DISCOVER BROOKHAVEN

FALL 2008

Collaborating for a “Perfect” Scan of Nuclear Matter

ON THE COVER

With just millimeters of room
for error, engineers merge together
two of the three major pieces of
the ATLAS inner detector. ATLAS
is one of four experiments at
CERN's Large Hadron Collider.

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Photograph of Brooklyn Bridge on
page 18 by howarddigital.com

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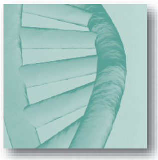
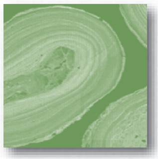
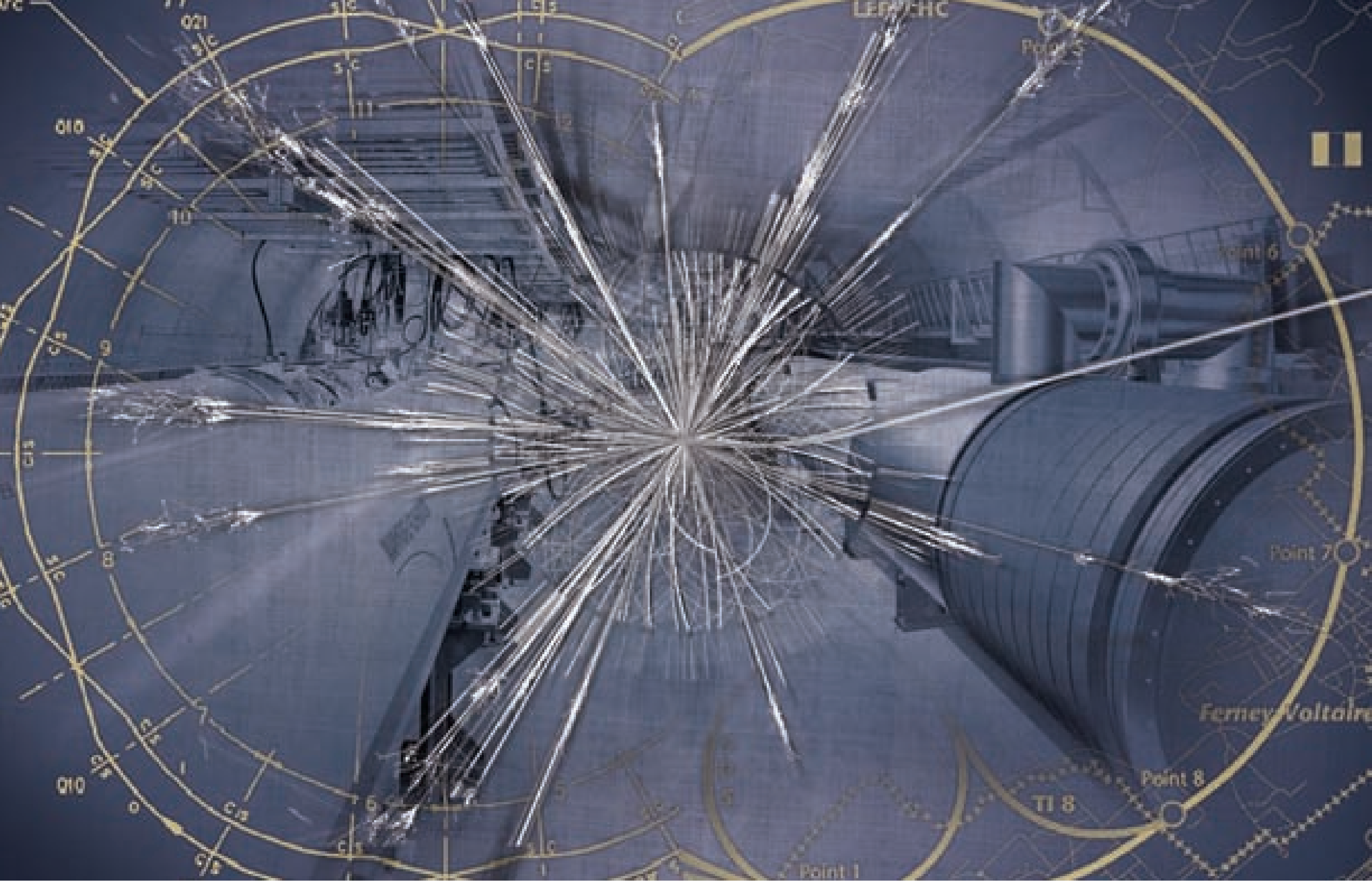






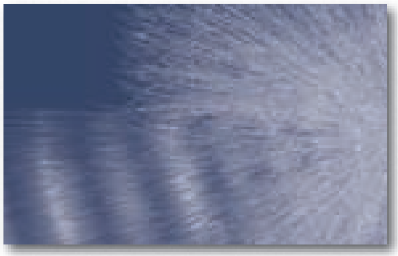
COLLABORATING FOR A "PERFECT" SCAN OF NUCLEAR MATTER

As the finishing touches are put on the world's most powerful particle accelerator in Switzerland, and plans for others pop up across the globe, Brookhaven's Relativistic Heavy Ion Collider (RHIC) continues to exploit its unique ability to explore the surprising features of matter bound by the strongest of Nature's forces. Although RHIC's overall mission is quite different from other machines on the horizon, new scientific facilities are incorporating heavy ion capabilities similar to RHIC. This healthy competition and collaboration with facilities worldwide will greatly enhance the exploration of nuclear matter — the inner cogs that make up the nucleus, and really, everything around us.

On the most basic level, scientists know that the nucleus is made of particles called protons and neutrons, which are made of smaller particles called quarks and gluons — the most fundamental constituents of matter. They know that the quarks are grouped into triplets held together by gluons (named for their Elmer's-like properties). But, they also know that these elementary particles weren't always glued together. Go back about 13.7 billion years, a hundred-millionth of a second after the Big Bang, and you'd find quarks and gluons floating freely. And that's where it gets sticky.

By Kendra Snyder

Healthy competition and collaboration with facilities worldwide will enhance the exploration of the inner cogs that make up the nucleus and everything around us.



Using RHIC, researchers have revealed surprising results in their quest to recreate this moment in history, in microcosm. By colliding beams of heavy gold nuclei at very high energies, RHIC provides a small-scale replication of the ultra-hot, dense conditions thought to have existed immediately following the birth of the universe. However, instead of producing a gas of free quarks and gluons, RHIC's energetic collisions appear to produce something more like a *liquid* — a "perfect" liquid with almost no viscosity, or frictional resistance to flow.

To continue exploring the nature of this perfect liquid, RHIC physicists are building on their remarkable early discoveries to mount precision studies with newly refined experimental and theoretical techniques. A near-term upgrade, expected to increase the machine's collision rate and improve the sensitivity of detectors, would make critical measurements at RHIC more quantitative, allowing scientists to learn more from theory-experiment comparisons of the properties of the perfect liquid. For example, scientists can examine the applicability of "string theory," which has suggested completely unanticipated connections between the strongly interacting matter produced at RHIC and gravitational systems such as black holes.

But physicists will need the assistance of multiple scientific facilities to determine the so-called phase diagram of nuclear matter. A phase diagram shows the boundaries between different types of the same substance as external conditions, such as pressure and temperature, change. One of the best-known phase diagrams illustrates what happens to water as it freezes in an ice cube tray or turns to steam while boiling in a pot on the stove. For nuclear matter, the phase diagram aims to show the boundary between normal matter, composed of compact neutrons and protons, and a system of liberated quarks and gluons.

Exploring the phase diagram of nuclear matter requires much more than kitchen-sink experiments. To reach the extreme conditions required to "melt" normal matter into a soup of quarks and gluons, which happens at temperatures more than 100,000 times hotter than the center of the sun, scientists need an array of accelerators capable of creating collisions of varying energies.

The Large Hadron Collider (LHC), a powerful accelerator now coming online in Switzerland, is expected to reveal how the perfect liquid evolves at even higher temperatures than are produced at RHIC. Although the machine's primary focus is to create new, massive particles by colliding beams of protons, the LHC also will collide lead ions and devote a short amount of its run time — about four weeks per year — to nuclear physics.

