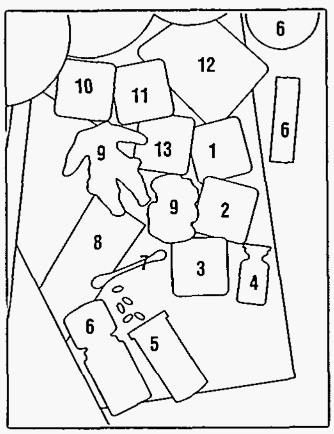
Brookhaven National Laboratory

Brookhaven Highlights 1994

This report highlights the Laboratory's activities for fiscal year 1994, a period dating from October 1, 1993, through September 30, 1994. For more information about work described in this report or for information about Brookhaven, contact the Public Affairs Office, Brookhaven National Laboratory, P.O. Box 5000, Upton, New York 11973-5000, ph. (516) 282-2345.



On the Cover:

Established in 1947 as a multidisciplinary scientific research center, Brookhaven National Laboratory has a long history of doing research that has made a difference in everyday life. BNL graphic designer Theresa Anne Esposito has arranged on a light table objects that show the range of BNL inventions and developments.

1 — Two BNL scientists hold the original patent for magnetically levitated trains.

2 — BNL's patented zinc-phosphate coating dramatically cuts corrosion of steel surfaces. Already licensed to TRW Inc., a large conglomerate that serves the automotive industry, the coating can be used to protect other consumer goods, such as appliances.

3 — Recognized as one of the most influential houses ever designed, the Brookhaven House demonstrates the substantial energy savings that result from heat storage and the passive use of solar energy.

4 — BNL's long-standing research in nuclear medicine has yielded important radioisotopes. For example, this vial is from a technetium-99m kit used on 200,000 patients each year in the diagnosis of internal bleeding, cardiovascular problems and other disorders.

5 — The use of L-dopa for treatment of Parkinson's disease was pioneered at BNL in the 1960s. To date, the disease has no known cure, but with L-dopa, a great many patients have become self-reliant individuals once again.

6 — Polymer composite materials, shown here in demonstration items, are used for construction and road repair.

7 — AIMS, short for air infiltration measurement system, was developed to study building ventilation. The latest application of this compact tracer system has been in hospital isolation rooms, to test for air-flow leaks.

8 — Blueprint for the first video game ever invented — electronic tennis for BNL visitors in 1958.

9 — Neutron activation analysis can determine the origin, age, method of manufacture and, in some cases, authenticity of art objects and archaeological artifacts, such as these ancient Mexican figurines.

10 — A device that monitors the performance of residential oil burners has been licensed for commercialization under the name Oil Watchguard Light, or OWL.

11 — BNL contributes expertise and technology to an international program aimed at safeguarding nuclear materials. BNL researchers have also developed new ways to store and dispose of nuclear waste.

12 — The proteins in this gel were made using the BNL-developed and patented T7 gene expression system, which has been licensed to about 170 biotech companies. Revenue to the Laboratory from patent royalties funds new scientific projects, graduate student appointments and educational efforts.

13 — Satellites that transmit news, entertainment and weather worldwide are more reliable thanks to the Tandem Van de Graaff, where microcircuits are tested for vulnerability to cosmic rays in space.

On the back cover — The data sheets are from a logbook for ongoing research on a novel method for determining the sequence of the three billion base pairs of DNA in the human genome. Unlike the examples above, this research is still in development. If it fulfills its promise in a practical way, it will help scientists reach a new depth of understanding of human biology and provide a basis for comprehending and treating genetic diseases.

DISCLAIMER

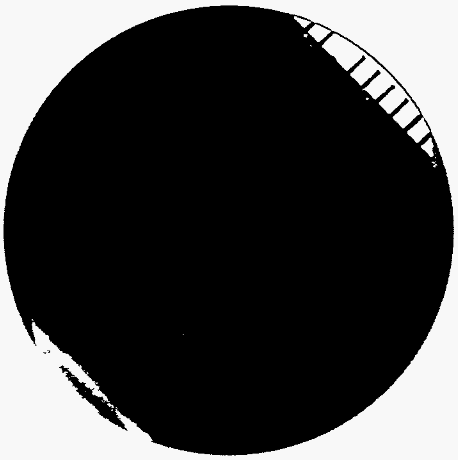
Contents

About Brookhaven

Established in 1947 on Long Island, New York, on the site of the former Army Camp Upton, BNL is a multidisciplinary laboratory that carries out basic and applied research in the physical, biomedical and environmental sciences and in selected energy technologies. The Laboratory is managed by Associated Universities, Inc., under contract to the U.S. Department of Energy.

BNL's annual budget is about $400 million, and the Laboratory's facilities are valued at replacement cost in excess of over $2.8 billion. Employees number around 3,300, and over 4,000 guests, collaborators and students come each year to use the Laboratory's facilities and work with the staff.

Scientific and technical achievements at BNL have made their way into daily life in areas as varied as health care, construction materials and video games. The backbone of these developments is fundamental research, which is and always will be an investment in the future.



Brookhaven Today

The more things change, the more they remain the same. And such is the case of Brookhaven National Laboratory.

Since we opened our doors in 1947, BNL has been changing the world through the fundamental research done here — from studies that unlocked critical secrets of matter and yielded four Nobel Prizes in Physics, to the discovery of L-dopa, still a key treatment for Parkinson's disease, to the development of technetium-99m, the radioisotope used in over 85 percent of the world's nuclear medicine procedures.

But even as we continue working toward more world-changing discoveries, one thing does not change. As President Bill Clinton and Vice President Al Gore wrote in their August 1994 publication, *Science in the National Interest:*

> *"While we cannot foretell the outcome of fundamental research, we know from past experience that, in its totality, it consistently leads to dramatically valuable results for humanity. We have every reason to expect that the science investment will continue to yield a very high rate of return."*

As always, Brookhaven is doing its very best to ensure that the U.S. sees a high rate of return on its investment of 47 years ago in a research laboratory in the Northeast where scientists could come to use major facilities and other resources that their home institutions could not support.

As times have changed, these facilities have changed to reflect new technologies and new national priorities, but their goals have remained the same — to help scientists unlock secrets that will lead to even more positive change.

Often, such secrets are hidden in the smallest particles of the universe and in the deepest recesses of the human brain. Yet the breadth of facilities at Brookhaven should uncover many of them.

The smallest particles include protons, neutrons, photons and electrons — the probes used by researchers at, respectively, our Alternating Gradient Synchrotron (AGS), High Flux Beam Reactor (HFBR), National Synchrotron Light Source (NSLS) and Scanning Transmission Electron Microscope (STEM). Larger atomic species — heavy ions — are the probe that physicists look forward to using later in the decade when our Relativistic Heavy Ion Collider (RHIC) comes on line. By recreating conditions that existed in the universe at the earliest moments of its creation, immediately after the Big Bang, RHIC will be a unique world-class facility with unparalleled potential for discovery.

Our individual universes, our brains, also hold many mysteries, some of which we expect to solve with the new Brookhaven Center for Imaging and Neurosciences. In September, I was pleased with the groundbreaking ceremony for the new, state-of-the-art, four-tesla magnetic resonance imaging, or MRI, facility that will join two other medical-imaging devices as the core of the new center. The others are the positron emission tomography, or PET, facility, which has gained world renown since beginning operations at BNL in the 1970s, and the single photon emission computed tomography program, or SPECT, where research started in the 1980s.

Brookhaven has a unique strength in the life sciences area. Our strong structural biology capability utilizing the HFBR, NSLS and STEM facilities; the genome center, which has made huge advances in the sequencing of the human genome; and the protein data bank, which is collecting and disseminating structures at an exponential rate, form a powerful combination in the biological sciences. The recent successes of these programs are outstanding. This has placed a huge stress on our available infrastructure, and, to meet an urgent need for laboratory and office space, we are requesting a new building from the U.S. Department of Energy.

Other research at Brookhaven could bring a cure for a type of brain cancer known as glioblastoma multiforme. That's the goal of our work on boron neutron capture therapy (BNCT). Though it's too soon to say for sure, a new boron compound and the beam from the upgraded Brookhaven Medical Research Reactor may have enabled us to save a human life, as our scientists used the combination to treat the first patient with our new BNCT, in September.

Lifesaving treatment has become routine at BNL for about 30 patients each day, in the three years since the University Medical Center at Stony Brook began operating its Radiation Therapy Facility (RTF) in our Medical Department. Now, we are exploring the possibility of building a proton therapy facility, to treat localized tumors that remain unaffected by electron facilities like the RTF.

Like our Brookhaven Linac Isotope Producer (BLIP), the proton facility would make use of excess protons siphoned from those our Linac is delivering to the AGS. For 20 years now, BLIP has been supplying the medical community with radioisotopes for diagnostic imaging, measurement of physiological function and cancer treatment. This year, we began an upgrade of BLIP that will help the U.S. reduce reliance on foreign radioisotope production.

High energy physics and medicine may seem like two different worlds, but the interconnection between different scientific areas has always been recognized at Brookhaven, which was conceived as, and remains, a multidisciplinary laboratory. As a physicist, I have always found the interaction with scientists from other disciplines to be stimulating and productive. Let me cite a few examples to show the variety and excitement of the research here.

Our biologists have developed "primer walking," a new method for DNA sequencing, which could lead to successful attacks on diseases with genetic links and will play an important role in our dream of having a biotech center at the Laboratory.

Our atmospheric scientists, oceanographers, computer scientists and others have teamed up to lend their expertise to the national effort to understand the mechanisms associated with global change and formulate strategies to deal with it.

Our energy scientists and computer analysts are part of two multiyear Cooperative Research and Development Agreements, called CRADAs, aimed at improving the competitiveness of the AMerican TEXtiles industry, or AMTEX.

Our environmental scientists are developing new ways to cope with various wastes. Some have developed a unique encapsulation process for sealing radioactive, hazardous and mixed waste in plastic for safe disposal; others are investigating the use of microbes to devour wastes that have already found their way into the soil.

Our most inventive minds are tackling the problem of the nation's infrastructure, from resurfacing our roadways to bolstering our bridges.

Some problems are of particularly local concern. For example, like many areas in the Northeast, Long Island has one of the highest incidences of breast cancer in the nation, and, as part of a national study, our epidemiologists are helping to determine possible causal factors.

Also prevalent on Long Island is Lyme disease, and our biologists are collaborating on a new test for early diagnosis of this debilitating, deer tick-borne disease.

Brookhaven is also giving Long Island's defense contractors opportunities to diversify. For example, Northrop Grumman is building the superconducting dipole and quadrupole magnets needed for RHIC, as well as the electron gun and beam transport system for our Chemistry Department's new Pulse Radiolysis Facility. And through our participation in the Long Island Research Institute, we're helping small defense-related manufacturers on Long Island to expand their product lines.

We also opened our doors this year to the National Weather Service, providing a much-needed home for the Doppler radar system that is enhancing weather forecasting for Long Island and the metropolitan New York area.

And our door is always open to students, from grammar school to graduate school. The students nurtured at Brookhaven though our many educational programs of today will be the scientists and engineers of tomorrow. The youngsters excited by the world that opens to them in our Science Museum today will be the researchers of tomorrow.

In these times of limited resources, Brookhaven relies on its most important resource — an exceptionally creative and enthusiastic staff that addresses the scientific challenges of meeting the concerns of today's educated populace. Our people are surely those of whom Clinton and Gore were thinking when they wrote:

"Our scientific and technical communities represent an enormous reservoir of talent, dedication and drive. We challenge them to continue their vigorous exploration of the frontiers of scientific knowledge and simultaneously to ensure that all Americans share their vision of the excitement, the beauty, and the utility of science in achieving our national goals. . . ."

On behalf of the Brookhaven staff, I accept this challenge and look forward to the exciting future we will build together.

N.P. Samios

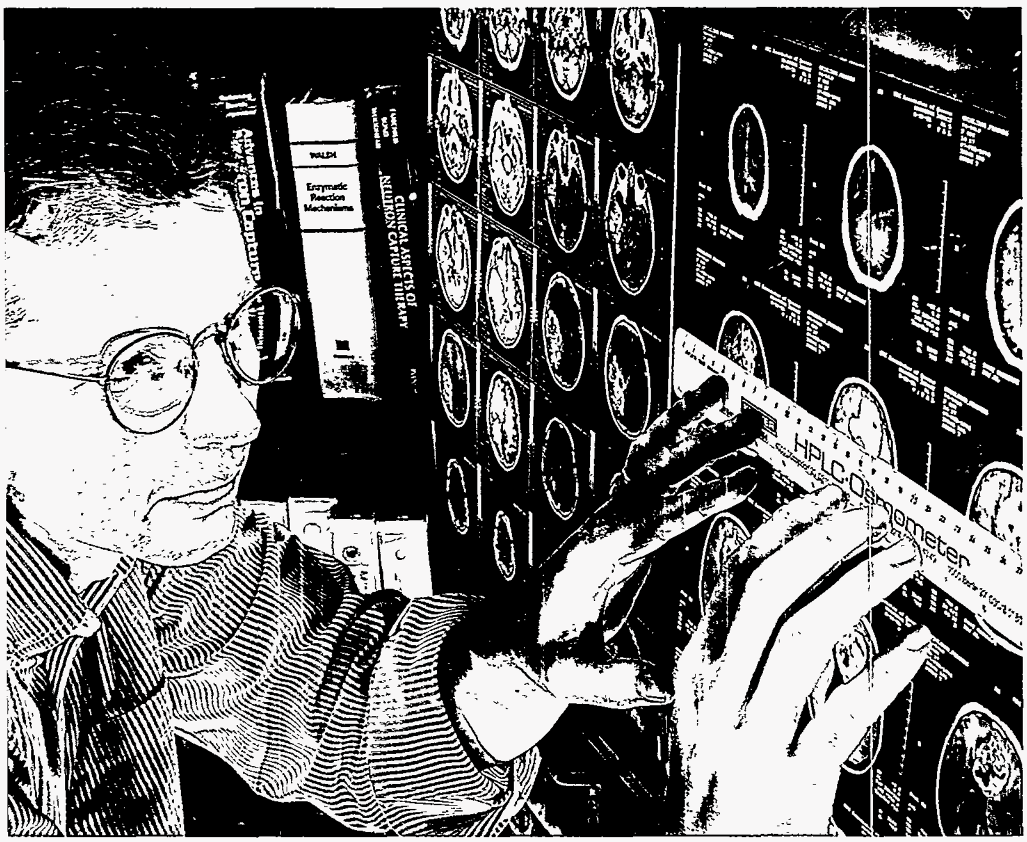
Nicholas P. Samios
Director

". . . changing the world through fundamental research."

Laboratory Director Nicholas Samios (left) with Robert Galvin, who chairs the task force appointed by the Secretary of Energy to evaluate the national laboratories, during an August visit.

Making a Difference in Everyday Life

The word science comes from scientia, the Latin word for knowledge. Throughout history, people have explored the world around them, gathering more and more details about how and why things happen. This broad base of knowledge is what feeds technology — the tools, materials and techniques that make life easier. Together, scientific and technological inventions have transformed human life.



Jeffrey Coderre measures the size and depth of a patient's brain tumor on a magnetic resonance image.

At Brookhaven National Laboratory, where research ranges from the development of new cancer therapies to the design of more efficient oil burners, we are very much involved in projects that make a difference in people's everyday lives.

Cancer Research

Cancer kills over 500,000 Americans each year, exacting a toll of fear, pain and suffering that is probably greater than for any other disease.

Drawing on the wealth of expertise available at BNL, scientists are developing experimental techniques to destroy cancerous tumors with electrons, neutrons, photons, protons and radioisotopes. Radioisotopes are also being applied to reduce the intense pain of cancer.

One promising project targets glioblastoma multiforme, a type of brain cancer so deadly that its victims have a life expectancy of less than one year after diagnosis. The treatment is called boron neutron capture therapy (BNCT).

In BNCT, a boron compound is administered to the patient and accumulates preferentially in malignant tumor tissue (see story on page 42). The tumor region is then irradiated with low-energy neutrons from the Brookhaven Medical Research Reactor. The boron nuclei absorb the neutrons and self-destruct, releasing powerful but very short-ranged radiation. Because the boron is mostly concentrated in the tumor cells, the cancer is thought to be destroyed without seriously affecting normal brain cells nearby.

A Window on the Brain

Brookhaven is a world leader in the development and use of an imaging technique that provides researchers and clinicians with a "window" on the brain. This technique uses a positron emission tomograph, or PET, to measure biochemical processes in the brain.

