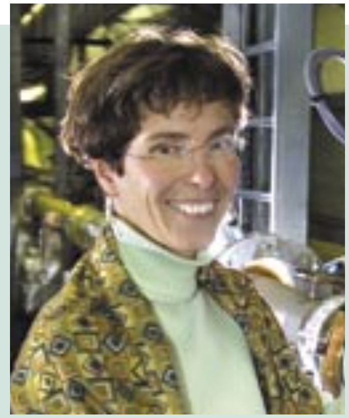
Peter Horton

RHIC was built as the largest link added to a chain of pre-existing Brookhaven accelerators, each of which helps to accelerate heavy ions or protons to nearly the speed of light.

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

For more information: http://www.bnl.gov/RHIC/

During RHIC's most recent run, the experiments collected a total of **675 Terabytes** of data — enough to fill roughly **1 million compact discs.**



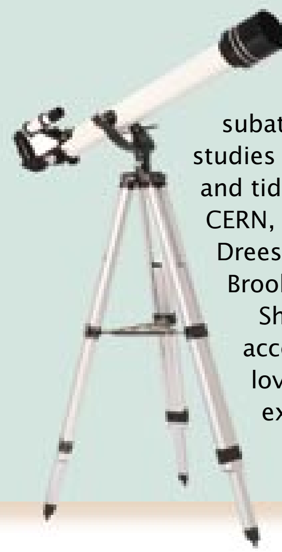
MEET ANGELIKA DREES

It takes many hands and minds to run the Relativistic Heavy Ion Collider (RHIC) and its four detectors. On the team of more than 1,000 scientists, engineers, and support staff, each person brings a unique combination of skills and insight to advance the RHIC program, with many playing multiple roles.

Angelika Drees is one such person. She's had a hand in both building and running the machine, and has been involved in the two main research missions at RHIC — exploring matter as it existed in the early universe and searching for the source of proton spin. A young mother, she also serves as a role model to high school girls who visit the Lab each year.

This isn't surprising considering Drees wanted to be an astronaut as a teenager, but was told there were no women in that field. Not to be deterred, she reasoned that by becoming a scientist, she could eventually accompany astronauts on their missions. Her growing interest in astronomy and the origins of the universe — and a waning desire for space travel — eventually led her to physics.

While majoring in high-energy physics at the University of Wuppertal in her native Germany, she volunteered as a counselor for disadvantaged children at a nearby horse farm, picking up skills as a blacksmith. Supporting herself as a blacksmith, she earned a master's degree from Wuppertal in 1992.



Then she moved from bending metal horseshoes to complex physics experiments and, eventually, to bending beams of subatomic particles in colliders. Participating in studies on how factors such as nearby electric trains and tides affected the energy and motion of beams at CERN, the European laboratory for particle physics, Drees earned her Ph.D. in 1997, and then came to Brookhaven to work on RHIC.

She now divides her time between running the accelerator and working on the experiments. "I love having the opportunity to work on both experiments and accelerator problems," she says.

NANOTUBES IN A NEW LIGHT

From flat-panel television displays to fuel cells to building materials, extraordinarily strong nanotubes contain properties applicable to new technologies

by Laura Mgrdichian

Nanotubes are tiny cylindrical molecules just a few nanometers (billionths of a meter) in diameter, but their potential for new technologies is vast. They are extraordinarily strong, conduct electricity well, and can even emit light. These properties are suitable for many applications, from flat-panel television displays to fuel cells to building materials. But nanotubes must be extensively studied before they can be used in industrial applications.

At the National Synchrotron Light Source, a group of scientists has pioneered a way of using x-ray light to investigate the two main types of carbon nanotubes: multi-walled nanotubes (MWNTs), which resemble cylinders concentrically nested together like Russian dolls, and single-walled ("un-nested") nanotubes (SWNTs).

The technique is known as "near-edge x-ray absorption fine structure," or NEXAFS, and it has been used for years to study the properties of various materials – specifically, to investigate the materials' surface chemistry (chemical phenomena occurring on a surface) and how their molecules are oriented. But for nanotubes, the application of NEXAFS is still quite new.

"The beauty of using NEXAFS to study nanotubes is that it gives us more detailed surface-chemistry information than other techniques are currently capable of. At the same time, it complements those techniques to give us a clearer picture of the sample's behavior," said scientist Daniel Fischer, who works for the National Institute of Standards and Technology, which owns and operates three research stations, called "beam lines" at the NSLS.

A front view of a carbon nanotube. During NEXAFS analysis, x-rays are directed at the nanotube and are absorbed by some of its electrons.

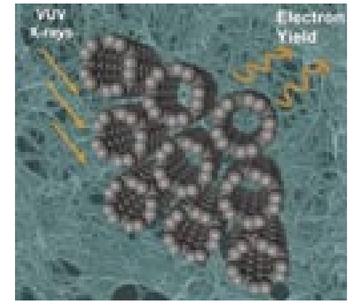
During a NEXAFS analysis, a nanotube sample is placed in the path of a beam of x-rays. The x-rays are absorbed by each carbon atom's "core" electrons – those closest to the nucleus – giving them enough energy to move away from the nucleus. When this occurs across many, many atoms, scientists can record the sample's absorption "spectra," measurements that track how the sample's chemical and electrical properties respond to the absorbed rays.

For the nanotube samples the researchers studied – a number of very thin SWNT films, known as "buckypaper," and a MWNT film "grown" on a surface of platinum metal – they produced several spectra and, by analyzing them, uncovered information about the nanotubes' physical and electronic properties. But the property of most interest to them is the order of the nanotubes (how organized or disorganized they are) because a very ordered nanotube sample is more desirable for practical applications. For example, its behavior is more predictable and it conducts electricity more efficiently.