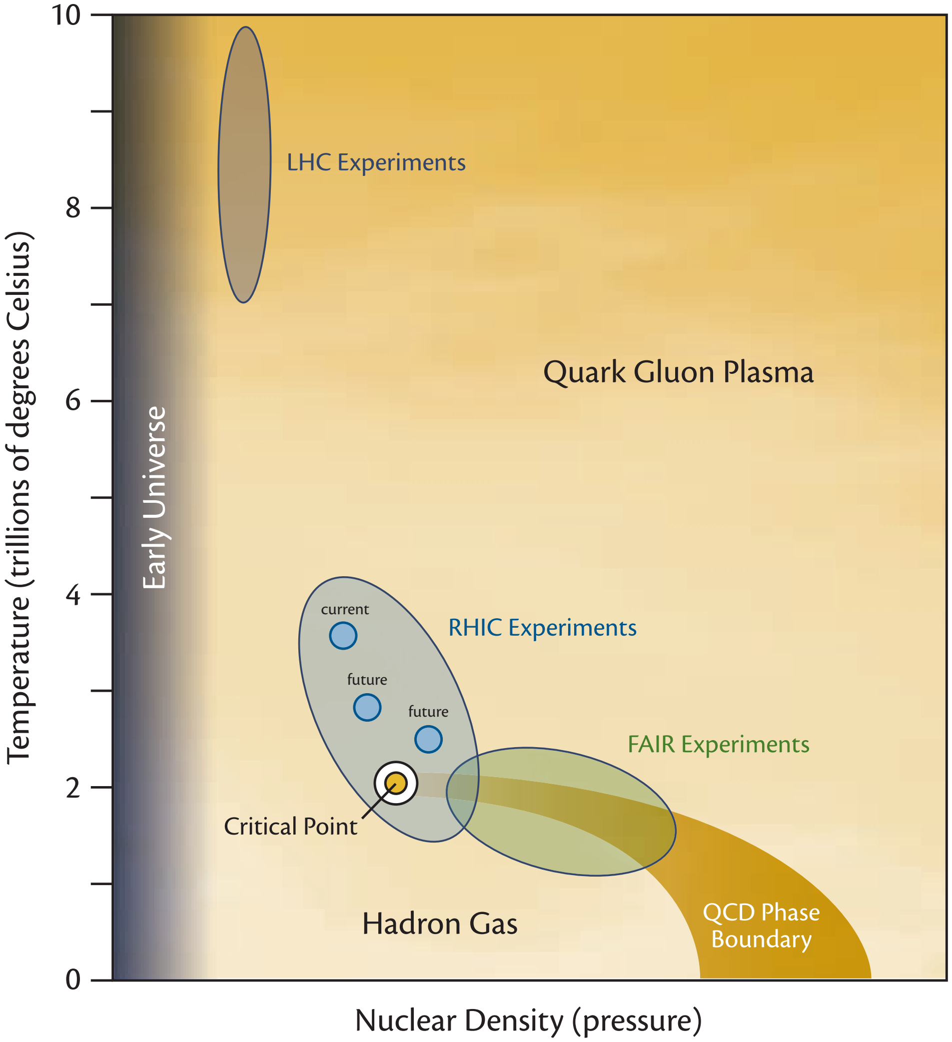
"We're curious to find out if matter analogous to the perfect liquid can be created at even higher temperatures,

(continued page 4)

Researchers at the Solenoidal Tracker at RHIC (STAR), a massive detector that specializes in tracking the thousands of particles produced by each ion collision at RHIC.

and if so, what it looks like,"said Brookhaven's Physics Department Chair Tom Ludlam. "Will it become even more perfect? Or will it actually behave like a gas for a fraction of its tiny lifetime? We may be able to determine that from studies at the LHC."

To further explore the nuclear matter phase diagram, future RHIC experiments will demand *lower* energy collisions than produced in the past. Researchers are particularly interested in using RHIC to pinpoint the location of the "critical point," a threshold of temperature and density above which there is no sharp transition between two phases. On one side of the critical point associated with nuclear matter, there is an obvious difference between normal matter and a substance of unconfined quarks and gluons, and the transition from one phase to the other is sharp. But on the other side, the two phases can coexist and the transition from one to the other is a smooth crossover. So far, collisions at RHIC result in temperatures well above the critical point. With versatility in beam species and energies, and long running times for collisions of heavy nuclei at lower temperatures, RHIC is well positioned to uncover this telltale transition point, Ludlam said.



The LHC, RHIC, and FAIR will each explore a different section of the nuclear matter phase diagram, which is depicted in this graphic. As temperature and density change, so does the boundary between normal hadronic matter, composed of neutrons and protons, and a system of unconfined quarks and gluons. The critical point is an as-yet-undiscovered landmark; the transition from hadron gas to quark-gluon plasma is predicted to be smooth at densities to the left of the critical point, but sharp on the other side, at higher densities.

"Pinning down a critical point in the phase diagram is the best way to understand how quarks and gluons work together over large volumes to form the perfect liquid," Ludlam said. "If we find it, experimental data on both sides of the point will reveal a great deal about the fundamental processes that have produced the matter we see in our universe today."

In addition to the LHC and RHIC, one more facility will soon enter the energy-scanning mission. GSI, the German research center for heavy ion physics, is currently building the Facility for Antiproton and Ion Research (FAIR), a series of synchrotrons, storage rings, and detectors meant to study numerous aspects of physics. FAIR, scheduled to begin operating in 2016, will use extremely high nuclear densities in a low-energy scan that could map out the nuclear matter phase diagram well to the right of the critical point.

"We need specialized information from each of these facilities to paint a complete picture of nuclear matter," Ludlam said, adding that "to make sense of what will be seen at very high energies at the LHC and very low energies at FAIR, physicists need to know what has happened and will happen at RHIC. As data emerge from all three of these world-class facilities, we will enter a golden age of heavy ion physics."

Basic RHIC Physics Feeds Future Workforce Pipeline

In addition to helping scientists peer into the very heart of matter, large-scale physics facilities like the Relativistic Heavy Ion Collider (RHIC) at BNL and the Large Hadron Collider at CERN, play a significant role in training the next generation of world-class physicists. These scientists often make important contributions that fuel the economy, provide for security, and pave the way to a healthier, brighter future. Indeed, more than half the students who earn doctoral degrees in nuclear physics in the U.S. go on to work in fields as diverse as national security, medicine, energy generation, space exploration, finance, and more. Among them are M. Munir Muniruzzaman, Andrew Hoover, Jane M. Burward-Hoy, Felix Matathias, and Robert Welsh: examples from the more than 30 students who earn Ph.D.s each year based in part on their work at RHIC.

One of the latest of dozens of students who have worked at RHIC, Ondrej Chvala from Prague in the Czech Republic, shown at the PHENIX detector.

M. Munir Muniruzzaman transferred his skill at analyzing RHIC's particle collisions to developing algorithms for a small company using fast neutrons to detect explosives and illicit materials such as drugs. He has worked on detectors for the Departments of Homeland Security and Defense, U.S. Customs, and a number of commercial companies.

"Then, after three years helping save lives from terrorists, I learned that a physicist can also save lives in danger of being cut short by cancer," said Muniruzzaman. Joining a company working on a robotic radiosurgery system that directs x-rays with pinpoint precision, Muniruzzaman is now in charge of using physics-based computer simulations to calculate doses for this innovative cancer radiation treatment.

Computer simulations and an understanding of radiation also play a role in the work of RHIC alumnus Andrew Hoover at Los Alamos National Laboratory, where he's helped design arrays of sensors for analyzing the composition of nuclear materials as part of an effort to track their origins and keep them out of terrorists' hands. "My skills here are applied across several projects involving radiation detection — even a space-based gamma-ray burst experiment on a NASA mission."

The space environment, filled with cosmic rays and energetic particle bursts, seems particularly well suited to the application of skills learned at RHIC. Jane M. Burward-Hoy, who now also works at Los Alamos, measures particle distributions in the outer edge of Earth's radiation belts to more accurately predict the space "weather" environment. The ultimate goal: Help protect Earth-orbiting satellites from damage to their electronic monitoring systems — which help protect us on Earth.