Besides being useful for studying disorders such as Parkinson's disease, Alzheimer's disease and schizophrenia, PET has also proven effective in research on substance abuse.

In a study of cocaine addiction, for example, our scientists have found that prolonged, heavy use of cocaine can deaden areas of the brain for a long time, possibly permanently.

Stalking the Silent Killer

The number one cause of death in the U.S. is heart disease. Using the world's brightest x-ray beam, Brookhaven researchers are pioneering the development of a new weapon to battle heart disease.

Called transvenous angiography, the new technique takes advantage of Brookhaven's National Synchrotron Light Source (NSLS), the only location in the U.S. for this medical research.

Routine coronary angiography, in which a catheter is threaded into a coronary artery to inject a dye, carries some risk of heart attack and stroke and is used only for patients with serious symptoms. In contrast, transvenous angiography at the NSLS calls for the catheter to be inserted into a peripheral vein. The procedure is safe enough that it can be repeated periodically to evaluate long-term effects of drug therapy and surgical treatment.

Laying the Foundation

In 1946, Associated Universities, Inc. (AUI) was founded by nine northeastern universities in order to bring together the resources of academia and the government to carry out broad research endeavors beyond the scope of a single university. This visionary idea resulted in the establishment of Brookhaven National Laboratory in 1947.

Brookhaven's achievements in science and technology have gained the Laboratory an international reputation. Consider this record: Four times throughout the Laboratory's history, world attention has focused on Brookhaven as the site of discoveries that merited Nobel Prizes. In the Laboratory's quest for knowledge, we are committed to the highest standards.

At the heart of Brookhaven is basic research, where we push at the frontiers of science. And we believe that from this research comes not only the pure joy of discovery today, but also the practical investment in a better life tomorrow.

The path from esoteric research to practical payoff, however, is often obscure. It takes time to make the connection.

For example, after more than a decade of fundamental studies of DNA, the carrier of genetic information, Brookhaven biologists patented a gene expression system in 1990. Today, about 170 licenses have been issued for this system based on T7 RNA polymerase in the bacterium *E. coli*. The numerous companies involved are using the method to make enzymes, proteins and other genetically engineered products for a variety of biotechnology projects — from investigating diseases to mapping chromosomes in the Human Genome Project.

Brookhaven expects to see similar widespread use of a patented corrosion-resistive coating system, which also grew out of basic research. At present, the coating system has been licensed by two firms, Novamax and TRW, and numerous other companies have expressed interest in it. The environmentally benign coating system uses organic polymers and zinc phosphate to protect steel surfaces against corrosion and enhances adherence of paints and plastics to steels.

At Brookhaven, we have seen that discovery carries the seeds of new technologies and new industries. We are convinced that basic research is the route to a brighter future.

A Beacon for Industry

Patients who come to the NSLS for transvenous angiography would be amazed by the rest of the facility.

As the world's largest synchrotron radiation facility, the NSLS serves about 2,600 users from over 400 institutions each year. About 350 scientists from close to 70 for-profit corporations conduct research there, some of it proprietary and destined to be applied to products that will directly affect everyday life.

Industrial research at the NSLS is wide-ranging: Exxon is probing platinum surfaces in order to design better industrial catalysts. AT&T Bell Labs is working to improve fiber-optics communications. DuPont is studying lead contamination in soils. All of these companies and more recognize the immense potential of the NSLS.

Environmental Concerns

Today more than ever, people are concerned about the environment.

Several BNL projects take a hard look at some tough cleanup problems. For example, the Laboratory is a partner in a joint project to demonstrate new technologies for cleaning up the New York/New Jersey Harbor, the nation's third busiest port — and one of the most polluted. New regulations ban ocean disposal of the six million cubic yards of contaminated materials dredged from the harbor annually, so technologies must be devised for decontaminating sediments.

One candidate may be a BNL-developed method that uses citric acid to remove lead and other heavy metals from contaminated soils and sludges. Already, the method is being field-tested with ash from incinerated municipal solid waste.

Air-flow leaks from hospital isolation rooms are another worry, as the number of tuberculosis cases and other infectious diseases increases in the U.S. Brookhaven is working with a Long Island company, Perfect Sense, Inc., to demonstrate the feasibility of using a perfluorocarbon tracer technology to detect air leaks from hospital isolation rooms. Currently, no such detection system is commercially available.

Global Change

Levels of carbon dioxide (CO_2) in the atmosphere have increased dramatically since the Industrial Revolution. CO_2 traps infrared radiation that would otherwise escape, thereby causing the earth to heat up.

But is there a consistent warming trend? Or might the rise in temperature be due to natural variability? Although the answers won't come easily, the quest is aided by unique tools developed at Brookhaven.

Our free-air CO_2 enrichment system, known as FACE, is a novel approach for doing field experiments in which plants are exposed to elevated levels of CO_2. Already, FACE is being used to study crops in Arizona, a maturing forest in North Carolina and managed grasslands in Switzerland.

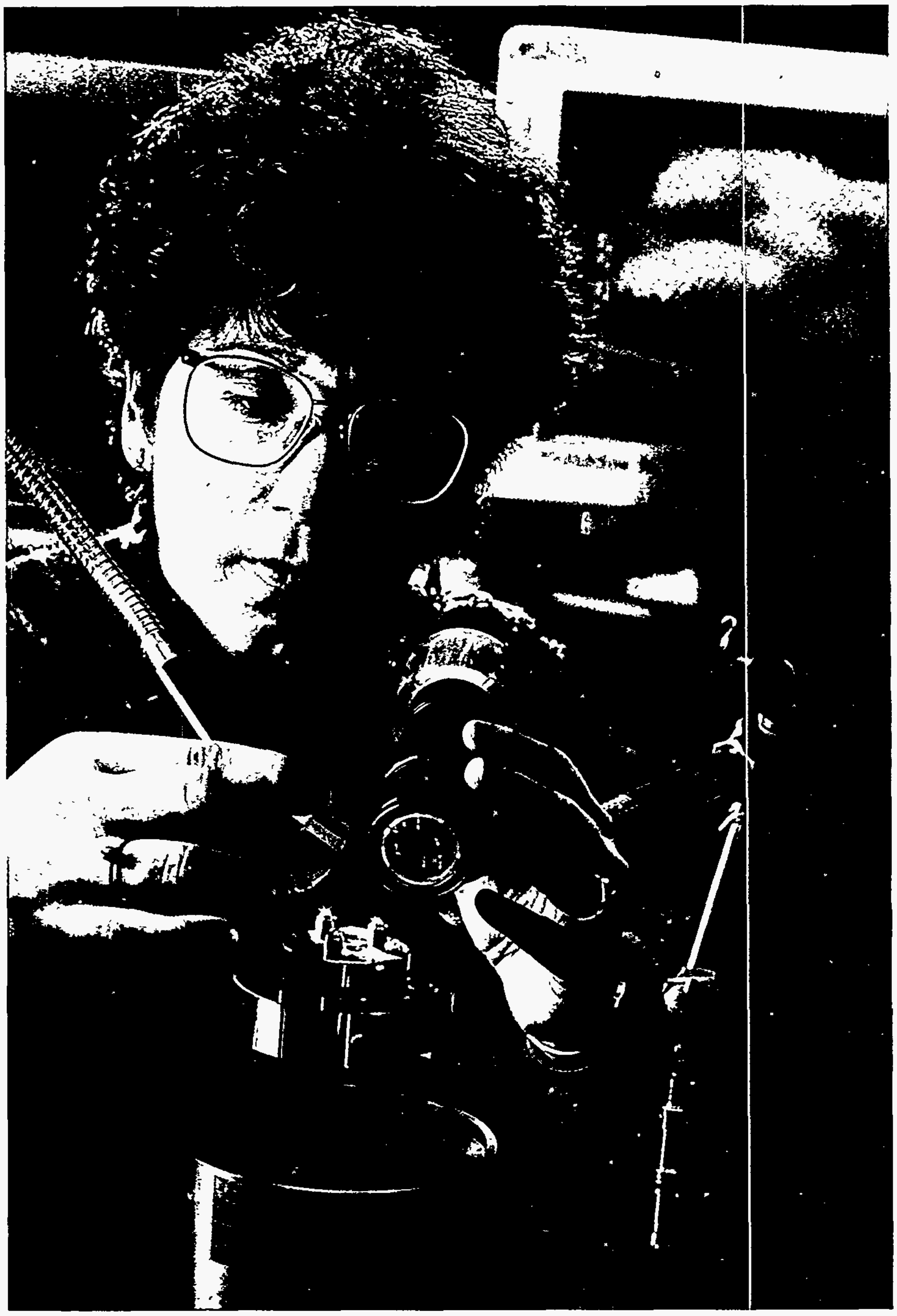
Nuclear Cleanup

With the Cold War ended, the U.S. is finally coming to grips with the enormous task of cleaning up hazardous and radioactive contamination resulting from nuclear weapons production. While Brookhaven has never been involved in weapons production, the Laboratory offers several solutions for managing the wastes generated by that activity.

One technique is polyethylene encapsulation. The process uses an extruder, a commercially proven technology of the plastics industry, to melt polyethylene plastic together with waste and form a solid, safe block. Compared to the conventional cement method, polyethylene can encapsulate as much as four times more waste into the same volume, making it more economical and more stable than cement.

Postscript

Caring for planet Earth and its people is a commitment to the future. Brookhaven makes this commitment every day, in its innovative research on health care, its outreach to industry and its unique programs on the environment.



Using a scanning probe microscope, Carissima Vitus studies surface films that make alloys resistant to corrosion.

A.J. Francis examines a flask of pollutants extracted from sludge using citric acid.

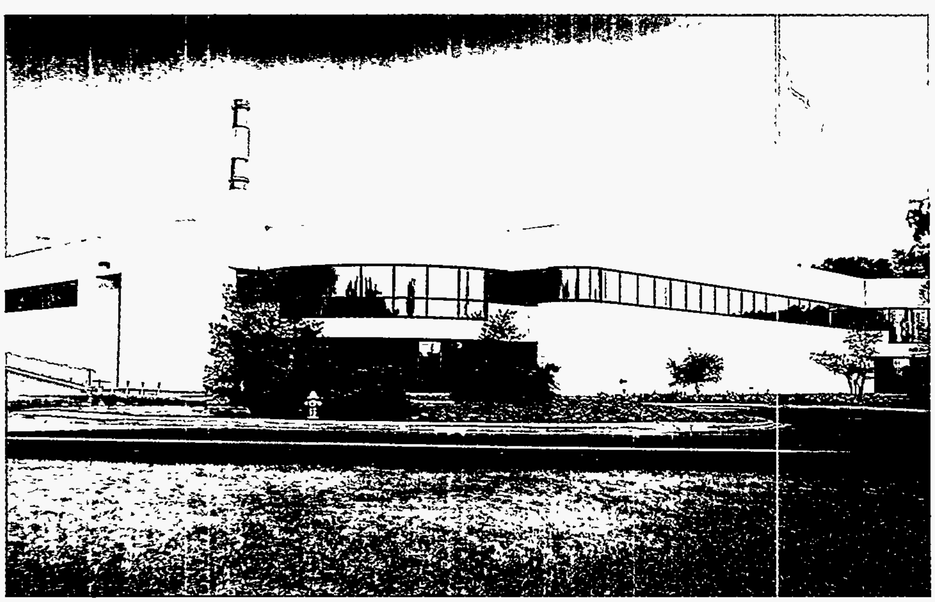
Highlights From the Past

Great discoveries are part of the legacy of research at Brookhaven. Here is a small sampling of the Laboratory's scientific and technological achievements that have benefited the world.

- L-dopa for treatment of Parkinson's disease.
- Pioneering work on the link between dietary salt and high blood pressure.
- Important radiotracers used in the diagnosis and treatment of diseases.
- Polymer concrete for road repair and construction.
- Invention of magnetically levitated trains.
- Design of energy-conserving Brookhaven House.
- Technology and expertise supporting an international program to safeguard nuclear materials.
- First video game, invented to entertain visitors touring the Laboratory.

The Big Machines

Performing forefront research requires not only knowledgeable, technically capable and insightful scientists, but also, state-of-the-art machines. Brookhaven's "big machines" — the National Synchrotron Light Source, Alternating Gradient Synchrotron, High Flux Beam Reactor and Scanning Transmission Electron Microscope — are world-class facilities that attract an international community of over 3,500 scientists each year to perform basic and applied research at the Laboratory. Representatives of industry, universities and other laboratories use these sophisticated tools for a variety of experiments in such diverse fields as biology, chemistry, physics and materials science. Brookhaven encourages collaborations with industry, and our Office of Technology Transfer assists industrial researchers who wish to use our facilities. Researchers may retain title to inventions and data generated during their work at the Laboratory by entering into a proprietary user's agreement with Brookhaven.



National Synchrotron Light Source

Brookhaven's National Synchrotron Light Source (NSLS) is the world's largest facility for scientific research using x-rays, ultraviolet and infrared radiation.

About 2,750 scientists from approximately 425 universities, laboratories and companies used the NSLS during fiscal year 1994, to study the atomic and electronic structure of materials. Such investigations are important for experiments in biology, physics, chemistry, medicine and materials science, among other fields.

Alternating Gradient Synchrotron

The site of three discoveries in physics that led to Nobel prizes, the Alternating Gradient Synchrotron (AGS) is also tops among the world's dozen proton accelerators in terms of proton intensity—it is now able to accelerate 40 trillion protons per pulse.

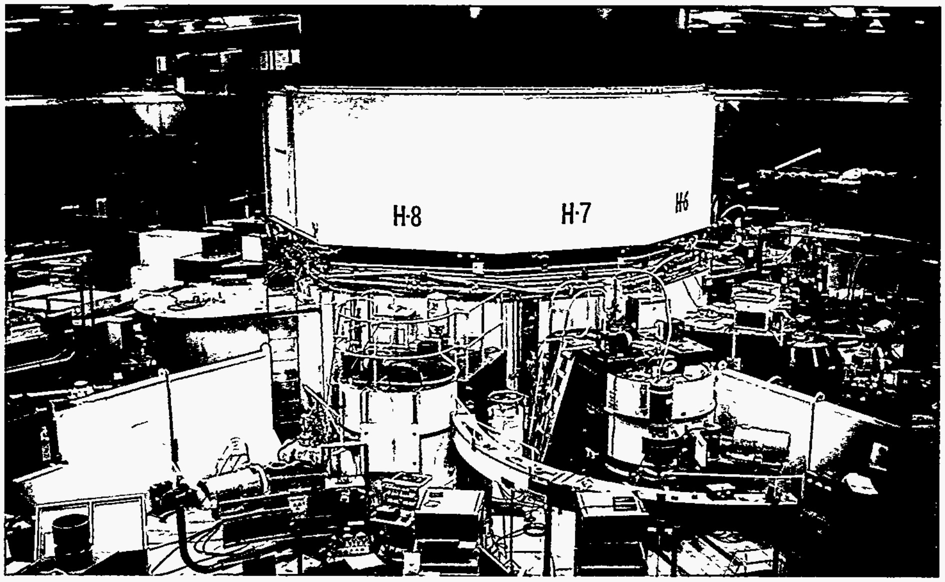
In the AGS, protons can reach an energy of 33 billion electron volts (GeV), polarized protons can climb to 22 GeV, and heavy ions can speed up to 14.5 GeV/nucleon. As a proton accelerator, the AGS is used for numerous rare kaon decay experiments, as it produces the world's most intense kaon beams. Some 650 researchers from 117 institutions probed the fundamental nature of matter at the AGS during fiscal year 1994.

High Flux Beam Reactor

The High Flux Beam Reactor is one of the world's premier research reactors. An international community of scientists uses its intense beams of neutrons for experiments in nuclear and solid state physics, materials science, biology and chemistry.