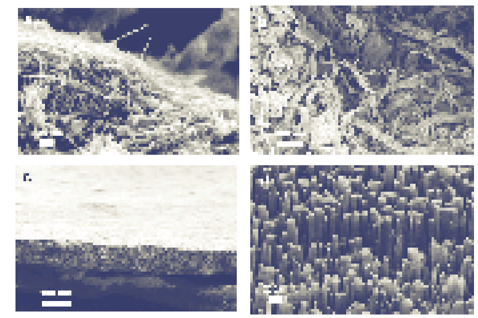
They compared their results to two "control" groups: graphite, a highly ordered form of carbon, and nanotube powder samples, which are not ordered at all.

The scientists found that the buckypaper is similar to graphite in one key way. For both, the spectra from x-rays that grazed the sample look different than the spectra from x-rays that hit head-on. This property – when the absorption behavior of a material in response to an outside electric field depends on the direction the field is applied – is called "anisotropy." It is a very useful behavior to study, since high anisotropy often implies a high degree of order. Conversely, a material shows "isotropy" when its reaction to an outside electric field is always the same, regardless of direction. Nanotube powders, containing nanotubes in all possible orientations, display isotropy.

In buckypaper, the group found, the anisotropy is not as pronounced as in graphite. Further analysis revealed that approximately 87 percent of the nanotubes in the paper lie on their sides. The analysis of the MWNT film showed that the film behaves as if most of the nanotubes stand upright. Thus, it also displays anisotropy.



Above: A rendering of carbon nanotubes being studied using NEXAFS. Light comes in (left) and electrons are emitted (right).



Above: Scanning electron microscope images of (a) MWNT powder, (b) SWNT powder, (c) SWNT buckypaper, and (d) aligned MWNTs.

"These results are encouraging because they indicate that two common nanotube systems already contain a fair degree of order," said Brookhaven Lab chemist Stanislaus Wong, who also participated in the research. "Moreover, for both the arrays and the paper, the results were stunningly close to what our preliminary theoretical calculations predicted."

He continued, "We plan to continue studying MWNT films grown on surfaces other than platinum, and we'll also look at single-walled nanotube films grown on various surfaces. Our hope is to find a way to produce a nanotube array with order comparable to graphite."

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MEET DANIEL FISCHER AND STANISLAUS WONG

For Dan Fischer and Stanislaus Wong, there is nothing unusual about working with powerful, highly focused x-rays, shining them at various materials to see what's holding them together. In fact, this describes a typical workday.

But their current project — using x-rays to study nanotubes — is special even by their standards. This isn't due to the investigation technique they are using. Nor is studying nanotubes a new experience. The compelling part of the project is the combination of the two. In fact, it is what led Fischer, a physicist, and Wong, a chemist, to become collaborators.


Dan Fischer and Stanislaus Wong

Fischer's background is rooted in synchrotron science. For the past 21 years he has worked on developing new ways to use a synchrotron. Wong's research interests are more focused on nanoscience and nanotechnology, particularly carbon nanotubes and metal-oxide nanostructures. Together, they make a great team.

"I heard about Dan's work and wanted to see if near edge x-ray absorbtion fine structure (NEXAFS) could complement the other material characterization techniques I was using to study nanotubes. Learning that the answer is 'yes' has been exciting," said Wong.

"This is a real NSLS success story," agrees Fischer.

Fischer received his Ph.D. in physics from Stony Brook University in 1984. For the past 14 years he has worked for the National Institute of Standards and Technology (NIST) and is supervising a group of NIST scientists stationed at the NSLS.

Wong completed his Ph.D in chemistry from Harvard University in 1999. Since 2000 he has been an Assistant Professor in the Chemistry Department at Stony Brook University with a joint appointment at Brookhaven Lab. He is an avid reader and an "amateur fashion aficionado."

A BETTER VIEW WITH NSLS-II

Slated to be the brightest light source in the world, National Synchrotron Light Source II (NSLS-II) is the planned successor to the NSLS and, by all accounts, it will be a stunning facility. It will make use of the most advanced, state-of-the-art technology, producing x-ray light 10,000 times brighter than the NSLS is able to. It will be huge — four times larger than the NSLS. It will attract some of the world's top researchers. And it will make possible some very exciting scientific work.

In that last respect, Dan Fischer and Stanislaus Wong don't intend to miss out on the action. The new synchrotron will be ideal for studying nanotubes because its x-ray beams will be much narrower, much more concentrated than those produced at the NSLS.

"With a beam line that can produce very small, focused 'spots' of x-ray light, we might be able to actually image and work with single nanotubes, watching what happens as electric current passes through them," said Fischer. "That would be unprecedented."

And in the field of nanoscience in general, which is one of the most rapidly developing areas of research, NSLS-II will significantly extend the reach of current synchrotron-based research techniques. The new facility's ultra-bright x-ray beams, as small as 10 nanometers in diameter, will make new imaging methods possible. With these capabilities at hand, scientists will be able to engage in completely new experiments.

NSLS-II will significantly extend the reach of current synchrotron-based research techniques.

Many other fields will be similarly impacted by NSLS-II. One example is structural biology, in which scientists use x-rays to determine the atomic structures of disease vaccine candidates, proteins, and other important molecules. With NSLS-II, structural biologists will be able to study smaller samples, opening new doors to breakthroughs in health and medicine.

Brookhaven Lab proposes that construction for NSLS-II will begin in 2008, with operations beginning in 2013.