Burward-Hoy attributes her career path to the terrorist events of September 11, 2001 — the day she was scheduled to defend her Ph.D. thesis. "I decided I really wanted to contribute to national security and make a difference," she said.

RHIC alum Felix Matathias hopes to have his impact in the world of finance — using data-analysis and computing skills to pin down pricing information for rarely traded bonds in a less-than-transparent market. "Because of my work analyzing very limited early RHIC data, I was no stranger to working with sparse and rare data trying to extract a statistically significant signal. My physics training also provided me with invaluable technical skills in computer programming, which I now apply every day."

Being an outsider in a new field can be a real asset, says Robert Welsh, who transferred skills gained through 10 years of experimental particle and nuclear physics to the field of neuroscience. "My training in physics has greatly contributed to my ability to think outside the box and to learn new experimental and theoretical concepts."

Welsh is involved in a number of studies using functional magnetic resonance imaging and other brain-scanning techniques. He specializes in tweaking experimental designs to maximize the detector's sensitivity to the "signal" he wants to measure — for example, a change in brain activity in response to different facial expressions or cognitive tasks — for studies of psychiatric diseases such as schizophrenia and obsessive compulsive disorder, as well as amyotrophic lateral sclerosis ("Lou Gehrig's disease") and cancer.

By offering students the opportunity to develop such wide-ranging skills and showcasing ways to apply them, the RHIC program constitutes a technical, scientific wellspring that feeds many fields. Maintaining such facilities keeps an ever-more-sophisticated, highly specialized workforce growing.

BASIC RESEARCH FOR ENERGY SECURITY

Our nation faces a grand challenge: finding alternatives to fossil fuels and improving energy efficiency to meet our exponentially growing energy needs over the next century and beyond.

By Peter Genzer

The Role of Basic Science

Recent advances in the scientific tools available to researchers have set the stage for fundamental discoveries in the energy arena. These tools themselves are often the result of basic research. In addition, basic research — particularly in the emerging field of nanoscience — can help researchers develop new approaches that transcend the limitations of today's technologies.

Nanoscience is the study of materials on scales with dimensions of billionths of a meter. It has enormous promise in developing solutions to our energy challenges because the processes of energy production, conversion, and use — from the movement of electrons to the catalysis of reactions that convert energy from one form to another — all occur at the nanoscale. At the nanoscale, materials have vastly different properties from their bulk counterparts. If tapped, these properties may enable breakthrough technologies.

Recent advances in nanoscience tools and facilities — like Brookhaven's new Center for Functional Nanomaterials — have opened up this frontier of discovery, enabling scientists to fabricate, characterize, and model the behavior of materials at this scale. Such basic research — aimed at understanding the details of these processes and structures — will enable scientists to design/engineer improvements to optimize efficiency and performance across the energy spectrum.

The U.S. currently consumes about 3.5 terawatts of energy on a continual basis — think 35 billion 100-watt light bulbs burning constantly, or the output of 3,500 coal-burning power plants. Right now, we derive the bulk of that energy from oil, gasoline, coal, and natural gas — non-renewable fossil fuels that, when burned, add carbon to Earth's atmosphere. Levels of man-made carbon dioxide (CO_2) going into the atmosphere are currently at an all-time high, and CO_2 is the main "greenhouse gas" associated with climate change.

U.S. demand for energy is only expected to grow — upwards of 50 percent for electricity alone by the year 2030. To meet this ever-increasing demand, we need breakthrough solutions. Science can meet the daunting challenges of our energy future through fundamental, game-changing approaches that require long-term investment in basic research. By investing in this long-term approach, today's scientists and policymakers can ensure that our nation's ever-growing energy needs are met.

Basic research conducted at national labs like Brookhaven, at universities, and in industry is leading to advances that transcend the limitations of current technologies and may enable completely new and vastly more efficient energy systems.

PRODUCTION

Constantly growing demand for energy and its inefficient utilization are the driving forces behind the energy issues facing the nation today. Currently, our largest energy demands are for transportation and electricity. Most existing technologies for the former rely on products derived from petroleum. For electricity, we burn close to a billion tons of coal each year. To build a foundation for our future in the 21st century and beyond, we clearly need replacements for these 19th century technologies.

Scientists across the country are focused on identifying and advancing renewable, sustainable sources of energy such as solar, wind, hydro, and biofuels/ biomass. Practically speaking, less than 0.02 percent of energy in the U.S. currently comes from solar cells, but new scientific advances could help improve efficiencies and drive costs down.

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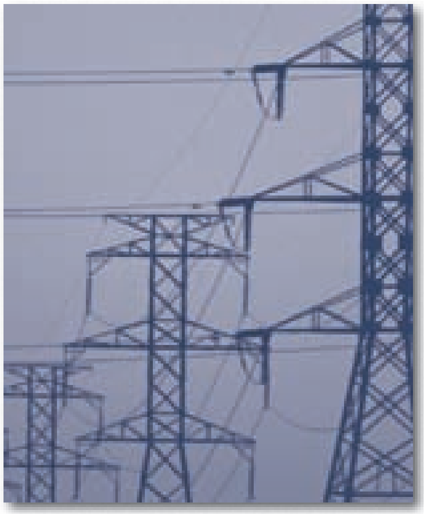


Brookhaven researchers are focusing on new ways to collect solar energy and convert it to more useable forms. Scientists estimate that 600 million megawatts of solar power — equivalent to the output of more than a half million typical coal-burning power plants — could theoretically be captured and used on Earth.

A Call to Action

The challenge is clear: The scientific breakthroughs that will enable paradigm-shifting advances in the energy arena require both long-term investments in basic research as well as short-term investments in applied science and technology. The potential payoff in improved energy efficiency and security is enormous, and is key to our nation’s continued growth and success.

The areas most essential to meeting these challenges are:

Chemistry - for the synthesis and discovery of new, higher-performance materials and systems

Physics - to understand the detailed physical mechanisms that are fundamental to energy science and the design of new materials for energy applications

Computational science - for modeling the behavior of new materials and advancing the theory with numerical simulations

Facilities and tools - such as advanced light sources and nanoscience research centers to provide the probes to reveal the nature of these new materials

Only through investment in these basic sciences will the nation be prepared to meet the challenges of the 21st century and ensure a secure energy future.

Scientists have long sought to improve the efficiency of photovoltaic cells and find new ways to use the sun to produce power. Some interesting possibilities growing out of basic research include:

Semiconductor-based photovoltaic (PV) cells employing nanostructured “quantum dots” that have different properties than the bulk semiconductors currently used in PV applications.

New, inexpensive nanocatalysts for “artificial photosynthesis” systems that use the sun’s light to split water and cheaply produce hydrogen for various energy applications.

Materials for use in solar thermochemical systems, which use large focusing mirrors to harness and concentrate the sun’s rays, providing input for chemical reactions that need heat.

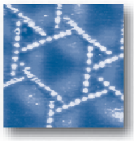
CONVERSION

Basic research in the field of nanoscience also plays a key role in developing improved methods for converting energy sources into various forms for use. One promising approach involves improving the efficiency of fuel cells. Fuel cells combine hydrogen and oxygen without combustion to produce direct electrical power and water. They are attractive as a source of power for transportation applications because of their high energy efficiency, the potential for using a variety of fuel sources, and their zero emissions. Brookhaven scientists are working to improve fuel cell technology by developing less-expensive, more-efficient, and longer-lasting fuel cell catalysts. Researchers have discovered that adding gold nanoparticles to the platinum catalysts can help stabilize them and greatly reduce CO poisoning. This results in lower cost — because you don’t have to replace the expensive platinum — and higher energy yield.

TRANSMISSION

Just as important as generating energy is effectively transmitting it to end users. Our aging electrical grid faces significant capacity, reliability, quality, and efficiency challenges that can be met by basic research. Reliability

U.S. demand for energy is only expected to grow — upwards of 50 percent for electricity alone by the year 2030.