National Synchrotron Light Source

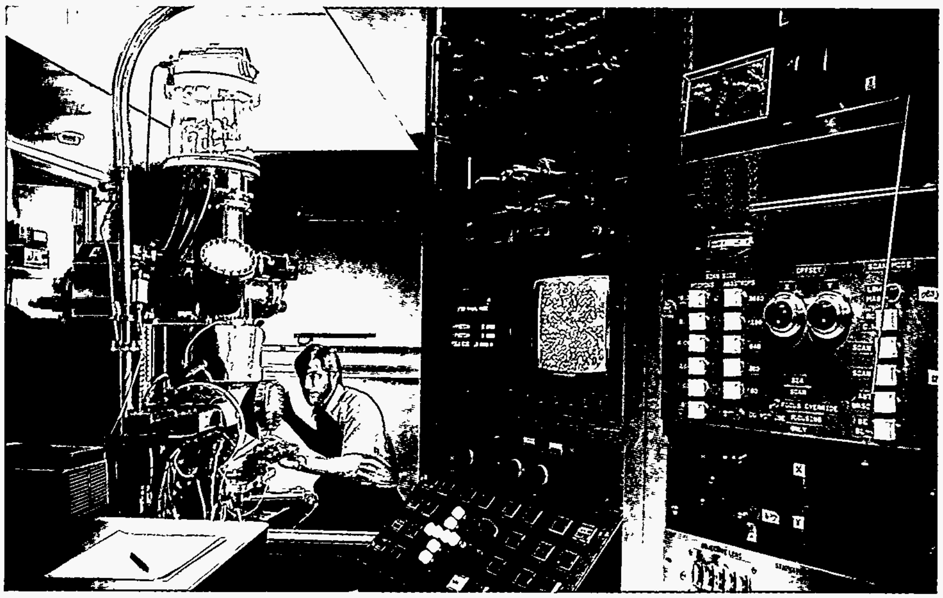
This year, the reactor attracted approximately 250 scientists from industry, universities and other laboratories. The facility was recently upgraded with the addition of a high-resolution neutron powder diffractometer, which is used to determine the atomic structure of polycrystalline materials.



High Flux
Beam Reactor

Scanning Transmission Electron Microscope

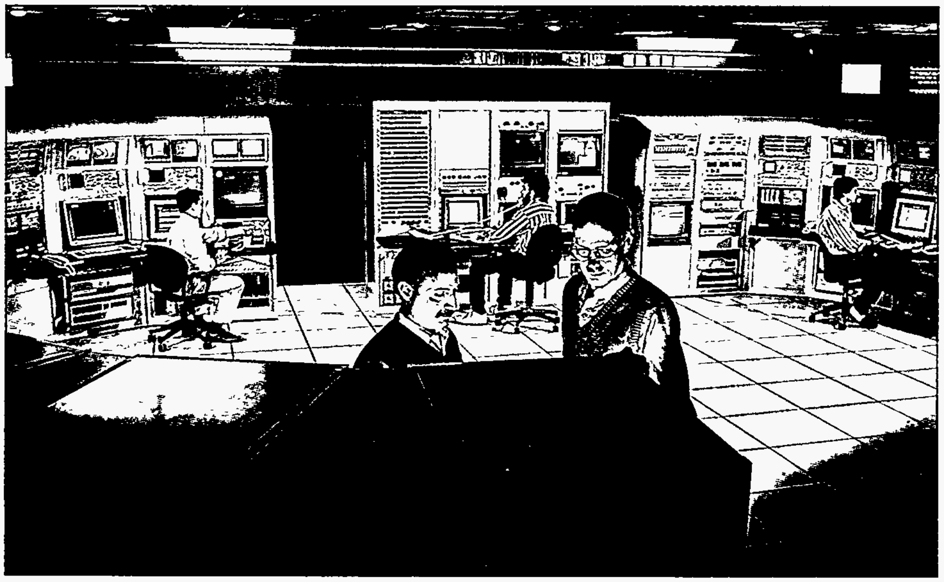
The Scanning Transmission Electron Microscope (STEM) is one of three microscopes in the world that can easily image single heavy atoms. Scientists use STEM to view biological specimens without adding heavy metals for staining or shadowing, and for determining the masses of proteins and DNA.



Scanning Transmission
Electron Microscope

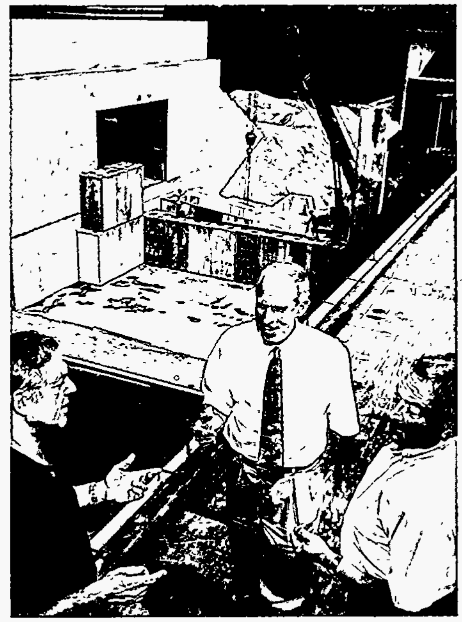
The microscope has a resolution of 2.5 angstroms (2.5 ten-billionths of a meter), and it can magnify samples up to ten million times. About 60 researchers from 35 institutions used STEM this year.

Another STEM was assembled by scientists at Brookhaven in 1994. It is used for elemental mapping of biological specimens.



Alternating
Gradient Synchrotron

RHIC Update



It was an exciting fourth year of construction of the Relativistic Heavy Ion Collider (RHIC). The facility quickly began taking shape, with civil construction completed this year and a growing string of magnets starting around the tunnel. And the action isn't limited to the collider itself. A visit to buildings 197, 902, 903, 905, 920, 924, 930, 935, 1000P, 1002, 1004 and 1005 shows bustling activity, as magnets and other hardware for the collider are worked on by the various specialty crews that make up the RHIC technical force. When completed in 1999, RHIC will be the world's premier facility for nuclear physics research. Within the collider's two rings of superconducting magnets, beams of heavy ions traveling at nearly the speed of light will smash head-on, creating the hot, dense plasma of quarks and gluons believed to have existed in the early universe immediately after the Big Bang.

Civil Construction

Pictured *above right* at the just-completed 12 o'clock collision area of RHIC are: (from left) Jack Feldman, Michael Schaeffer and George Capetan.

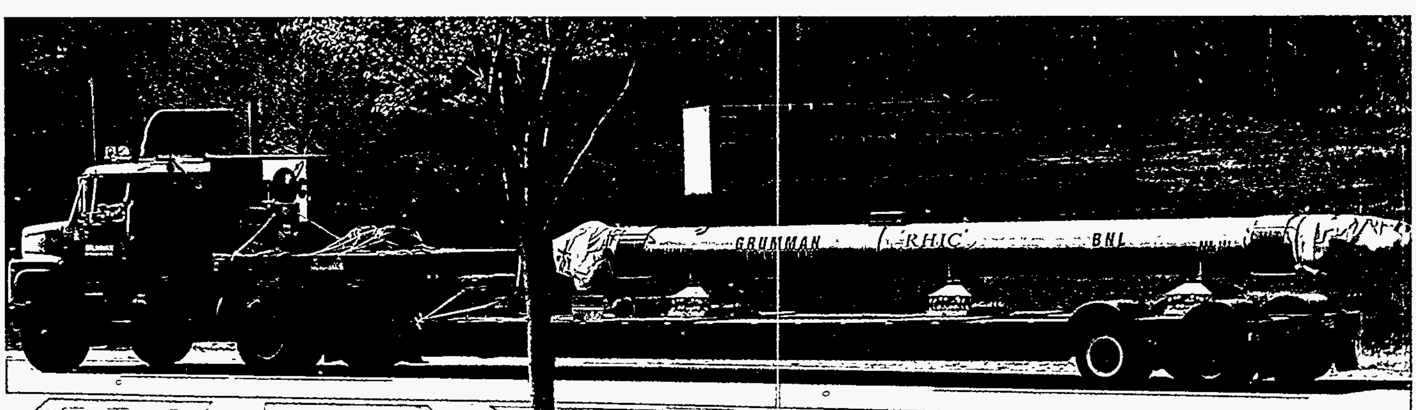
With the completion in late August of the accelerator enclosure at the 10 and 12 o'clock positions around the ring, and with the addition of magnet-access tunnels at 8 and 12 o'clock, the main contract for civil construction of the RHIC facility has been completed on time and within budget by Seacrest Construction, Inc., a Long Island firm.

During the 14-month civil-construction period, Seacrest employed approximately 200 people through 30 subcontractors, poured 6,800 cubic meters of concrete, moved 42,000 cubic meters of earth, and put down 3,600 cubic meters of topsoil.

Magnet Progress

RHIC will need a total of 1,700 superconducting magnets, including dipoles, quadrupoles, sextupoles and special-purpose magnets. Industry will manufacture 1,200 of these magnets, based on BNL's designs. — a major technology-transfer effort between the Laboratory and industry.

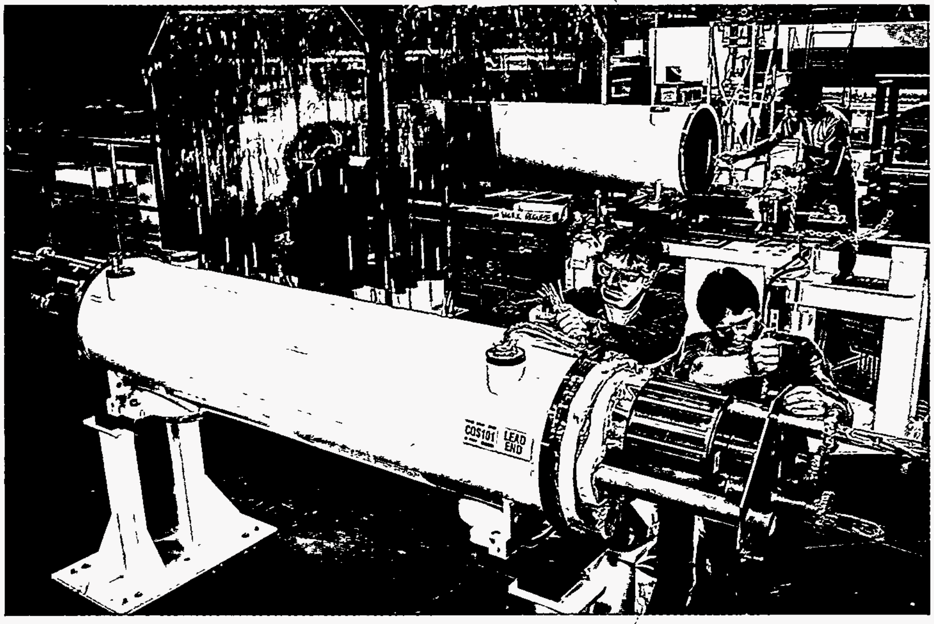
Below, the first Northrop Grumman Corporation dipole magnet for RHIC rolled



through the Laboratory's main gate in May. Tested for a week, the magnet exceeded its design requirements by more than 30 percent. This magnet was the first superconducting dipole production magnet made by U.S. industry for use in a particle accelerator.

Earlier, in April, Grumman had delivered the first RHIC quadrupole magnet. It, too, tested superbly.

All the Northrop Grumman dipoles and quadrupoles, as well as certain insertion dipole magnets that BNL will build, use superconducting cable made by Oxford Superconducting Technology, a New Jersey-based company. The cable contract, originally signed in fiscal year (FY) 1991,



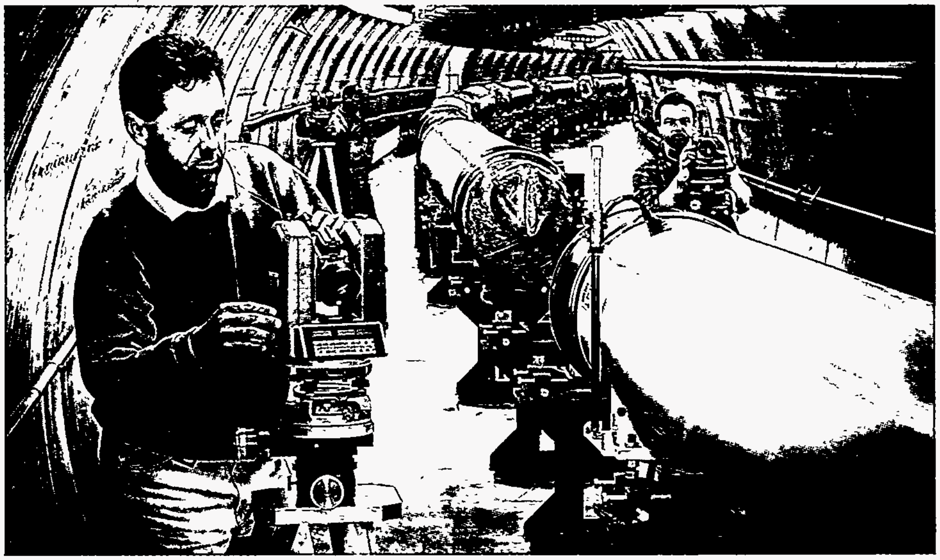
In the foreground with CQS 101 are Thomas Dilgen (left) and Edward Ulrich. In the background, Mark Cohen (behind the welding screen) and Domenick Milidantri are preparing the vacuum vessel for the second production magnet. After assembly, CQS magnets are tested for magnetic field quality and cryogenic integrity before delivery to the ring.

By year's end, one section, *below*, of the 3.8-kilometer RHIC tunnel boasted a string of dipole magnets. Surveying and aligning RHIC dipole magnets in the tunnel are (from left) Donald Kazmark Jr., Timothy Carroll and Douglas Gordon.

was fulfilled in FY94, when Oxford delivered the final shipment of 567,000 meters (about 1.9 million feet) of cables made of niobium-titanium alloy and copper.

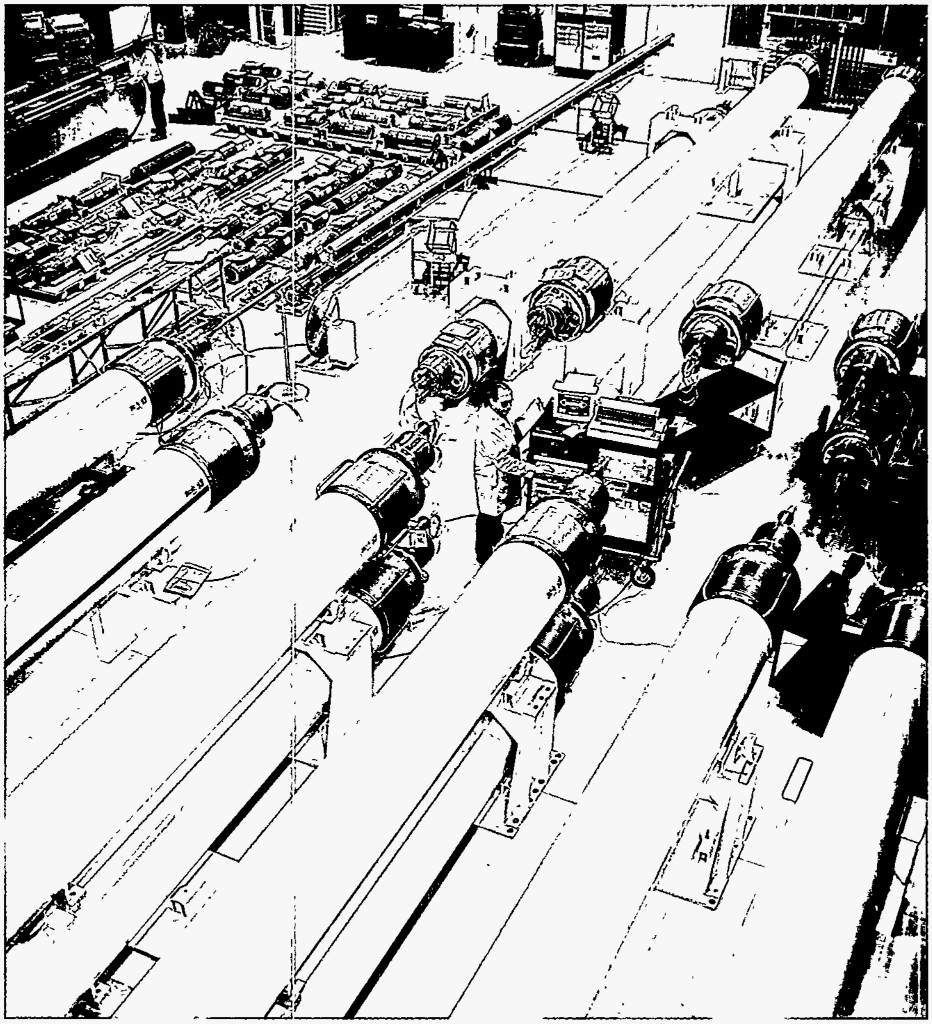
Above right, standing by the first industry-made superconducting magnet to be installed in the RHIC tunnel, Project Head Satoshi Ozaki addresses the crowd at the installation ceremony in August.