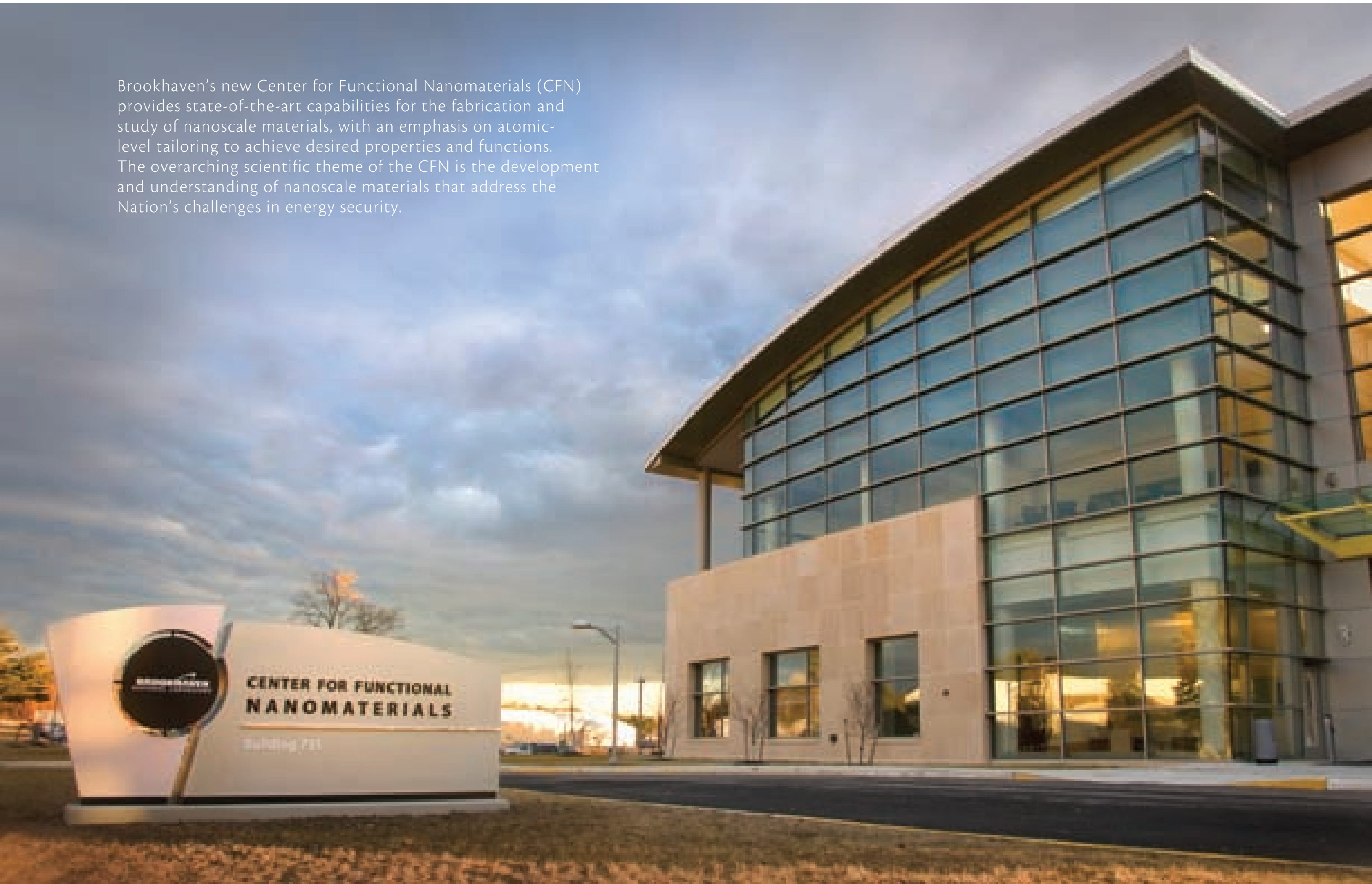
is a big issue — momentary over-voltages and dips in electrical power occur regularly, and are the leading cause of equipment and machinery failures and associated economic losses.

The distribution lines themselves could be made more efficient. Currently, nearly 10 percent of all electricity generated is lost as heat in transmission, mostly a result of natural resistance in the metals used in the lines. New classes of superconductors, materials that carry electrical current with no resistance, can help solve these challenges. One key to advances in this field being studied at Brookhaven is basic research aimed at developing a better understanding of the mechanisms of superconductivity.

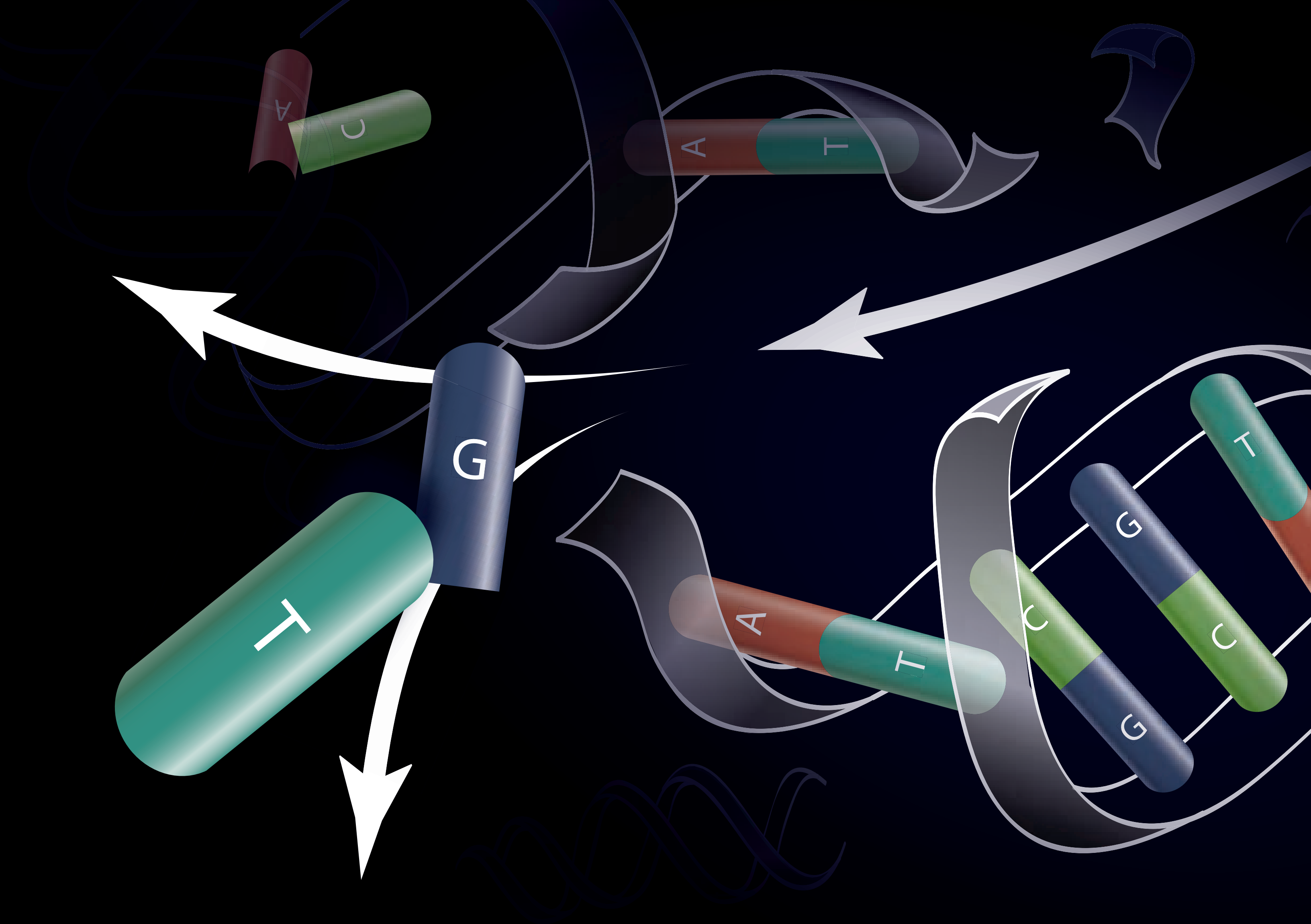
STORAGE

Basic research can also lead to more efficient energy-storage materials and systems. Such improvements could enable renewable energy to flourish by compensating for the intermittency of energy output from the sun and other renewable sources. This research may also increase battery-powered transportation options, or even increase the lifespan of batteries used in laptop computers and other personal electronic devices.

Challenges in this area are linked to the inherent limitations of today's batteries, which, despite recent advances in the area of rechargeables, have been around in a basically unchanged form since Thomas Edison discovered the light bulb. Scientists are now looking at various new materials to leapfrog over the limits of lithium cells. Nanoscience again plays a large role here, as batteries (chemical storage) and capacitors (physical storage) based on nanostructured materials may become the new paradigm.



Brookhaven's new Center for Functional Nanomaterials (CFN) provides state-of-the-art capabilities for the fabrication and study of nanoscale materials, with an emphasis on atomic-level tailoring to achieve desired properties and functions. The overarching scientific theme of the CFN is the development and understanding of nanoscale materials that address the Nation's challenges in energy security.



Radiation can damage DNA by knocking off one or more bases (A,T,G, or C), or by breaking through the DNA strands.

A new technique for assessing repair of the damage radiation causes to DNA, life's genetic instruction molecule, indicates that the spatial arrangement of damaged sites, or lesions, is more important than the number of lesions in determining the severity of damage.

The technique helps reveal why high-energy charged particles, such as the heavy ions found in outer space, are more potentially harmful than lower-energy forms of radiation, such as x-rays and gamma rays. These findings, published recently in the journal *Nucleic Acids Research*, may help clarify the risks faced by future astronauts flying long-term missions to the moon or Mars.

"Understanding the effects on humans of radiation exposure — whether in the natural environment, in outer space, in the workplace, or due to radiation therapy — requires insight into the induction and repair of damage to DNA," said Brookhaven National Laboratory biologist Betsy Sutherland, an expert in the study of space radiation.

Sutherland developed the new technique for monitoring the repair of radiation-damaged DNA with colleague Brigitte Paap, now at Arizona State University, with funding from the Office of Biological and Environmental Research within the U.S. Department of Energy's (DOE) Office of Science, the

NEW METHOD OFFERS INSIGHT INTO RADIATION DAMAGE TO DNA

A new study assessing cells' ability to repair DNA damage suggests a mechanism for why some types of radiation are more harmful than others. The findings may help clarify the risks faced by future astronauts on long-term missions to the moon or Mars.

National Aeronautics and Space Administration (NASA), the National Space Biomedical Institute, the National Institutes of Health, and the Brookhaven Lab Pollution Prevention Program.

The technique uses different colored fluorescent "tags" instead of radioactive ones to monitor repair of damage to DNA. Because these fluorescent tags reduce the amount of hazardous waste associated with the research (as well as its cost), Sutherland and Paap have been recognized by DOE's Office of Science with a "Best in Class" pollution prevention award.

(continued page 12)

By Karen McNulty Walsh

DNA-Monitoring Method Wins Pollution Prevention Award

Using fluorescently labeled synthetic DNA fragments to monitor DNA repair replaces a technique in which radioactive isotopes are used as tags. While efficient, radioactive isotopes are more expensive than fluorescent tags. Also, using radioactive tracers requires frequent preparation of freshly labeled DNA, and disposal of the experimental samples as hazardous waste — which further increases the cost of the research.

Fluorescently labeled molecules, on the other hand, can be stored frozen for long periods. So the new method minimizes waste generation and improves worker safety by avoiding the handling of radioactive material.

The technique, which earned biologists Betsy Sutherland and Brigitte Paap a "Best in Class" pollution prevention award from the U.S. Department of Energy's (DOE) Office of Science, may now be used throughout the DOE labs and in universities and industry.

"It's very rewarding to come up with a new technique that helps us understand the process of radiation damage repair while at the same time reducing the waste associated with traditional techniques," Sutherland said.

NASA Space Radiation Laboratory

When she's not building artificially damaged DNA molecules in her Biology Department laboratory, Betsy Sutherland studies the potentially damaging effects of simulated space radiation at the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory — one of the few places in the world that can simulate the harsh cosmic and solar radiation environment found in space.

Built and operated by NASA in cooperation with DOE's Office of Nuclear Physics and operational since 2003, NSRL employs beams of heavy ions extracted from Brookhaven accelerators to irradiate a variety of biological specimens (including tissues, cells, and DNA), as well as industrial materials being studied for their suitability for space suits and spacecraft shielding.

"The major challenges for research at the NSRL are to uncover the risks of radiation to space travelers and to develop counter-measures that allow the safe, long-term presence of human beings at the space station and beyond," Sutherland explained.

Each year, during three experimental "runs" lasting approximately eight weeks each, scientists from more than 25 research institutions from throughout the U.S. and abroad work at NSRL to address these challenges, supported mainly by NASA funding. Each summer they are joined by a group of 15 or so international students (graduate to postdoctoral) and young independent investigators for an intensive hands-on research program designed to provide a "pipeline" of future space radiobiology researchers.

"While there is a wealth of data describing the effects of conventional radiation like x-rays, the same is not true for the types of radiation present in space," explained

> Understanding the effects on humans of radiation exposure requires insight into the induction and repair of damage to DNA.

Brookhaven biologist Betsy Sutherland is an expert in the study of space radiation.

DAMAGING THE DOUBLE HELIX

Radiation can damage the DNA "double helix" — a two-stranded, twisting molecule — in a variety of ways: 1) by knocking off one or more of the DNA "bases" known by the letters A, T, G, and C, which form the bonds between the two strands; 2) by oxidizing these bases; or 3) by breaking through one or both strands. All can result in a failure of the molecule to perform its main task — telling cells which proteins to make. That can lead to out-of-control cell growth (cancer) or death.

Cells can often repair radiation-damaged DNA, using specialized enzymes to excise and patch up the damaged segments. But damage from ionizing particle radiation appears to be harder to repair than that caused by lower-energy forms of radiation such as x-rays and gamma rays.

Scientists have long hypothesized that the reason for this difference was that the high-energy ionizing particles caused more complex damage containing many lesions close together on the DNA, leading to slower and less-accurate repair. The technique developed by Sutherland and Paap allowed them to test this hypothesis.

Using standard techniques of molecular biology, the scientists created synthetic DNA with known lesions in a variety of spatial arrangements with a red fluorescent

Peter Guida, medical department liaison scientist for this program at Brookhaven Lab. “It is essential to define the potential risks of exposure to space radiation and, if necessary, develop effective countermeasures to these risks.”

2008 marks the fifth year of the summer program. “Even though the program is still young, many of our graduates are already making contributions to the field,” noted Guida.


Students participating in the space radiation summer program at NSRL.

tag attached to one end of the strand and a green fluorescent tag at the other end. They then applied a DNA repair enzyme, which clips the DNA at damaged sites.

The scientists then used gel electrophoresis to separate the fragments according to their lengths. By looking at the red- and green-tagged bands, and determining their lengths, the scientists were able to measure how well the repair enzyme recognized and repaired the DNA damage.

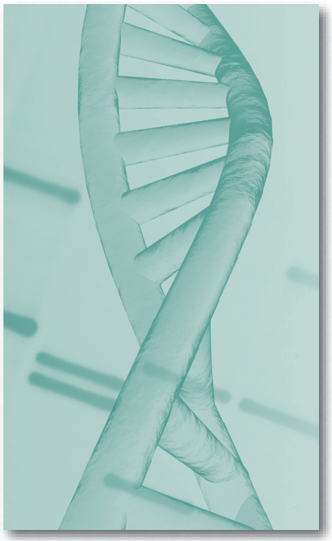
LOCATION, LOCATION, LOCATION

The results were surprising: Instead of being dependent on the number of lesions, the ability of the repair enzyme to recognize the damaged sites appeared to be most affected by the spatial arrangement of lesions on the DNA strands.