In the assembly area *above* for CQS magnets, a BNL-made corrector magnet, a quadrupole from Northrop Grumman and a sextupole from Everson Electric Company have been assembled into the first of 432 production CQS magnets that will be installed in the RHIC ring.



The annex of Building 902 *at right* is literally knee-deep with magnets. The long white ones surrounding Richard Kurz Jr. are dipoles made by Northrop Grumman. In the upper left corner, where Jim Luneberg (left) and Wing Louie are working, are Northrop Grumman quadrupoles, Everson sextupoles and BNL-made correctors.

All RHIC magnets pass through the annex. Incoming magnets are inspected for electrical and mechanical parameters, surveyed and then measured for magnetic field at room temperature. After they are cold-tested, just meters away at the cryogenic test facility, the magnets are returned to the annex for final electrical and mechanical measurements. When all parameters are acceptable for use in the ring, the magnets are loaded onto a truck and sent out to the collider for placement in the tunnel.



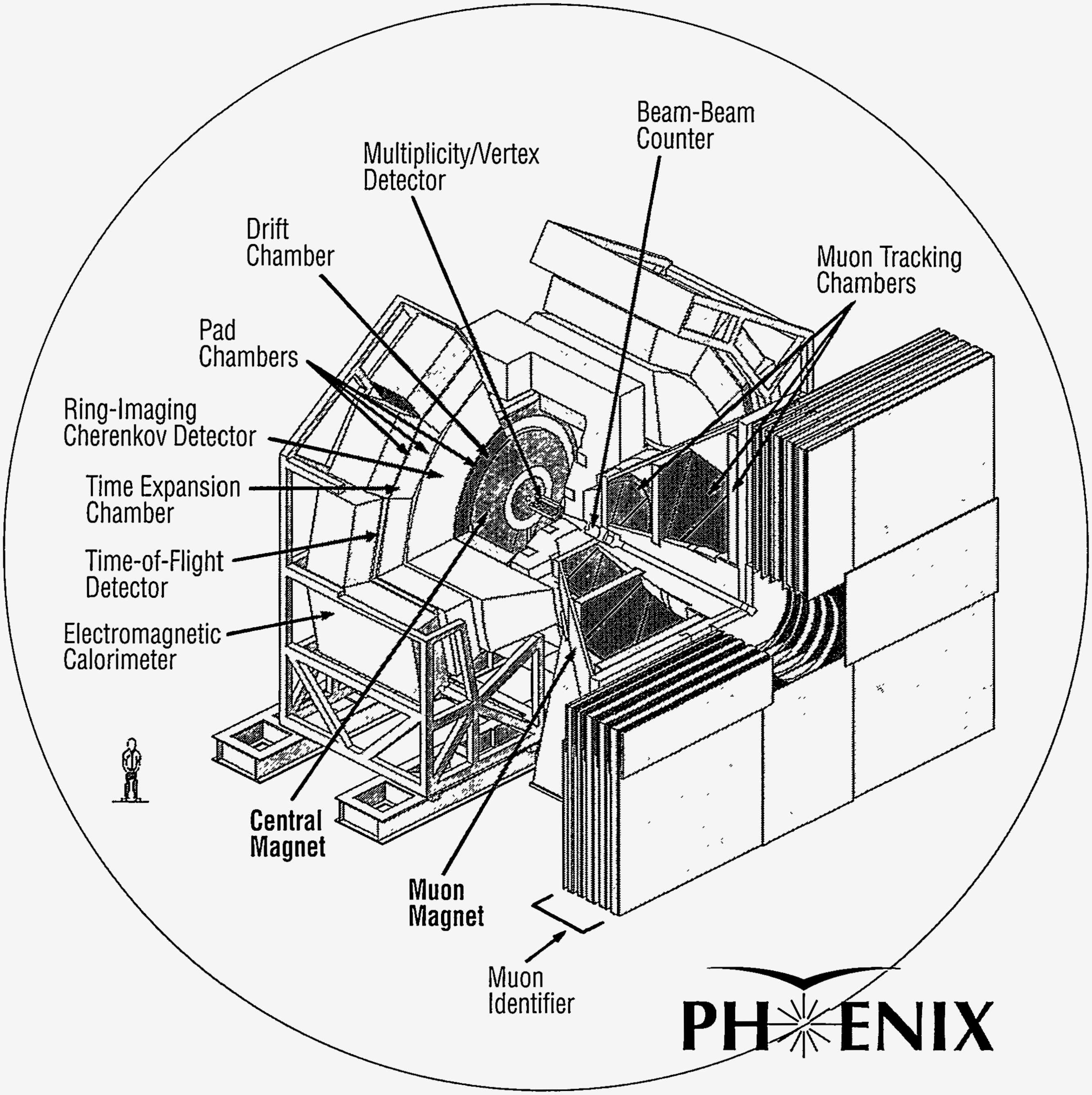
Experiments

When RHIC comes on line in 1999, two major detectors will be ready to search for the transition from ordinary nuclear matter to a new state of matter consisting of momentarily unconfined quarks and gluons.

One detector is called the Solenoidal Tracker At RHIC (STAR). Construction began in FY93, and this year, the British company Tesla Engineering, Ltd., was awarded a contract to build the magnet coils for the detector.

At left, this full-size mockup of a section of one end of the cylindrical STAR detector shows the locations of (from left) the time projection chamber end cap, the time-of-flight detector, the electromagnetic calorimeter and the magnet yoke. The mockup was built at Lawrence Berkeley Laboratory, one location where the detector's major systems are now under construction.

Photo courtesy of Lawrence Berkeley Laboratory.



The second major detector *above* bears the name PHENIX, for Pioneering High Energy Nuclear Interaction Experiment.

During the year, a cost-and-schedule review verified that the PHENIX detector was ready for construction. Prototypes of detector components are now being built at various laboratories around the world: certain pad chambers in Canada, another type of pad chamber in Sweden, the electromagnetic calorimeter and the drift chamber in Russia, the time-of-flight detector in Japan, and the time expansion chamber at BNL.

Also this year at the Laboratory, the Alternating Gradient Synchrotron was used to test some of the detector components for both STAR and PHENIX.

Altogether, the STAR and PHENIX detectors represent nearly 700 collaborators from 68 institutions in 13 countries.

Scientific Departments

BNL has been a multidisciplinary laboratory from its inception. The diversity of research is reflected by the Laboratory's organization into eight different scientific departments: Advanced Technology, Alternating Gradient Synchrotron, Applied Science, Biology, Chemistry, Medical, National Synchrotron Light Source and Physics. It is Brookhaven's breadth of expertise that helps keep us at the forefront of scientific discovery—a place where new ideas, new developments and new techniques flourish.

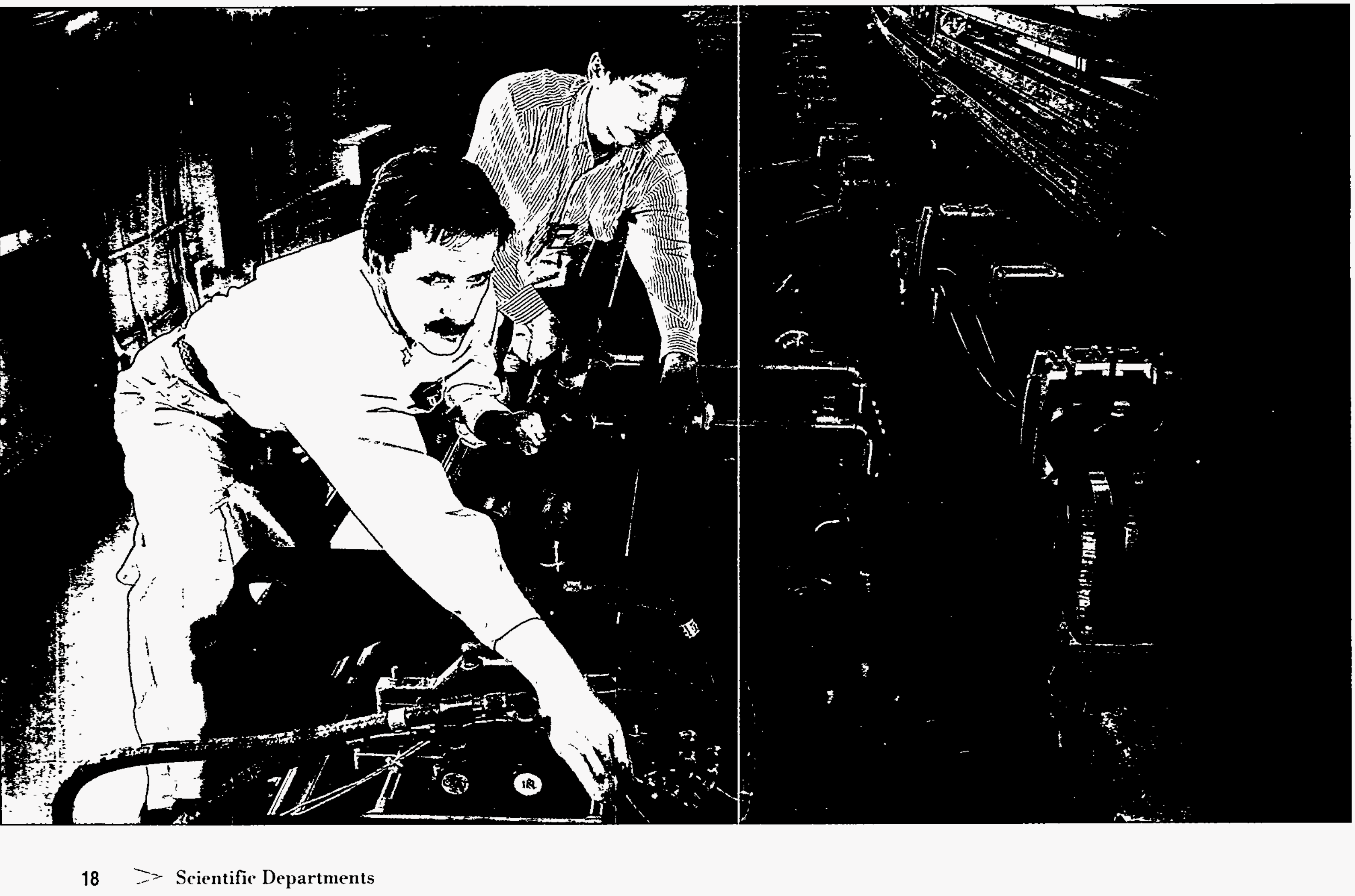
The AGS Department operates the Alternating Gradient Synchrotron (AGS), one of the world's most intense high-energy proton synchrotrons. Thanks to the Booster preaccelerator and other improvements made through the years, the AGS can now deliver 2.47 x 10^{13} protons per pulse. Accelerating heavy ions since 1987, the AGS also pushes gold ions to a record 11.7 billion electron volts per nucleon, pointing to the future of nuclear physics at the Relativistic Heavy Ion Collider, now under construction at Brookhaven.

Alternating Gradient Synchrotron Department

Siberian Snakes To the Rescue!

The name may suggest reptiles that inhabit the coldest regions of Russia, but Siberian snakes are a series of magnets that cause a polarized proton beam to wriggle like a snake.

Invented by Siberian scientists in 1974, these friendly "snakes" prevent polarized



protons, or protons that all spin in the same direction, from depolarizing—spinning randomly in various directions. A partial snake makes a polarized proton beam easier to achieve at Brookhaven's Alternating Gradient Synchrotron (AGS), while a series of full snakes opens up new possibilities for experiments involving polarized proton collisions at the Relativistic Heavy Ion Collider (RHIC) now under construction at Brookhaven.

Testing the Partial Snake

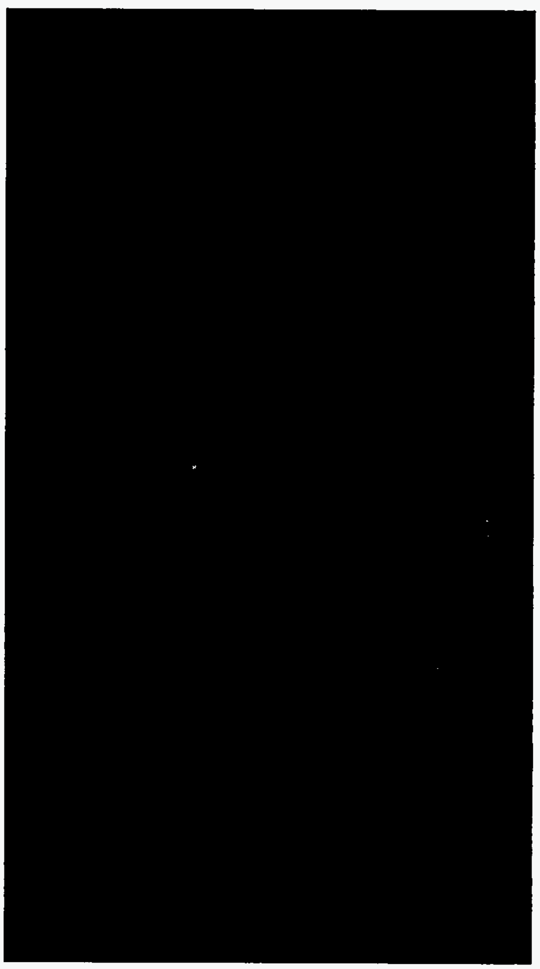
During fiscal year 1993-94, a collaboration involving Brookhaven, Argonne National Laboratory, Fermi National Accelerator Laboratory, IHEP in Russia, Indiana University, KEK in Japan and TRIUMF in Canada has been testing the effectiveness of a partial snake installed at the AGS. With it in place, the polarized proton beam was accelerated to an energy of 12 billion electron volts (GeV) with no depolarization. Without the snake, however, no polarization survived. The scientists plan to test the partial snake at its full operational energy of 25 GeV in early 1995.

Polarized protons come from hydrogen gas that is stripped of its electrons in BNL's polarized ion source. From there, the protons are preaccelerated in the linear accelerator to 200 million electron volts. Next, they are accelerated by the Booster to 1.5 GeV and then by the AGS to 25 GeV for research on the basic structure of matter. Polarized proton experiments measure spin effects in high-energy reactions.

A Depolarization Dilemma

It is a challenge to keep polarized protons spinning in the same direction in a circular accelerator like the AGS. They are kicked off their vertical axis by an accumulation of horizontal magnetic fields as they speed around the accelerator about a half a million times per second.

When hit by horizontal magnetic forces, the polarized protons precess, or wobble, similarly to the way that a spinning top wobbles when it is kicked from the side. When the frequency of the horizontal magnetic force is the same as the polarized protons' precessing frequency, the effects of the repeated kicks accumulate and completely depolarize the protons. This happens 40 times during the one second it takes to accelerate the polarized protons to 25 GeV.



Thomas Roser, BNL, (foreground) and Haixin Huang, Indiana University, are examining the partial snake in the Alternating Gradient Synchrotron tunnel.

Slithering in to overcome this depolarization comes the partial Siberian snake. It is made from a solenoid, an electrically energized coil of insulated copper wire that produces a magnetic field pointing along the beam of polarized protons.

The partial snake performs a clever trick: It rotates the spin of the polarized protons by nine degrees away from the vertical axis at each revolution around the AGS, so the effects of the kicks on one turn cannot combine with the kicks on the next turn. In fact, after 20 times around the accelerator, the kicks cancel themselves. It is as though the top were kicked from opposite directions —the force from one kick cancels the other, keeping it stable.

Snakes at RHIC

For RHIC experiments, polarized protons will be accelerated in the AGS before they move on to RHIC's two rings, where they will be accelerated to energies of up to 250 GeV per beam, colliding at an energy of 500 GeV. When RHIC is completed by the end of the decade, it will be the only high-energy accelerator in the world able to collide polarized protons.

In RHIC's 3.8-kilometer circular tunnel, the effect of the horizontal magnetic fields will be much stronger than in the AGS. To counteract this, two full Siberian snakes will be installed in each of the two accelerator rings of the collider. These Siberian snakes will flip the polarized protons' vertical axis a complete 180 degrees at each turn around RHIC. Thus, the horizontal magnetic forces will cancel themselves at every other turn.

Each ten-meter-long full snake will be constructed from four corkscrew-shaped, helical magnets using niobium titanium, a superconducting material. A prototypical helical magnet is being created by the RHIC Project magnet designers.

Searching for Strange Matter

The only known nuclear matter is found in the submicroscopic nuclei of atoms or in huge neutron stars. But that accounts for only 10 percent of matter in the universe. What happened to the other 90 percent?