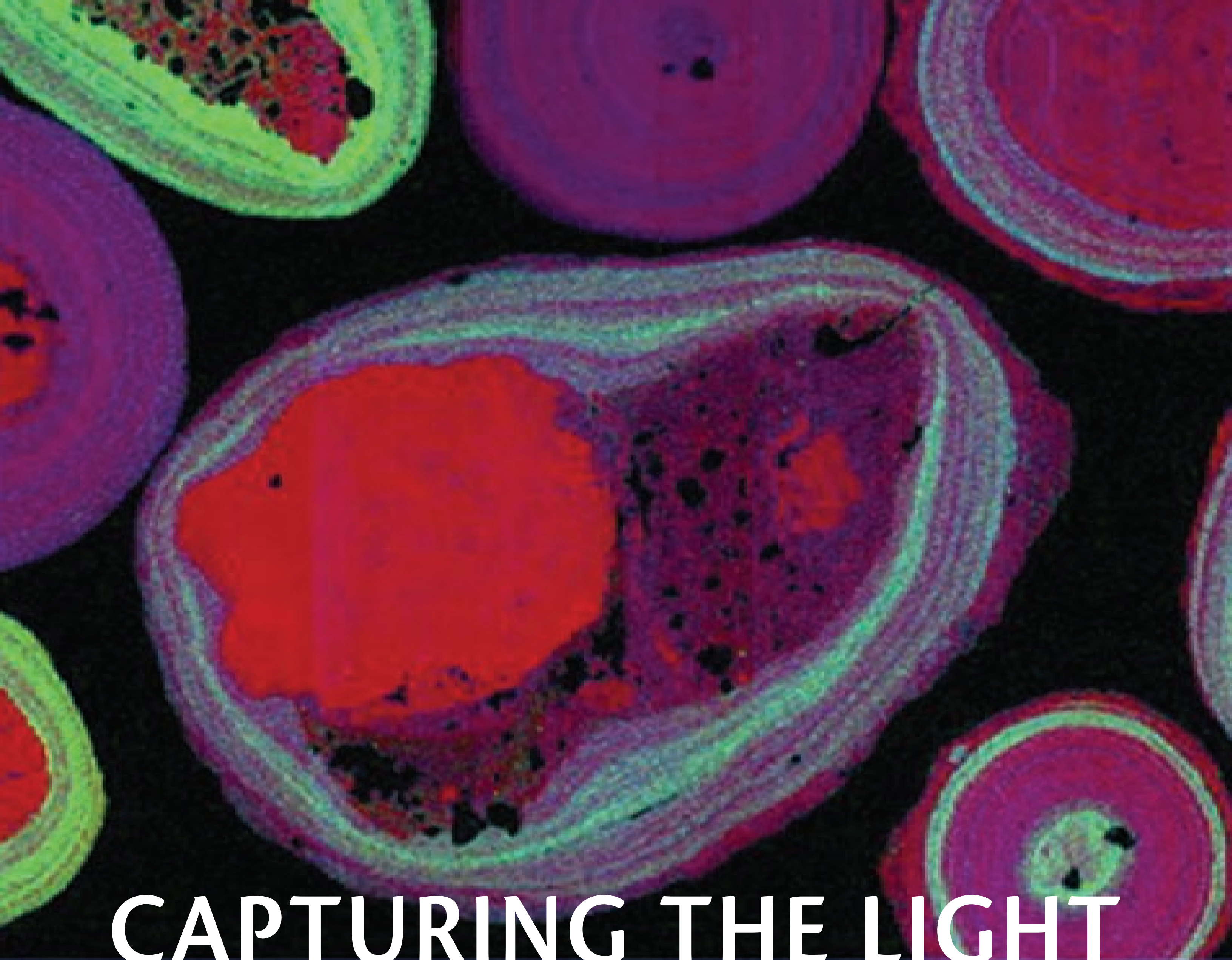
The scientists found that the enzyme readily recognized and repaired lesions on one of the DNA’s two strands that occurred all to one side of a reference lesion on the opposite strand (think of it as “upstream”). These upstream lesions were successfully repaired regardless of whether there were only two or many lesions in the damage.

If the lesions occurred “downstream” from the reference lesion, however, the repair enzyme was unable to work properly, no matter whether the clustered damage was a simple, two-lesion cluster, similar to those caused by x-rays, or a complex multi-lesion cluster like those induced by space radiation. When the lesions occurred in a two-sided cluster both up and downstream from the reference lesion, again the repair enzyme worked poorly.

“Since x-rays produce about half upstream, easily repaired clusters and about half downstream, repair-resistant clusters, about half of them would be readily repaired,” Sutherland said. “The heavy, charged particles in space radiation, on the other hand, produce much more complex, two-sided clusters, containing so many lesions that most of them are repair-resistant. This directional dependence of the ability to repair lesions explains why damage from charged-particle radiation, such as that encountered in outer space, is more harmful,” Sutherland said.



Since many enzymes participate in the repair of DNA, the Brookhaven investigators now plan to study the effectiveness of these enzymes in repairing the complex damages modeled by the technique using dual-color fluorescent tags.

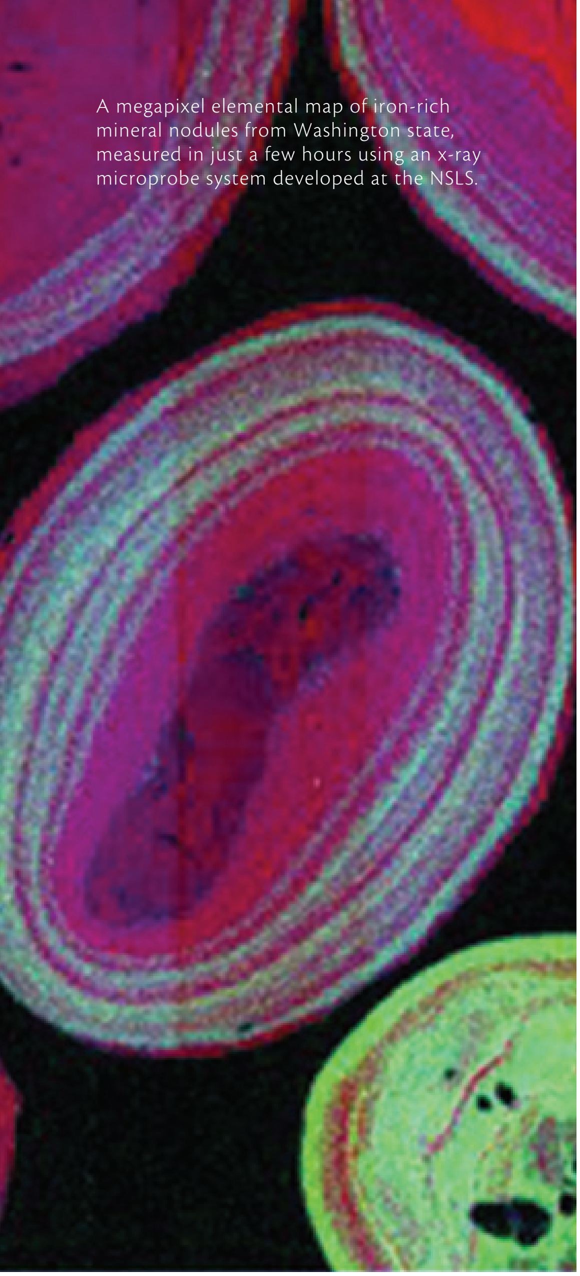


CAPTURING THE LIGHT

ADVANCED NSLS DETECTORS BOOST PRECISION, SPEED OF DATA COLLECTION

As the capabilities of synchrotron facilities around the world continue to rapidly grow in number and complexity, a group of researchers at Brookhaven's National Synchrotron Light Source (NSLS) and the Instrumentation Division are helping experimenters on site and world-wide implement new and more efficient ways to "see" their results.

By Kendra Snyder



A megapixel elemental map of iron-rich mineral nodules from Washington state, measured in just a few hours using an x-ray microprobe system developed at the NSLS.

There are three major components to a synchrotron experiment: an intense beam of infrared, ultraviolet, or x-ray light in the form of photons at varying energies; "optics," an arrangement of mirrors and lenses used to focus and aim the light at the sample being studied; and a system of detectors used to determine how the light interacts with the sample. All three elements are equally important, yet the development of advanced detectors — used to collect data for a broad spectrum of experiments ranging from environmental studies to protein characterization — has not kept pace with the rest of the field, said NSLS physicist Pete Siddons.

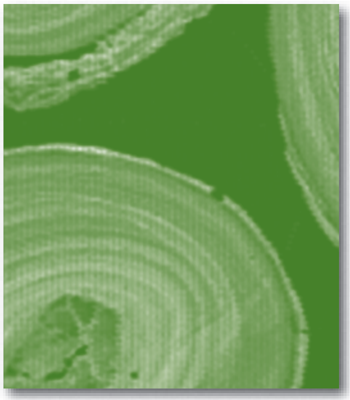
"We've been building these synchrotrons around the world for 30 years, and each consecutive one is more powerful," said Siddons, who leads the NSLS Experimental Systems Detectors Section. "But, with a couple of exceptions, the detectors have remained the same. Increasing the power of the accelerator doesn't give an increase in the number of photons detected at the beamlines. And when you let those photons go, you're limiting the depth at which you can study a certain phenomenon."

In an ideal world, every experiment would have a customized detector, Siddons said. His group, made of a half dozen full-time staff and postdoctorate researchers, strives to meet that ambitious goal with a little help from some scientific neighbors.

"What saves the day is our strong collaboration with Brookhaven's Instrumentation Division," Siddons said. "That allows us access to great technology, which is applied to everything from nuclear and particle physics to medical imaging and synchrotron experiments."

One recent example of the successful work from this collaboration is an x-ray fluorescence microprobe system that will be about 1,000 times faster than previous methods.

X-ray fluorescence is a powerful technique often used in the environmental and geological sciences for measuring trace element concentrations in a sample. Typically, a very tiny x-ray spot is focused on a sample, which ionizes electrons from the material's atoms. These excited atoms relax, filling the vacancies, and in doing so, emit x-rays at energies characteristic of specific elements. However, scientists can only determine the elements present in the portion of the sample that's exposed to the x-ray spot. To get an idea of the entire sample's chemical composition, the spot must be manually moved from one location to another — a process that can take many hours to produce low-resolution



(continued page 16)

As part of a Department of Energy Faculty and Student Team, Southern University professor Elhag Shaban (right) brings his students to the NSLS in the summer to work on numerous detector and synchrotron-related projects.

maps of just a few thousand pixels. Working with Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO), the BNL team developed a method that allows researchers to scan the scheme continuously along a line. This "on-the-fly" scanning method, which has been tested at the NSLS, also incorporates many small detectors (32 in the test run) into one device, and advanced data analysis techniques that can handle the increased processing speed and map the x-ray energies in real time. Led by physicist Chris Ryan, scientists at CSIRO developed software and hardware to unfold the signals from chemical elements at up to 100 million events per second.

In the first demonstration of this technique, the research team produced a 4 mega pixel image of a 14th century tooth and looked for lead accumulation that might indicate the presence of lead poisoning hundreds of years ago. The image was produced in just about six hours, a task that would normally take days, Siddons said. The group is currently building two 400-element detectors: one for the NSLS and one for the Australian Synchrotron.

The BNL group has also developed novel detectors for powder diffraction experiments. In this technique, researchers illuminate a crystalline sample with "hard," or high-energy, x-rays, which are scattered into very specific directions with various strengths. Detectors are used to measure this "diffraction pattern," which is then processed by computers to determine the arrangement of atoms within the crystal.

NSLS-II Anticipates Expected Needs of Its User Community

The NSLS-II is scheduled to start full operations in June 2015. Staff members are working on final engineering design documents, which will be used to build the facility. After they are reviewed, the project expects to receive approval of CD-3, which will allow construction to begin. By early 2009, the project expects to award a $200 million contract for ring construction.

Steve Dierker, Associate Laboratory Director of Light Sources who heads the project, said that the NSLS upgrade has been seriously underway for the past six years. About six years from now, he said, beam will be available to the beamlines.

Some changes to the facility design have included increases in beam height, tunnel height, and in the experimental floor's radial width, as well as the addition of spaces between the laboratory office buildings to allow for the extension of beamlines outside of the storage ring. The current design accommodates nine of these extra-long beamlines, each up to several hundred meters long.

Dierker said there is a need for the project team to develop a "coherent, facility-wide plan that is responsive to the needs of the various user communities." Input from the first NSLS-II User Workshop, held in July 2007, and a series of planning workshops held with the NSLS earlier this year, will be used to meet that goal.

"One clear message was the advantages, both scientific and technical, to be gained by appropriately combining communities with similar requirements," Dierker said. The white papers produced at the workshops also show why it is important for careful strategic planning, as the total number of beamlines requested greatly exceeds the number of ports that will be available at NSLS-II.

"We need to prioritize among competing demands and weigh new ideas versus the needs required for the continuation of existing communities served well by NSLS," Dierker said.

> “I’m always keeping my eyes open for places where a detector could make a difference.”

The new devices, just 80 millimeters long and 4 millimeters wide, contain 640 individual detectors arranged on 20 extremely thin strips. Each strip can register up to one million photons per second — a performance level that no other competing detector can achieve, Siddons said. The detectors group recently built three of these detectors: one for Argonne National Laboratory, one for a beamline run by Brookhaven’s Center for Functional Nanomaterials, and another as a pool instrument for general use at the NSLS.

These new devices will improve data collection for numerous materials science studies, from catalysts and semiconductor technology to drug design, Siddons said.

Although small, the NSLS detector group has made its presence known around the world. The group is producing fast imaging detectors for the LUSI project, a portion of the Stanford Linear Accelerator Center’s x-ray free-electron laser project; working with a Faculty and Student Team (FaST) from Southern University in Louisiana on a detector meant to pinpoint small concentrations of elements in environmental experiments; and is starting up new collaborations everywhere from Brazil to Taiwan.

“I’m always keeping my eyes open for places where a detector could make a difference,” Siddons said.

Meet Peter Siddons

It was 1968, and halfway through a degree in electrical engineering from the University of Bristol in the United Kingdom, Pete Siddons “did what everyone else was doing in the late 60s and early 70s.”

He dropped out.

The aspiring scientist and guitarist left the university to pursue the latter career. But after returning to the school as a technician soon after, Siddons’ boss set him back on the educational path by allowing him to work toward his master’s degree. Siddons, who calls his return to the science field “serendipitous,” went on to receive his Ph.D. in physics from Kings College in 1979.

After a brief stint at Precision Electronic Components in Canada, Siddons joined Brookhaven’s NSLS in 1985. He’s remained there ever since. Siddons first made his mark at the NSLS by developing novel beamline optics, the systems of lenses and mirrors needed to focus and aim synchrotron light at the sample being studied. In 2000, his focus switched to detectors.

“I’ve always had an interest in detector development,” said Siddons, who currently leads the NSLS Experimental Systems Detectors Section. “Many of the current photon and detector systems date back to the ‘70s, and upgrading them is the best way to provide better utilization in synchrotron facilities. The NSLS plays a leading role in promoting this kind of development.”

Siddons is married with three children. His wife, Liz, works across the street from Brookhaven at the American Physical Society. Their eldest daughter, Rebecca, is a teacher in Providence, RI; their middle child, Louise, is an assistant professor in art history at Michigan State University; and their youngest child, Giles, is a chef at a vegan restaurant in Manhattan.

Although he chose physics over the life of a musician, Siddons hasn’t abandoned his guitar. A member of several BNL-based bands throughout the years, you can still catch him performing at the annual NSLS holiday party.

NEW RADIATION DETECTOR TECHNOLOGY WILL HELP SECURE U.S. CITIES

You won’t see any Geiger counters trained on trucks entering the Midtown Tunnel into Manhattan. But Brookhaven scientists are pioneering research to detect radiological threats at transportation choke-points in many urban areas.

In the post-9/11 environment, security personnel at bridges and tunnels leading into New York and other large cities have a daunting task to perform: to screen vehicles and their passengers for radiation, which might be evidence of a so-called “dirty bomb” or other radiological device. Unfortunately, much of the existing technology does not discriminate between such threats and the gamma rays that might be given off by a person who recently received a heart stress test, a truck loaded with granite or a crate of bananas. And while the presence of neutrons will more clearly indicate a potential threat, their source can be difficult to locate.