Physicists have hypothesized that another form of nuclear matter, which they call strange matter, makes up the bulk of the universe. They believe it originated less than a second after the Big Bang, following the formation of an intensely hot, dense matter called quark-gluon plasma. When the plasma cooled, according to theory, strange matter should have condensed out of it.

Further analysis of conditions in the early universe indicates that the strange matter would probably not have survived in substantial amounts. Nevertheless, making strange matter anew in the laboratory remains an exciting possibility.

For the last few years, researchers at Brookhaven's Alternating Gradient Synchrotron (AGS) have started a search for strange matter. But, beginning this year, these efforts will reach a new level of sensitivity when a team of scientists tries to find it in a new experiment called E864.

A Mini Big Bang

To detect strange matter, an international collaboration of eight universities and BNL, headed by Yale University, will simulate a mini Big Bang at the AGS. They will accelerate heavy gold ions around the AGS to an energy of 11.7 billion electron volts per nucleon until they hit a gold target. At the expected beam rate of 10 million ions per second, the experiment will examine one million particle interactions per pulse.

A huge, 30-meter-long spectrometer with seven detectors — each the fastest of its type — will be able to keep track of 4,000 particle interactions per second. Physicists will examine these interactions in an attempt to find particles with the special characteristics of strange matter.

Examining Antimatter

Every elementary particle has an identical antiparticle with an opposite charge. Among the particles produced by the heavy-ion collisions in E864 at the Alternating Gradient Synchrotron will be several forms of antimatter: antideuterons, antiprotons, antitritons and antihelium particles. These are also of interest to the researchers looking for strange matter.

The E864 team will measure the production of these antiparticles with the goal of understanding how they are made. Also, light nuclei — nuclei with masses lighter than carbon — will be studied as they are produced in central collisions with the gold target. The production of antinuclei has been suggested as a signal of quark-gluon plasma formation. Thus, these investigations may lead to further understanding of how the universe was formed during the microseconds after the Big Bang.

Ordinary vs. Strange Matter

All ordinary nuclear matter is made of protons and neutrons, and these two particles are made of smaller ones known as quarks, of which there are theorized to be six kinds. A proton has a positive charge, while a neutron has a neutral charge. Ordinary nuclear matter cannot remain stable after it reaches a certain mass because the positive charges of its protons repel one another and overcome the short-range force that holds the protons and neutrons together.

Quarks can only exist in self-contained entities called bags. So far, physicists have detected bags of three quarks in ordinary, stable nuclear matter — the neutron being composed of one up and two down quarks, and the proton, two ups and one down. Another, heavier quark, dubbed the strange quark, has only been found in unstable particles.

Recently, however, physicists have theorized that the up and down quarks can combine with strange quarks to form strange matter. Strange matter would be almost neutral in charge, so it would not be limited by proton repulsion. Huge pieces of it could exist, and, indeed, scientists are searching for strange matter in meteorites and in neutron stars that are the result of the collapse of supernovas.

Unlike ordinary matter, strange matter could theoretically contain bags of more than three quarks. Normally, the weak force, a short-range force that determines the production and decay of many nuclear and subnuclear particles, would change a strange quark into a down quark, making the strange particle unstable. But physicists believe this would not happen in strange matter.

All nuclear matter contains various energy states that accept particles upon their decay by the weak force. According to some theorists, strange matter could be the low-

E864 researchers (from left) Richard Majka from Yale University, Carl Dover from BNL, and Guy Diebold, Jack Sandweiss, Frank Rotondo, all from Yale, discuss the installation of a large vacuum chamber for the experiment with BNL liason engineer William McGahern.

est energy state of nuclear matter, so no empty energy states would be available to receive down quarks that result from the decay of the strange quarks. Thus, strange matter would be stable.

As incredible as it might seem, some scientists speculate that the existence of stable strange matter could solve the world's energy crisis. By bombarding a chunk of strange matter with neutrons, energy would be released in the form of photons. If this electromagnetic energy could be harnessed, it would be an energy bonanza for future generations.

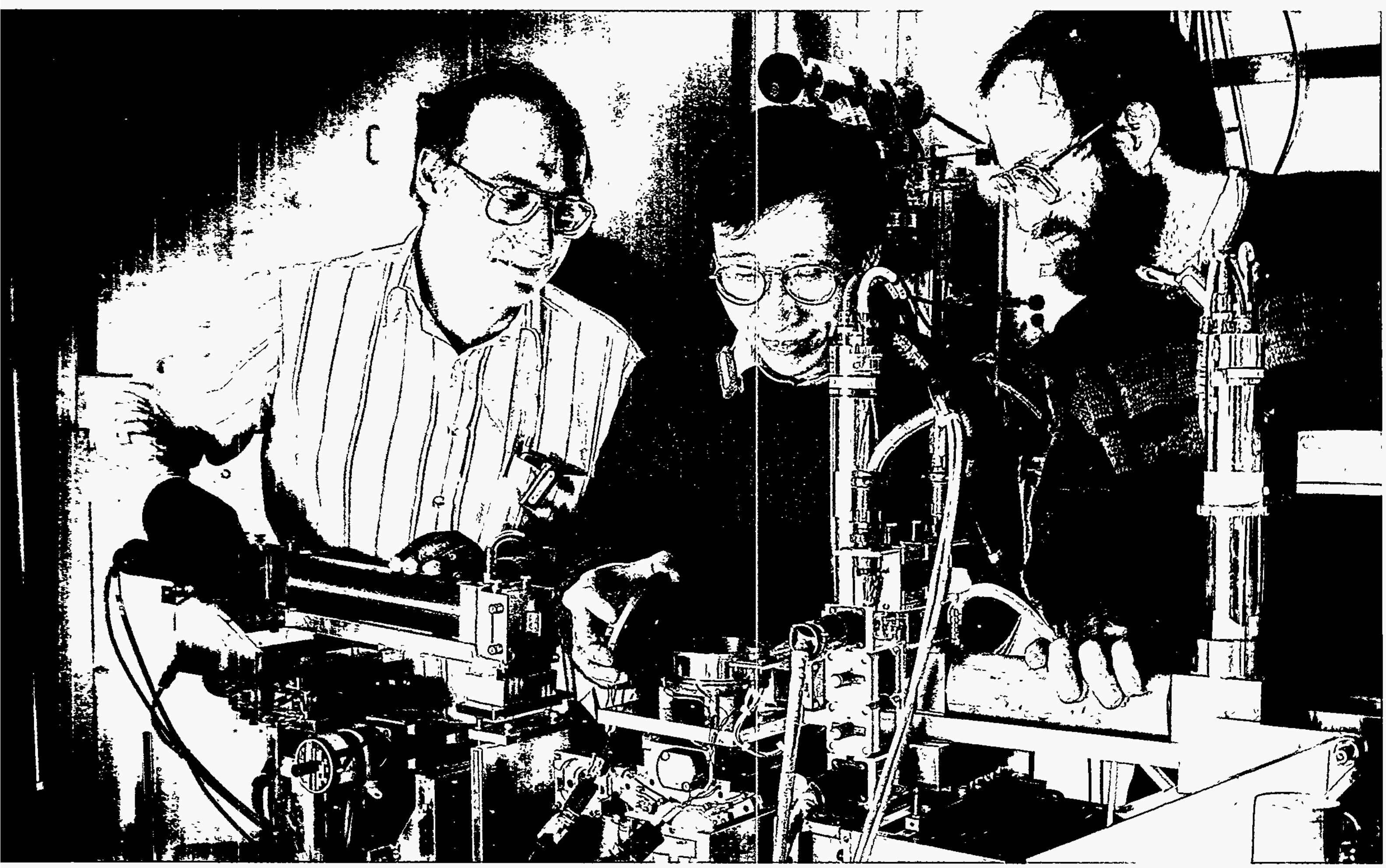
○ ○ ○ ○ *Research in the Physics Department focuses on the characteristics of matter. Particle physicists are interested in the building blocks of matter — quarks and leptons. Nuclear physicists study nuclear matter under extreme conditions, as well as the excitations and structure of atomic nuclei. And condensed-matter physicists examine properties of bulk matter and its surface, including such phenomena as high-temperature superconductivity. Also within the department, a facility to study the effects of radiation on microchips is available to outside users.*

Physics Department

Surface Studies — A Surprise Surfaces!

For many people, the sight of glowing candles usually evokes images of festivity, glamour or romance. But for some physicists, melting wax may bring about thoughts of surface studies.

These researchers investigate surfaces of materials at the atomic and molecular



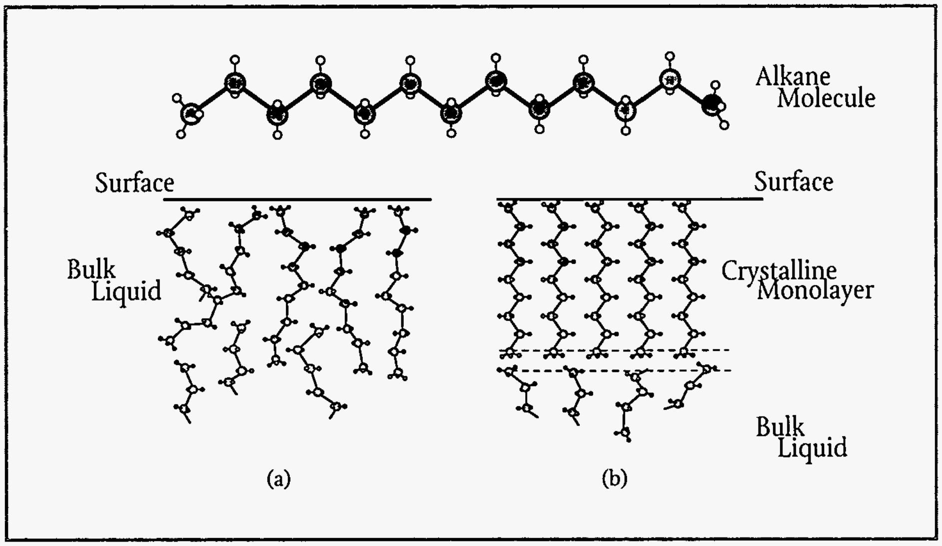
levels. This basic research may lead to industrial developments, since understanding surfaces is crucial to lubrication and catalysis, optical coatings and corrosion resistance.

Researchers from Brookhaven's Physics Department, in collaboration with Exxon Corporation and Bar-Ilan University in Israel, have been investigating the surfaces of wax-like materials known as alkanes. Composed of hydrocarbon molecular chains, alkanes are not only the constituents of candles, but also the building blocks of all organic matter. They are the major components of oils, fuels, polymers and lubricants — all tremendously important materials in industry.

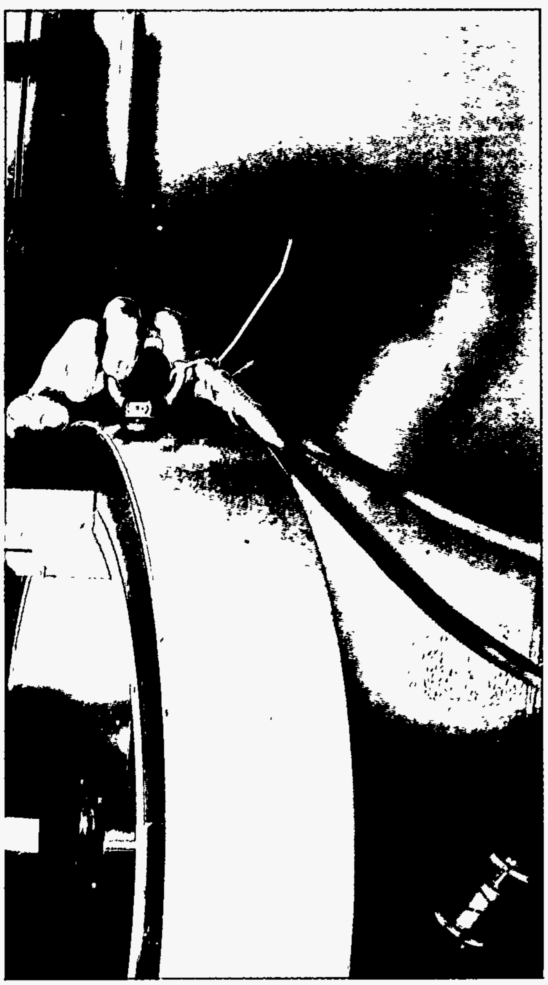
An Unusual Discovery

Using x-rays as probes at BNL's National Synchrotron Light Source (NSLS), the researchers have found that the top molecular layer of alkanes freezes, or crystallizes, at a higher temperature than the bulk freezing temperature. This is surprising because the entire sample — surface and bulk — is at the same temperature.

For example, an 18-carbon alkane is a liquid when it is above 30°C, but between 30°C and 27°C, its transition from the liquid phase to the crystalline phase begins to take place at the surface. In other words, the surface is crystallized and the bulk is liquid. At temperatures below 27°C, the entire sample is crystallized. This is the simplest system in which surface crystallization has been observed.



In figure a, the entire sample is liquid above 30°C; b shows that between 27°C and 30°C, the surface molecular monolayer-thick crystalline alkane phase coexists with the bulk liquid alkane.



Inspecting an alkane sample for surface crystallization at the National Synchrotron Light Source are: (from left) Moshe Deutsch from Bar-Ilan University; Xia-Zhong Wu, Exxon Corporation; and BNL's Ben Ocko. Also involved in these studies were Exxon's Sunhil Sinha and Eric Sirota.

It is an unusual discovery, since the opposite phenomenon — surface melting — is characteristic of most other materials, including metals and semiconductors. For these materials, over a range of temperatures, the surface is liquid even when the bulk is crystalline.

Using X-Ray Probes

At beam line X22B at the NSLS, the sample was placed in a temperature-controlled cell, and the physicists used a liquid spectrometer designed by researchers from BNL's Physics Department and Harvard University to characterize the structure of the liquid-vapor interface. This unique spectrometer, the first of its kind to be used at a synchrotron in the U.S., is designed so that the x-ray beam, rather than the sample, can be tilted — an essential feature for studying liquids.

To gather the data, the researchers focused x-rays on the sample and measured their scattering distribution. Using a technique known as x-ray reflectivity, they determined the molecular density of the sample along a direction perpendicular to its surface. Also, with a method called grazing incidence diffraction, they determined the lateral packing of the molecules.

The scientists observed that the surfaces of alkanes formed a near-perfect molecular crystalline layer at a temperature at which the bulk remained disordered. Specifically, x-ray reflectivity showed that for the 18-carbon alkane, a single 20-angstrom-thick layer of molecules crystallized at the surface. Within this surface monolayer, the molecules were standing straight up. Laterally, the molecules were arranged hexagonally — each molecule was surrounded by six neighboring molecules.

Exxon's Explorations

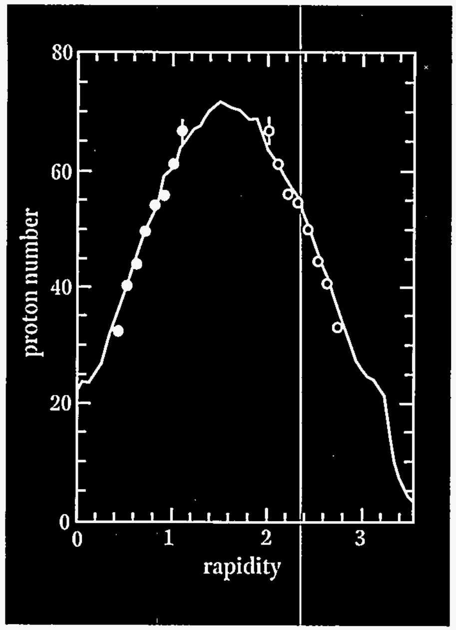
In their laboratory, the Exxon scientists measured the difference in energy between molecules at the surface and in the bulk liquid by monitoring the alkane's surface tension as the temperature was changed. An abrupt change in the surface tension slope occurred at exactly the same temperature at which the x-ray measurements showed surface crystallization.

Exxon is interested in this basic research because it has been developing modifiers that prevent wax crystallization. Crystal build-up can clog diesel fuel lines and injection systems. Understanding the structure and crystallization processes of alkanes may be essential for making the most effective additives.

On Target With ARC

From what kind of matter was the universe formed? What were the temperature and density conditions at its birth?

These are some of the fundamental questions physicists explore with current experiments at Brookhaven's Alternating Gradient Synchrotron (AGS). In the future, they will continue these investigations at BNL with a much higher energy accelerator, known as the Relativistic Heavy Ion Collider (RHIC).



The graph shows the distribution of protons from central gold-on-gold collisions at a beam momentum of 11.6 billion electron volts per particle. The solid curve, which represents the ARC predictions, closely matches the black and white circles, which show the measured distributions from E866.

At the AGS, the researchers accelerate beams of gold ions at nearly the speed of light until they hit a gold target, producing more than 500 new particles in the most violent collision.

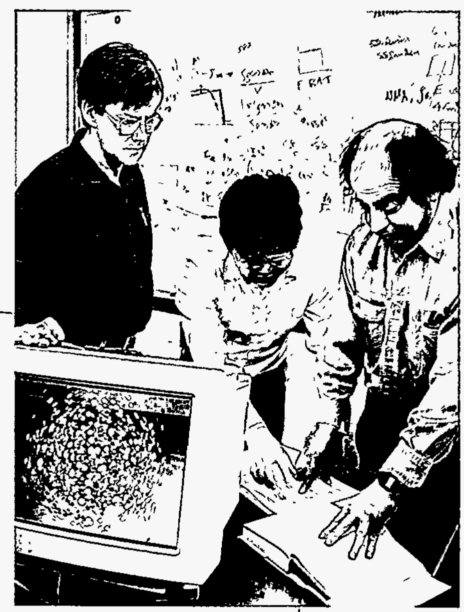
By studying the particles that result from these collisions, scientists hope to find evidence for a quark-gluon plasma — a form of hot, dense matter that has not existed since the earliest stages of the Big Bang, more than ten billion years ago.

Visualizing Collisions

To prepare for these unique experiments at the AGS, as well as those at RHIC — which is expected to produce at least 5,000 particles for gold-on-gold collisions — theoretical physicists in Brookhaven's Physics Department have designed a computer model for studying the quark-gluon plasma. It provides dynamic computer images of some of the particles that emerge from heavy-ion experiments. Such modeling is necessary to recognize the presence of the phase transition to a new type of matter.

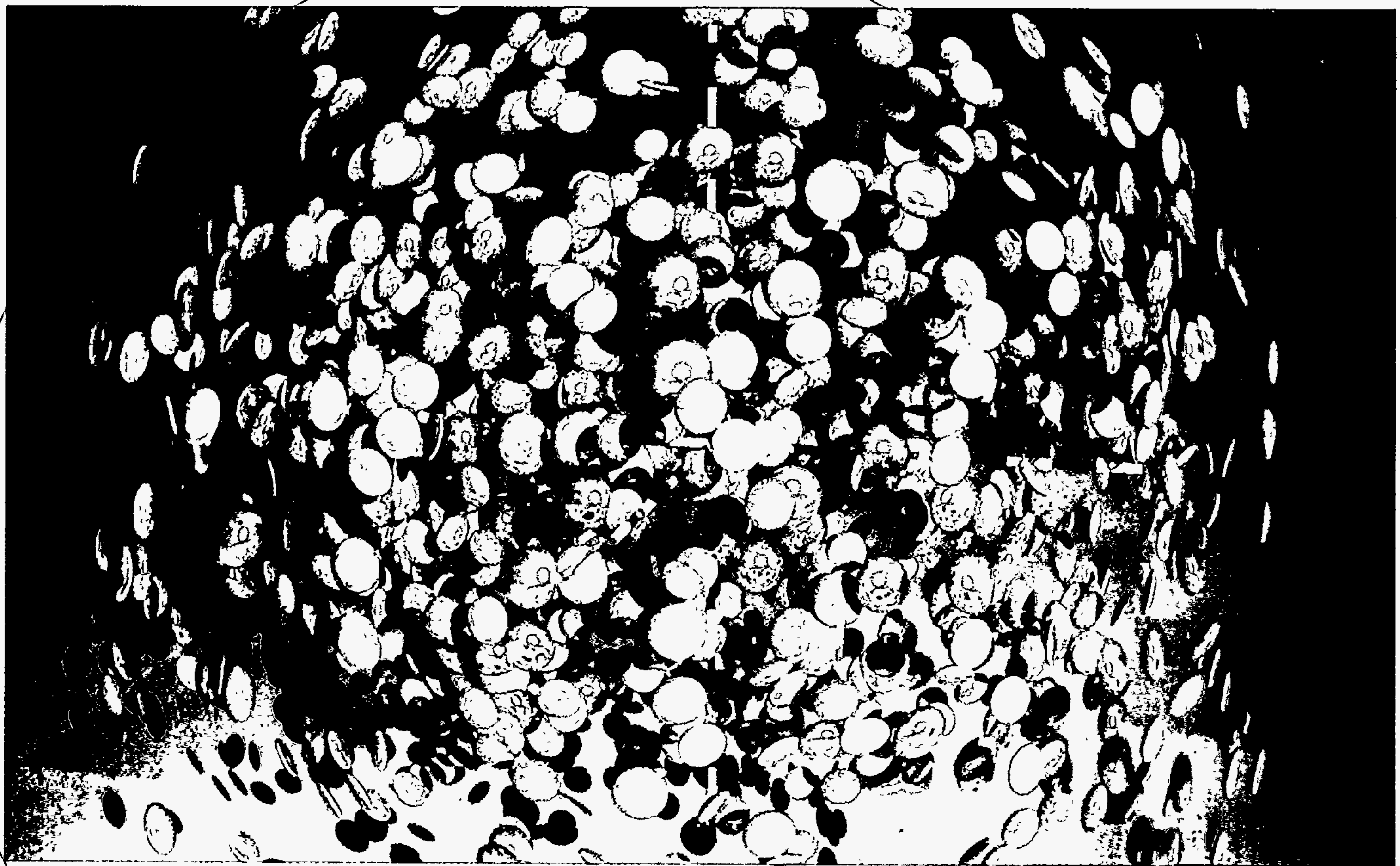
This innovative computer model, called "A Relativistic Cascade" (ARC), describes the multiple collisions and production of new particles from two nuclei travelling through each other at nearly the speed of light.

The formation of particles that results from a gold-on-gold collision is shown on the computer in a simulation produced by the ARC code, invented by: (from left) Thomas Schlagel, Yang Pang and Sidney Kahana.



Creating the Model

By creating ARC, our theorists hope to understand the underlying motion and interactions of particles produced in these high-energy collisions. The theoretical data include labels for each type of particle, as well as energy, momentum, position and time. Experimental data are used as input to the program for elementary collisions, such as collisions between two nucleons,



ARC visualization of the particles produced in a central gold-on-gold collision.

and predictions are made for nucleus-nucleus collisions. Thus, the theorists extrapolate from collisions involving two particles to much more complex collisions involving hundreds of particles.

Looking for the Plasma

Particles called hadrons, such as protons and neutrons, experience the strong force, which binds nucleons into nuclei. These particles are made of more fundamental particles called quarks and gluons. Under normal conditions, the quarks and gluons are confined inside the hadrons. But under extremely high temperatures and densities, the quarks and gluons may break free of the nucleons in hadronic matter — thus forming a quark-gluon plasma, as predicted by the theory of quantum chromodynamics.

When gold ions hit a gold target at the AGS, ARC suggests the collisions produce proton and neutron densities that are about ten times those of hadronic matter — a condition that physicists believe favors the creation of a high baryon-density quark-gluon plasma, in contrast to the baryon-free plasma that is expected to form at RHIC.

RHIC will offer another path to finding the quark-gluon plasma. When the new, higher-energy accelerator is completed before the turn of the century, two beams of heavy ions will speed around a 3.8-kilometer circular tunnel in opposite directions until they collide at a combined energy of 200 billion electron volts for each of the protons and neutrons contained in the colliding nuclei. As a result of these high-energy collisions, nuclei are expected to pass through one another, leaving in their wake a quark-gluon plasma at very high temperatures.

ARC simulates AGS experiments and is being extended to apply to RHIC experiments, providing important feedback for researchers who are looking for the quark-gluon plasma. As more data become available at the AGS and, eventually, at RHIC, the computer model will help to separate the ordinary from the exotic observables.

Biology Department

Research in the Biology Department aims to understand basic genetic and biochemical processes at the molecular level, including how genetic information is organized and used, how DNA is damaged and repaired, and how molecular structures determine biological function. Sophisticated facilities for analyzing biological structures are maintained at the National Synchrotron Light Source, High Flux Beam Reactor and Scanning Transmission Electron Microscope. And technology for large-scale DNA sequencing is being developed for the Human Genome Project.

From Dieter's Downfall To Cell Component

Anyone who has ever tried to lose weight knows to avoid saturated fat and to lower intake of unsaturated fats, too.

But it's probably a safe bet that few dieters know exactly what these "dreaded" fats are, nor how, where and why plants and animals make them.

Each cell in every plant and animal is enclosed in a membrane composed of both saturated and unsaturated lipids, or fat

molecules. Lipids are first made by the cell as fatty acids: long, hydrogen-rich — or saturated — carbon chains. Then, in a process called desaturation, some fatty acids are robbed of two hydrogen atoms and left with a double chemical bond, making them desaturated (see diagram). One double bond earns the fatty acid the designation "**mono**unsaturated," while two or more double bonds make it "**poly**unsaturated."

Scientists only poorly understand the process by which desaturation occurs. But a team of BNL biochemists is striving to learn more, through an investigation of how plants use an enzyme to desaturate these crucial molecules.

Through work done in the Biology Department, we have already isolated and sequenced the genes for the desaturase enzyme from several plants. With further research, we hope to find out more about the structure of different desaturases, and to determine how desaturases perform their crucial task.

This basic research holds great promise outside the laboratory too, for industries that use unsaturated plant oils to make everything from plastics to food additives.

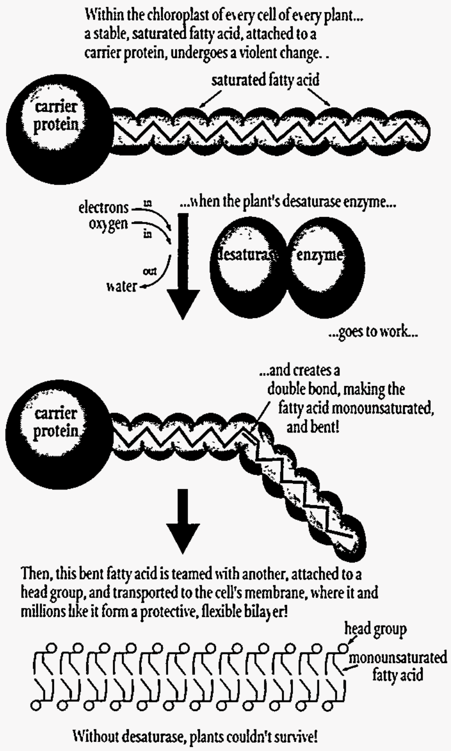
It's the Double Bond That Matters

Just like dieters, plants and animals are discriminating in the kinds of fats they use.

Since the membrane of each plant or animal cell needs to be flexible in order to function correctly, unsaturated fats make a very good membrane material — they are fluid even at relatively low temperatures because of the double bonds that give them their name.

In a growth chamber, (from left) Edgar Cahoon, Edward Whittle and John Shanklin gather seeds of the Spanish weed *Euphorbia lagascae*, which produces a unique fatty-acid-modifying enzyme.

Desaturation



But since plants first manufacture saturated fatty acids, very stable compounds that are solid at room temperature, their survival has depended on enlisting fatty-acid desaturase enzymes to insert the necessary double bonds.

Most common plants, including the major food crops, place the first double bond in the same place in the carbon chain, between the ninth and tenth carbons. But a rare few plants have a desaturase that puts this double bond in an odd place — between the sixth and seventh carbons, for example. Coriander, whose flavorful leaves are known as the herb cilantro, is one such plant.

The placement of that bond is critical to the interaction between lipid molecules and, hence, to the properties of the oil itself. Oils from two plants whose lipids differ in double-bond placement by just one position may have, for example, different boiling and melting temperatures, viscosities and effects on the human digestive system.

The genes for these novel desaturases are tightly regulated and expressed only in the seeds, so this is where the unusual fatty acids accumulate. In turn, these lipids can be extracted to make oils with novel properties. And that's where industrial interest lies.

Basic Biology Lays the Foundation

Before an industrially practical supply of these oils can be obtained, basic research must lay the foundation by examining desaturase from every possible angle.

It starts with finding out how desaturase is made. Our BNL biologists were the first to isolate the gene for a plant desaturase, from the castor plant. Grown in India, castor produces the oil given to generations of children for its laxative properties. Because its seeds are plentiful and oil-rich, castor is also a useful model for studying oil biosynthesis and modification.

Once they had found it, our scientists transferred the gene to the well-known *Escherichia coli* bacterium. *E. coli* grows relatively quickly and accumulates very high levels of desaturase, which can easily be extracted for experiments designed to establish the mechanics of the desaturation process.

A key to understanding this process comes from our discovery that the enzyme recruits iron, using it to bind oxygen. It is this fiercely active enzyme-iron-oxygen complex that allows the enzyme to attack the stable, saturated fatty acid.

Another goal is to figure out how the desaturase gene is regulated — what turns it on and off. To do this, our researchers have selected as their model a simple plant, *Arabidopsis thaliana,* also known as mouse-eared cress.

We have isolated all five of *Arabidopsis'* desaturase genes, and are now investigating how they contribute to the desaturation process in this model organism.

From Laboratory to Farmer's Field

Even though this is basic research, definite applications loom in the future. Preliminary experiments have already shown that the gene for an "odd" desaturase can be transferred successfully not only to bacteria, but to an entirely different plant species as well.

For example, coriander produces oil at levels much lower than soybean or oilseed rape plants. Instead of growing coriander for its oil's special properties, one option may be to put the special coriander desaturase into these existing crop plants for farmers to grow.

Once an existing crop can be engineered to produce new oils, it is conceivable that those oils could be used as petroleum substitutes for products such as plastics or nylon.

In addition to desaturase, the team is working to isolate other useful lipid-modification enzymes, such as an epoxidase enzyme from the Spanish weed *Euphorbia lagascae.* This enzyme adds an epoxy — the same hardening group that allows paint and some adhesives to set — to lipid molecules.

The research raises the possibility that soybean oil extracted from plants engineered to contain the *Euphorbia* epoxidase gene could be used directly as a setting agent, rather than requiring the chemical conversion of oil now used to make epoxy fatty acids.

This rosy picture of the future depends, however, on the detailed knowledge now being collected on how plants modify their fatty acids. And this work is complemented by a constant search for plant species with uncommon lipid-changing enzymes, such as the desaturase in the wildflower black-eyed Susan, in order to build a bank of knowledge from which future bioengineers can draw.

Picking the Tiniest Locks

They keep the necessary in and, most of the time, the harmful out. They serve as gates for needed supplies and harbor intricate locks that can be opened only by the most specific of keys.

But despite all we know about their vital function, the proteins that reside in the cell membranes of every living thing still guard many secrets.

Now, however, a team of structural biology researchers in BNL's Biology Department has used the technique of neutron diffraction at the Laboratory's High Flux Beam Reactor (HFBR) to unravel some of those mysteries.

Our research and the technological advances that accompanied it bore much fruit in 1994, especially those studies that concentrated on the virus that causes influenza and a drug that fights it.

An Influential Influenza Protein

The culprit in many pandemics, including one that killed 20 million people worldwide in 1918-1919, the influenza virus is a wily foe for medical science. The cell-invading mechanism of this virus mutates easily, making it difficult to develop a vaccine.

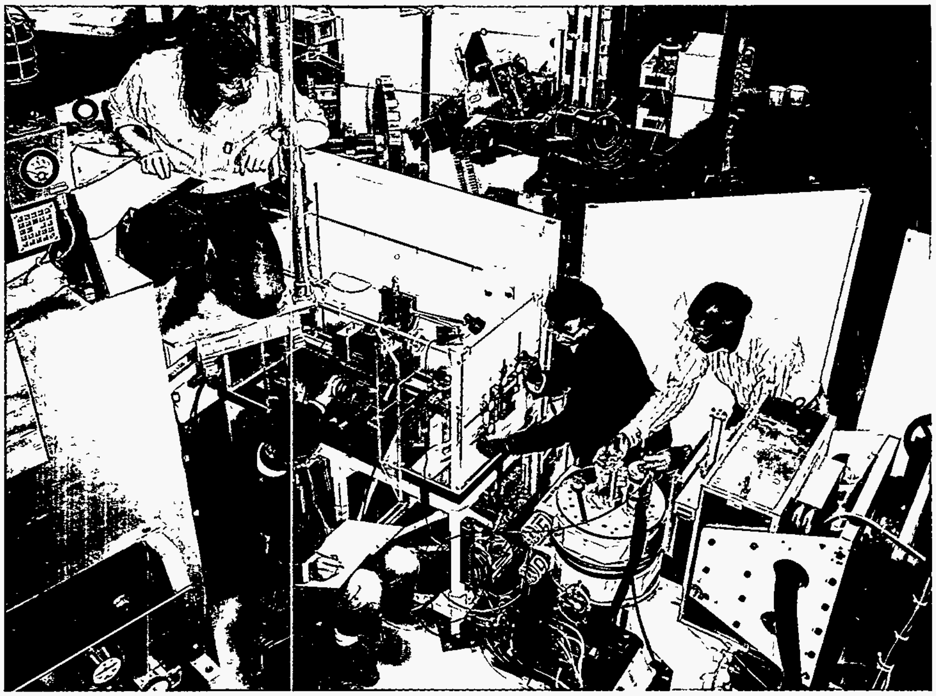
To defeat this crafty virus, scientists search for ways to interfere with its replicative cycle, so that, even if it invades a cell, the influenza virus cannot multiply. This kind of Achilles heel could prove medically useful.