Brookhaven scientists are in the forefront of technological advances that may bring solutions to some of these problems. Working for the Department of Energy (DOE), the National Nuclear Security Administration (NNSA) and the Defense Department’s Defense Threat Reduction Agency (DTRA), Brookhaven is developing gamma ray spectroscopy to identify specific radioactive isotopes and imaging systems to locate the source of neutrons. Precise isotope identification will help law enforcement differentiate between potentially dangerous radioactive materials and otherwise harmless radiation sources.

by Kay Cordtz

CHARACTERIZING GAMMA RAYS

"We live in a world awash with gamma radiation coming from walls, from the ground, from space, and even from our own bodies," said Ralph James of the Nonproliferation and National Security Department, who conducts research in gamma spectroscopy. "A useful detector must be able to discern a material of potential threat from these naturally occurring sources."

Existing germanium crystal detectors are large and bulky and must be cryogenically cooled to operate, making them impractical in many field operations. Detectors based on scintillators, which convert x-ray energy into visible light, operate at room temperature, but they have poor ability to identify isotopes. Brookhaven is working to combine the advantages of both minus their drawbacks by developing detectors based on cadmium zinc telluride (CZT) crystals.

When a gamma ray strikes a CZT detector, it creates electron-hole pairs. These drift under the influence of an applied electric field, creating a signal that reveals a unique signature of the isotope. Brookhaven scientists grow and characterize the crystals, fabricate them into detectors, test them for performance, design the electronics to read the signals, and integrate the components into working field instruments.

"It's very unusual to have research that spans fields ranging from crystal growth to prototype instrumentation," James said. "This work reaches across the Lab, connecting basic and applied programs. It also takes advantage of the unique tools at the National Synchrotron Light Source to identify the material properties limiting detector performance." He added that "the higher resolutions and precise energies that will be offered by the soon-to-be-built NSLS-II are expected to provide an added boost."

The CZT detectors meet the need for portable devices that can detect and image radiation without the false alarms characteristic of many conventional systems. They are now being deployed in niche applications. For use at greater standoff distances, however, they begin to lose performance ability. *(continued page 20)*

Community Outreach Programs Stress Training And Vigilance

Brookhaven Lab is the key to the federal government's response to possible radiological emergencies in the Northeast United States, responsible for training first responders, monitoring high-risk events, and coordinating response as situations develop. As the Regional Coordinating Office for the DOE/NNSA Radiological Assistance Program, known as RAP, the Laboratory provides first-responder radiological assistance to local, state, tribal and federal agencies in the detection, identification and analysis, and response to events involving the use of radiological/nuclear material.

The program encompasses an 11-state area, and is managed by the DOE Regional Response Coordinator, Richard Diem, along with Kathleen McIntyre, who manages the contractor resources. After the 2001 attack on the World Trade Center, the RAP team was deployed to survey the debris for radiation. The RAP team also monitors events like meetings of the United Nations General Assembly, papal visits, the U.S. Tennis Open and Major League Baseball playoffs.

"Our latest response was to Alexandria Bay, where the U.S. Customs Border Patrol reported that something had set off neutron detectors," she said. "The U.S. Coast Guard sent an aircraft for the team members, and within four hours we were assisting the local first responders."

Members of the team are trained to evaluate the consequences of a radiological emergency and advise local authorities on what actions need to be taken to minimize the health and environmental effects of an incident. Training is a big part of the team's mission, McIntyre said. The team has developed emergency plans and procedures and participated in numerous emergency drills and full-scale exercises.

Regional Reachback is a Department of Homeland Security program set up to address potential threats by interpreting data from radiation detection equipment deployed by a variety of local agencies. The pilot program has been up and running for about 18 months, said Biays Bowerman, its Brookhaven coordinator.

"Lots of equipment is being purchased and deployed, and our program provides expert computer analysis over the phone when needed," Bowerman said. "There are nine Brookhaven specialists and eight more at the Environmental Measurements Laboratory in New York City covering the northern half of the U.S. On any call, both labs will respond and confer about what material caused the alarm and whether it constitutes a threat." Bowerman said that the Regional Reachback team is contacted about twice a month.

A team of Brookhaven researchers works on a directional detection system for "fast" neutrons. Checking the calibrations are, left to right, Cynthia Salwen, Leon Forman, and Istvan Dioszegi.

LOCATING THE NEUTRON SOURCE

Peter Vanier's team of researchers from the Nonproliferation and National Security Department wants to know the origin of the neutrons they encounter, rather than their precise spectroscopy, since they occur infrequently in the natural environment. Cosmic rays generate a few neutrons that travel in random directions.

"We've developed systems that tell the direction they are coming from," Vanier said. "If you detect 20 neutrons coming from the same point, you have to be suspicious that it's a man-made source."

The team has been exploring two main detection methods: a helium-3 camera for thermal or "slow" neutrons, and a "fast" neutron double scatter camera. In the first method, a helium-3 pressure chamber containing arrays of wires functions as a film that detects a pattern of arriving neutrons. An enclosure lined with cadmium acts like a pinhole camera, comparable to what you might use to image the sun during a solar eclipse. Neutrons that have slowed down until they are in thermal equilibrium pass through a specially designed pattern of apertures in the cadmium, creating a shadow of the pattern. The overlapping shadows can be mathematically converted into a picture that can reveal the source using the chosen properties of the coded apertures. Brookhaven scientists built the first thermal neutron coded aperture camera and have extensively tested it in collaboration with other DOE laboratories.

"We hope to construct a much bigger detector that can build up the picture more rapidly," Vanier said. "A bigger detector is more likely to find a source in a given time frame and at a given distance. The more quickly it's traveling, the harder it is to find."

To locate the origin of "fast" neutrons, Vanier and his team use an entirely different method — a "double scatter" camera that works like an analysis of billiard shots. When a neutron hits a proton in a plastic scintillator, it makes

Meet Peter Vanier

When Peter Vanier was growing up in St. Kitts in the West Indies, his father was both a studious lawyer and an industrious beekeeper who taught his three sons how to use a variety of woodworking and metalworking tools in their basement workshop.

"That probably influenced my decision to pursue science," he said recently. "I was fascinated by the inner workings of mechanical and electronic devices."

Vanier and his two brothers all won full scholarships to Cambridge University, graduating with degrees in natural sciences. His sister graduated from the University of the West Indies in Jamaica, and later earned a master's degree from London University. Both of Vanier's brothers are also scientists: one is a retired chemical engineer and information technology specialist who lives in France and is currently writing a book. The other is a chemist who specializes in nanoparticles at Pittsburgh Plate Glass.

Vanier earned a Ph. D. in physics from Syracuse University in upstate New York, where he met his wife of 37 years, Bonnie, who was at the time studying political science as an undergraduate at the Maxwell School. He came to Brookhaven 30 years ago in the materials science division, and worked on developing semiconductors, which can be used both for photovoltaics and for radiation detectors.

"These fields of physics lend themselves to several different practical applications," he said.

Besides his development of neutron imaging systems, Vanier has also worked on the measurement of gamma-ray spectra for an international arms control project, and for the Department of Homeland Security's Regional Reachback program (see Community Outreach sidebar, pg 19).

Vanier used to be an avid tennis player, winning the Brookhaven Lab doubles tournament several times. Nowadays, he spends most of his diminishing free time on home-improvement projects. His daughter, Sophie, is a 26-year-old actor who has been featured in many regional theater productions.

a particle track creating light that can be detected. Two planes of detectors give two sets of timing information for these scattering events. By comparing the energies of the scattered neutrons, the angle of the incoming neutron is calculated and projected in the form of cones. The direction where the cones intersect is the most likely source of the neutrons.

"We can't get an exact location from one neutron, but we can if there are many," Vanier said. "The double scatter camera gives two types of information: that there is a point source, and where that point source is. If they are all coming from one direction, you know you need to investigate."

"If you detect 20 neutrons coming from the same point, you have to be suspicious that it's a man-made source."

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