One potential weak spot in influenza's armor, which our researchers spent much of the year investigating at the HFBR, may be the seemingly inconsequential protein known as M2.

M2 does not seem to play any role in getting influenza past the cell membrane "guardhouse" — two larger spiky proteins on the virus' coat, called hemagglutinin and neuraminidase, take care of that. But an experiment at BNL in 1994 proved a recent hypothesis that M2 acts as a proton channel — and it is this function that is important to the virus's replication and proliferation.

When the virus enters the cell, it is engulfed in a cell-within-a-cell called an endosome. In order for the virus to escape the endosome and reproduce, hemagglutinin's structure must shift, to allow it to fuse with the endosomal membrane.

Hemagglutinin's metamorphosis requires the help of M2, which pumps water into the virus. This equalizes the acidity, or pH, inside the virus with that of the cell's cytoplasm. If M2 doesn't do this, influenza



At HFBR structural biology beam line H3B, (from right) Anand Saxena, Jai Parkash, Xihong Bai and Adam Bera align a sample in a spectrometer.

cannot release its genetic material into the host cell's nucleus and, hence, cannot reproduce and cause illness.

This makes M2 an intriguing subject for study. Using the HFBR's neutrons to probe for clues about the protein's structure, our researchers are attempting to determine the exact position of M2 as it sits in the virus's membrane.

Especially of interest is the part of M2 that does not stick out from the membrane, but instead lies hidden within it. This makes the research a kind of hunt for buried treasure—and neutrons are an extremely good probe for this kind of search.

New Tools for the Trade

Studying M2 as it is embedded in the virus's membrane has led to the development of novel techniques and instruments.

Membranes are mostly composed of fork-shaped fat molecules called lipids, which form a two-layered membrane with their fork tines adjacent. To study proteins in their membrane habitat using neutrons, it is important to create uniform bilayers of lipids containing proteins in their native conformation.

Making Thousand-Layer Mirrors

Findings on M2 and other biological molecules examined at the High Flux Beam Reactor rely on a technology developed at Brookhaven: carefully constructed, super-precise, thin-film monochromators used to reflect neutrons onto biological samples.

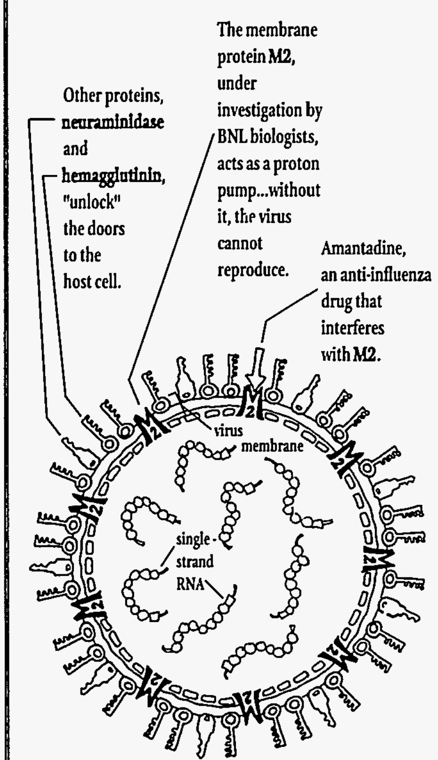
First built at BNL in 1974, these monochromators are now in use at facilities all over the world. They are valued for their ability to select neutrons within a narrow range of velocities, with minimal losses.

Even the most intense neutron source is about a million times less intense than a typical x-ray source. Hence, it is important to minimize the loss of neutrons as they travel from the reactor core to the sample, in order to give a signal that stands out from background "noise."

The BNL devices are made in our Biology Department, in a three-meter-long vacuum chamber. When they emerge from the chamber, the half-meter monochromators resemble mirrors. Actually, they contain thousands of precisely controlled, alternating layers of nickel and titanium.

The layers are carefully sprayed on a glass slide by a radio-frequency plasma as the slide moves back and forth through the chamber. Over the course of several days, the layers develop into a near-perfect synthetic, one-dimensional crystal.

Our engineers have a good record of keeping diffusion between layers to a minimum. And after years of improvements and experience in manufacturing monochromators, we can now craft these sophisticated devices at a rate of up to two each week.



Influenza Virus

A new technique was recently developed to deposit these layers on glass slides, using an ordinary hand-held, air-jet paintbrush purchased from a hobby store. The airbrush, similar to those used to make custom designs on T-shirts, makes it possible to "paint" a slide with a mixture containing water and roughly one part protein and 35 parts lipid. When the water is evaporated away, a stable and uniform layer is left on the glass plate.

Then, the sample is placed in the neutron beam. The distribution of neutrons that scatter in different directions contains information about the position of atoms in the sample.

Biological molecules contain large amounts of hydrogen, which gives a weak neutron-scattering signal. Luckily, hydrogen's heavier isotope cousin, deuterium, broadcasts its presence with a strong signal. In fact, it is the difference between the signals of hydrogen and deuterium that makes neutron diffraction such a powerful technique.

Drugs and Receptors

Using diffraction, we can examine analogs of M2's transmembrane sections built with different deuterated amino acids. This allows us to track the positions occupied by each type of amino acid and fit the results together like a puzzle.

Deuteration also makes it possible to study exactly how drugs interact with M2. One example is amantadine, an often-prescribed but little-understood anti-influenza drug that is thought to interfere with M2's proton-pump function.

Understanding more about amantadine, in turn, could lead to improvements in the drug itself, which is only effective for short durations because the devious influenza virus mutates quickly within a host and develops resistance to the drug. Other pharmaceuticals are also being examined here by collaborators from all over the country.

○ ○ ○ ○ *The world's foremost facility for scientific research using x-rays and ultraviolet and infrared radiation is operated by the National Synchrotron Light Source Department. In a single year, a total of about 2,750 researchers from almost 425 institutions perform experiments at the world's largest source of synchrotron light. Guest researchers often work in collaboration with staff scientists at the Light Source, conducting a wide range of innovative experiments in physics, chemistry, biology, materials science and various technologies.*

National Synchrotron Light Source Department

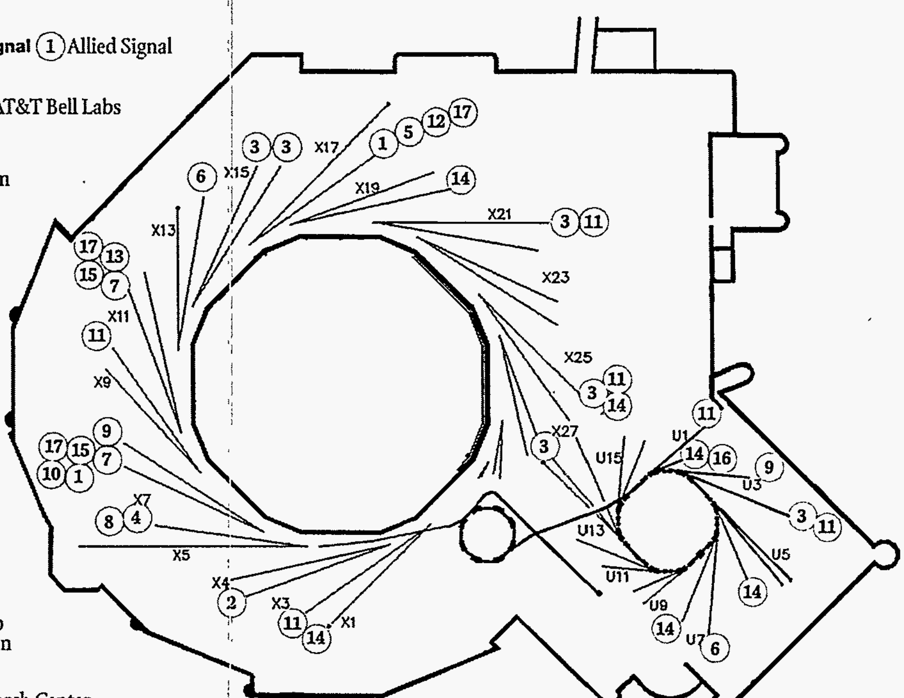
A Beacon for Industry

Since its commissioning in 1982, the National Synchrotron Light Source (NSLS) has been a beacon for industrial researchers and an important tool for facilitating technology transfer.

A source of light that is as much as 10,000 times brighter than conventional laboratory-generated beams, and a source of intellectual inspiration where hundreds of

Corporations that contributed to PRTs at Brookhaven National Laboratory's National Synchrotron Light Source

(1) Allied Signal
(2) Amoco
(3) AT&T Bell Labs
(4) BP America
(5) Chevron
(6) Dow Chemical
(7) Du Pont
(8) Eastman Kodak
(9) EG&G Energy Measurements
(10) Engelhard
(11) Exxon Research and Engineering Co.
(12) GTE
(13) Hoechst Celanese
(14) IBM
(15) Mobil Research and Development Corp.
(16) Northrop Grumman
(17) UOP Research Center



researchers from a range of institutions exchange ideas each working day, the NSLS is a powerful agent for transforming both basic and applied research into technological progress.

From AT&T Bell Laboratories to Upjohn Company, industrial giants as well as smaller entrepreneurial companies have been attracted to the Light Source to perform research on the 85 beam lines that surround its vacuum ultraviolet and x-ray rings. Today, some 350 industrial scientists from 70 companies are pursuing research that may lead to future innovative technologies.

Industry's Investment

Most of the beam lines are built by consortia of scientists from industry, universities and government laboratories called Participating Research Teams (PRTs). These scientists can use up to 75 percent of the available beam time to further their own research, with the research programs reviewed by panels of experts every three years. The remaining 25 percent is available for individual investigators through a peer-reviewed general user program. Beam time at the NSLS is free for all users unless their work is proprietary. In that case, a full-cost recovery fee is charged.

PRTs design the instrumentation at their beam lines to fit their individual needs. PRTs to which industry has contributed are listed on the previous page. Collectively, these 17 companies have invested more than $40 million and roughly 400 person-years of labor to design and install their own experimental equipment at the NSLS.

Pharmaceutical companies that use the National Synchrotron Light Source:

Bristol-Meyers Squibb

DuPont Merck Pharmaceutical Co.

Eli Lilly and Company

Genencor International, Inc.

Genentech, Inc.

Glaxo Inc.

Hoffmann-LaRoche Inc.

Merck & Co., Inc.

Miles, Inc.

Monsanto Company

Procter & Gamble Company

SmithKline Beecham Pharmaceuticals

Sterling Winthrop Inc.

The Upjohn Company

Advanced Analysis

For research that ranges from designing catalysts to developing computer chips, industrial researchers are drawn to the NSLS because it provides advanced analytical capabilities that are not available at their home laboratories. They study the absorption and scattering of x-rays at the NSLS to determine such properties as crystalline structure and magnetic characteristics of various materials. Such basic research may lead to practical outcomes, such as new pharmaceuticals and improved recording devices, or it may provide useful clues for solving problems in industrial processes.

For example, industrial researchers use a technique called x-ray diffraction, in which they measure the way an x-ray beam is deflected away from a sample, to determine the structure of crystals and monitor how that structure changes during industrial processing. The technique also can be used to detect defects in semiconductors. In addition, pharmaceutical companies use x-ray diffraction to understand how the arrangement of atoms in a drug molecule influences the way it works, so that they can design new drugs.

To keep up with the demand for beam time from structural biologists from pharmaceutical companies and academia, construction has started on an NSLS structural biology addition. When complete, it will house eight labs and a conference room. A summary of companies that have used the NSLS for pharmaceutical research is at left.

A Variety of Techniques

For materials that are difficult to study using x-ray diffraction, researchers can investigate local structural information using absorption spectroscopy, a technique in which they measure the absorption of x-rays by a sample. For instance, the local environment around the active species in a catalyst, which might affect its functioning, can be detected in this way.

Another technique that uses x-ray absorption, called microtomography, allows researchers to obtain three-dimensional images of the internal structure of visually opaque, heterogeneous materials. With the aid of this technique, for example, the oil industry can gain crucial information on oil flow through sedimentary rocks.

When a sample absorbs x-rays, electrons are emitted from its surface. Analyzing the behavior of these electrons can provide data on a sample's electronic structure, which is valuable in many industrial fields, most notably, the semiconductor industry.

New Discoveries

Also, synchrotron x-rays can change the structural properties of materials to make them industrially valuable. The best example is IBM's use of x-ray lithography at the NSLS to irradiate and chemically etch plastic-coated semiconductor wafers, thus producing some of the world's most advanced computer chips. In a new application of lithographic techniques, BNL and University of Wisconsin researchers are making micromechanical components that hold promise for many industrial applications.

In another recent endeavor, industrial researchers are attempting to make novel materials with the aid of synchrotron x-rays. For example, using synchrotron radiation to assist normally unfavorable chemical reactions in materials synthesis can yield products that are important for industry.

As the NSLS matures, still more innovative techniques for exploring materials are likely to be developed and new experimental capabilities will be discovered, undoubtedly leading to further industrial progress.

Industrial Research — A Sampling

From creating new catalysts to shrinking the size of computer chips, the wide variety of industrial research at the National Synchrotron Light Source (NSLS) reflects the diverse interests of the American marketplace. The following are a few typical examples:

Catalysis

Catalysts are vital to many industrial processes, as they drive the conversion of raw materials into useful products. Even small improvements in a catalyst's efficiency can lead to large savings in production. Thus, several of the nation's largest petroleum and chemical companies are using the NSLS for catalyst development.

For example, Exxon Corporation researchers use x-ray absorption spectroscopy to determine the geometric and electronic structure of catalysts. Solid, liquid or gaseous samples can be studied by this technique.

Recently, Exxon researchers have examined catalysts that contain tiny bimetallic clusters. By varying the surface composition of these catalysts, the researchers can alter the mix of chemical products as well as change the rates at which they are made. Such investigations may lead to more economical or environmentally safer gasoline.

Pharmaceuticals

At present, 14 pharmaceutical companies are working at the NSLS to develop novel drugs for treatment of a broad spectrum of diseases. Their approach, called structure-based, or rational, drug design, often involves designing molecules called inhibitors that attach themselves to enzymes, thereby blocking the action of disease-causing agents. To find effective inhibitors, the researchers use a technique called x-ray crystallography to determine the structure of an enzyme when a candidate inhibitor is attached.

Several companies — among them, SmithKline Beecham, Monsanto and Upjohn — are investigating the structure and functioning of the HIV protease, an enzyme associated with AIDS. Other research runs the gamut between attempting to find a cure for the common cold to designing new drugs for treating arthritis, hypertension and depression.

Environmental Assessments

Several teams at the NSLS are working on solving environmental problems. For example, soils in some regions of the U.S. have been contaminated with lead from mining, paints, leaded gasoline and industrial activities. To assess lead pollution, researchers from Du Pont are using x-ray absorption spectroscopy at the NSLS to determine the various types of lead found in contaminated soils.

One striking finding is the attraction of lead in soil for sulfur. When the two elements are combined, the resulting lead sulfide is highly insoluble, making it extremely unlikely that it would enter drinking water supplies. Such research can be used to make decisions concerning public health.

In another case, BNL researchers, with scientists from the Savannah River Ecology Laboratory and the University of Chicago, are using x-ray absorption spectroscopy to study the specific oxidation states of toxic metals and radioisotopes in contaminated soils at U.S. Department of Energy nuclear-processing facilities. Using an x-ray microprobe to determine how the oxidation varies within the sample, the scientists collect data on the extent of toxicity in the soil and the behavior of atoms in it.

X-Ray Lithography

A dramatic example of technology transfer at the NSLS came in 1988, when IBM announced that it had used x-ray lithography at the NSLS ultraviolet ring to make some of the world's most densely packed computer chips. With only 0.5 microns between components, the test chips were approximately four times denser than any mass-produced chip of the time. Such density promises vast increases in chip power and speed.

Based on this success, IBM has since built its own synchrotron storage ring in East Fishkill, New York, where chips are now consistently made with features as small as 0.25 microns. The company is now working to bring this technology to the marketplace.

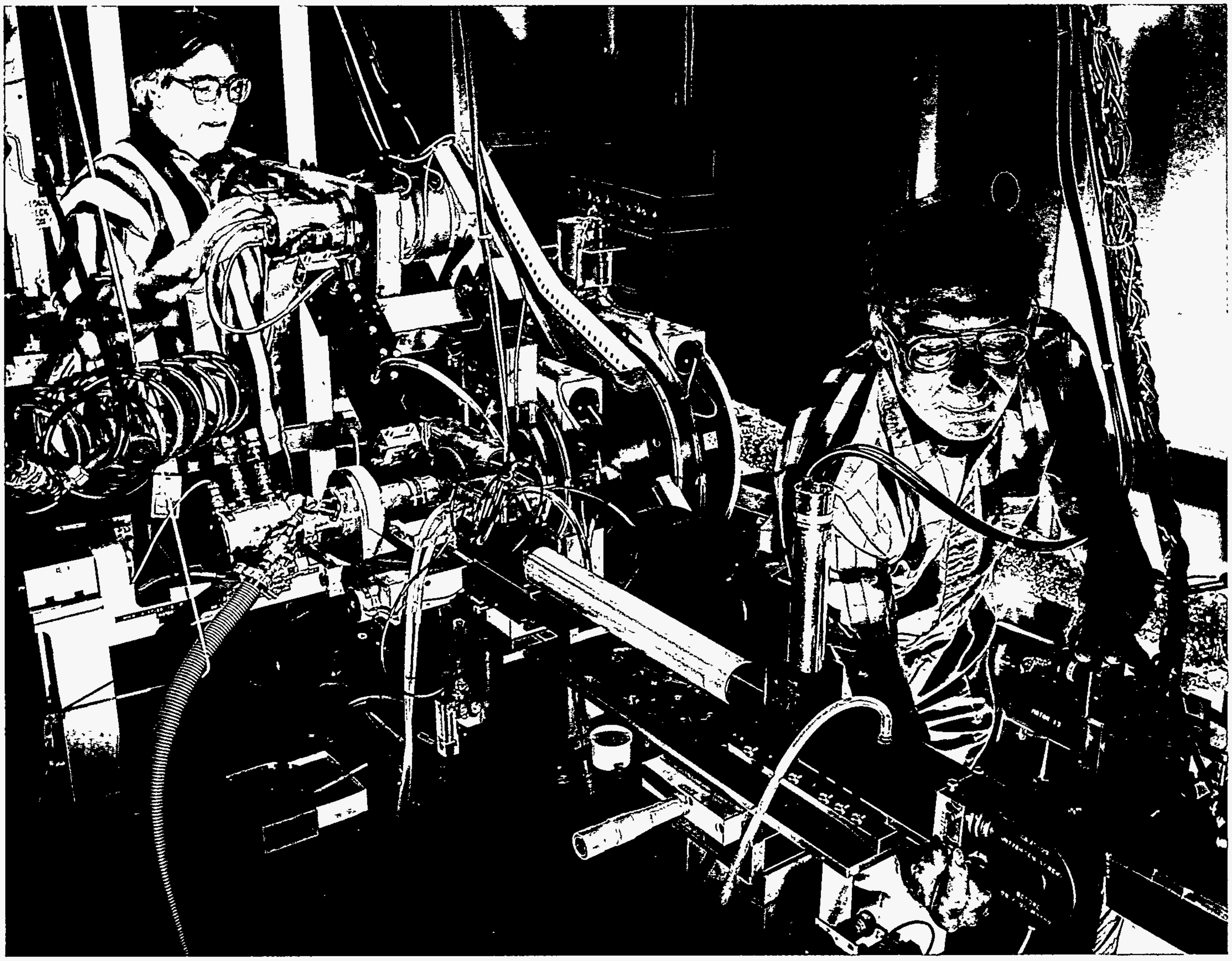
As the technology progresses, the number of circuits on chips is expected to increase approximately one hundredfold, making computers even faster and more powerful.

Elsewhere at the NSLS, AT&T Bell Laboratories is developing a technique called extreme ultraviolet projection lithography. This technique uses longer-wavelength light than IBM's shadow-mask x-ray lithography. In the AT&T method, which is far from the production stage, features as small as 0.05 microns have been imaged.

Another type of lithography — one that uses high-energy x-rays — is being developed by BNL and University of Wisconsin at Madison researchers to produce mechanical components that are several inches in size but match the precision of micromachines. These tiny mechanical components are used, for example, to make fiber-optic devices and electric motors the size of a pinhead. Successful development of this new lithographic technique into a full manufacturing process would expand micromachine applications and thus give the U.S. a competitive edge in the precision-machining area.

Medical Technology

The NSLS is at the forefront of developing promising medical technologies. Among them is transvenous coronary angiography, a technique that produces research-quality images of human coronary arteries. Since this angiography procedure requires catheterizing a vein, rather than a plaque-clogged coronary artery as in the conventional method, risk to the patient is reduced.



Before collecting powder diffraction data on a catalyst, Richard Harlow (left), DuPont Corporation and David Cox, BNL, make adjustments to the beam slits at beam line X7A.

An estimated one million angiographic procedures are performed annually in the U.S. to assess atherosclerotic disease, which is the number-one cause of death in the country. To make transvenous angiography more widely available, BNL scientists are currently working with two industrial partners — Advanced Acoustic Concepts, Inc., and Science Research Laboratory, Inc. — to improve the image-display system and to produce a compact source of high-intensity x-rays for hospitals and clinics.

Polymers

Polymers, chemical compounds made of giant molecules, are widely used in such products as plastics, nylon, rubber and vinyl. A new technique to study polymers at high spatial resolution has been developed at the NSLS by North Carolina State University and the State University of New York at Stony Brook in collaboration with Dow Chemical Company, Du Pont and Exxon.

Called x-ray absorption spectromicroscopy, the technique provides 50-nanometer resolution with little radiation damage to the sample. The new method gives information on the spatial distribution of chemical compounds and the orientation of specific chemical bonds in polymers. These data can help researchers to make new polymeric materials with such desirable properties as biodegradability, strength and durability.

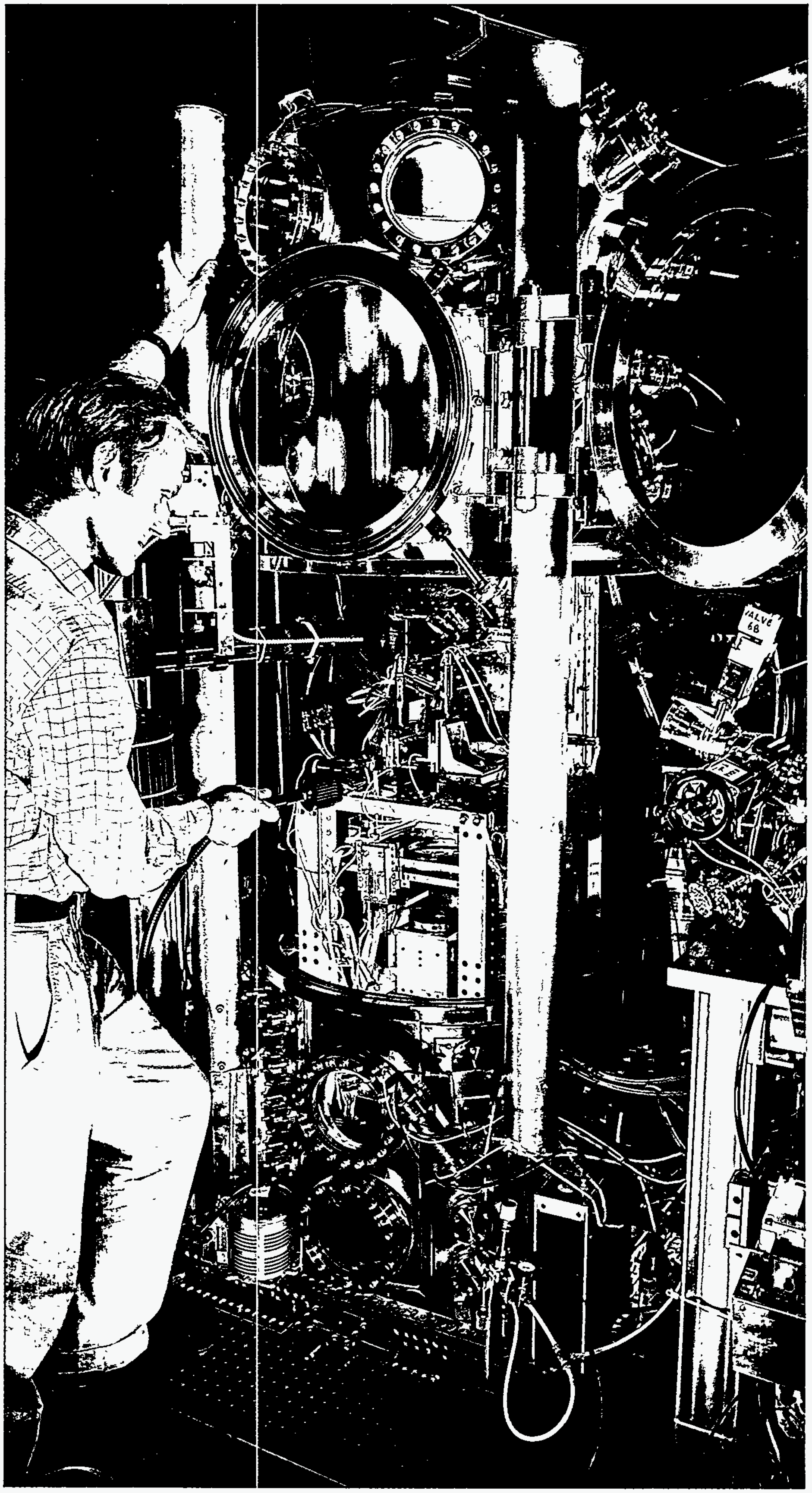
In other polymer-related research, Dow Chemical has used the NSLS to develop a unique nonadhesive coating that requires no cleaning, which may be used on a wide range of surfaces, from kitchen countertops to airplane wings. Instrumental to this discovery were data acquired from spectroscopic techniques used at the NSLS in collaboration with the National Institute of Standards and Technology to study the surface structure and composition of the material's constituent polymers. The new coating is made of both fluorocarbon and hydrocarbon molecules, which occur as parts of long polymer chains.

Microelectronics

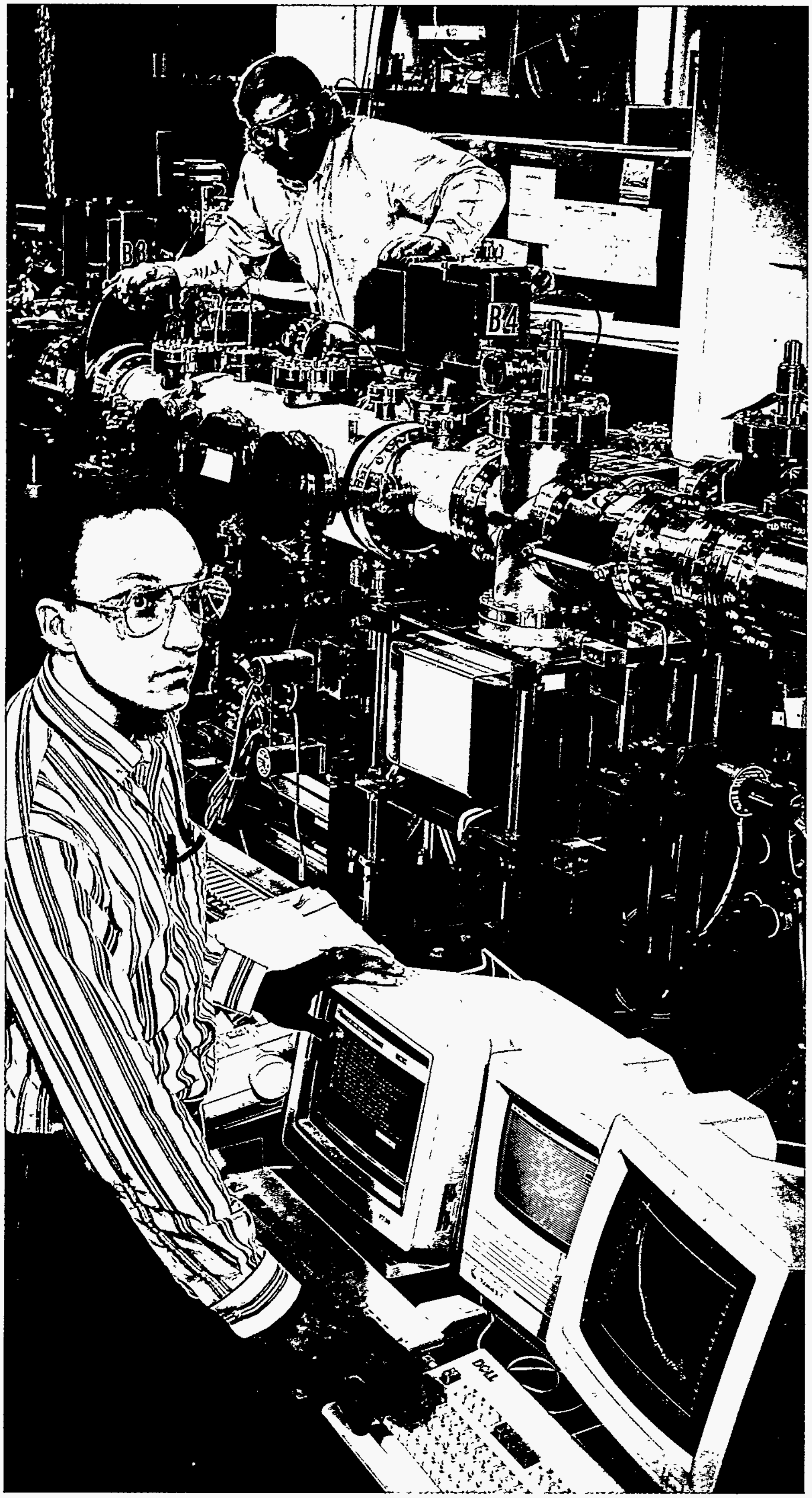
Just as the microelectronics industry continues to build computer chips with increasing densities, the communications industry designs more and more sophisticated fiber-optics systems to carry information from one computer or telephone to another.

Companies like AT&T Bell Laboratories and IBM come to the NSLS to study the atomic and electronic structures of semiconductors and semiconductor devices. As the feature sizes become smaller on computer chips, the required power densities increase. This in turn leads to new effects, which must be understood in order to design the next generation of chips.

Scientists from IBM study the dynamics of electrons moving through semiconductors at these high-power densities and compare the results with model calculations.



Alastair MacDowell, AT&T Bell Laboratories, characterizes optics needed for extreme ultraviolet projection lithography on beam line X13UB.



AT&T scientists investigate how thin films of aluminum that connect semiconductor devices deform under conditions of high-power density by a process called electromigration.

Defects and impurities play a critical role in semiconductor device performance. Scientists from the State University of New York at Stony Brook in separate collaborations with Northrop Grumman Corporation and the U.S. Army's Harry Diamond Laboratory are using a technique called x-ray topography at the NSLS to determine the types and densities of dislocations in semiconductor crystals.

Magnetic Recording

At least 25 institutions conduct research at the NSLS on magnetic materials, as they are important for developing state-of-the-art recording devices. Techniques developed at the NSLS since the 1980s have enabled researchers to probe magnetic thin films with better accuracy and precision than ever before.

Researchers from the Naval Research Laboratory are using polarized x-rays at the NSLS to probe the structure of thin magnetic films of terbium iron, the mainstay of certain computer storage devices. The direction of magnetization in these films can be made to align perpendicularly to the film's plane, which permits more efficient data storage. Studies at the NSLS revealed that the perpendicular magnetization is related to subtleties in the arrangement of the iron and terbium atoms. Such research is essential for the design and fabrication of more powerful storage devices for computers.

At beam lines X10B and X10C are Exxon researchers Brian DeVries (front) and Michael Sansone.

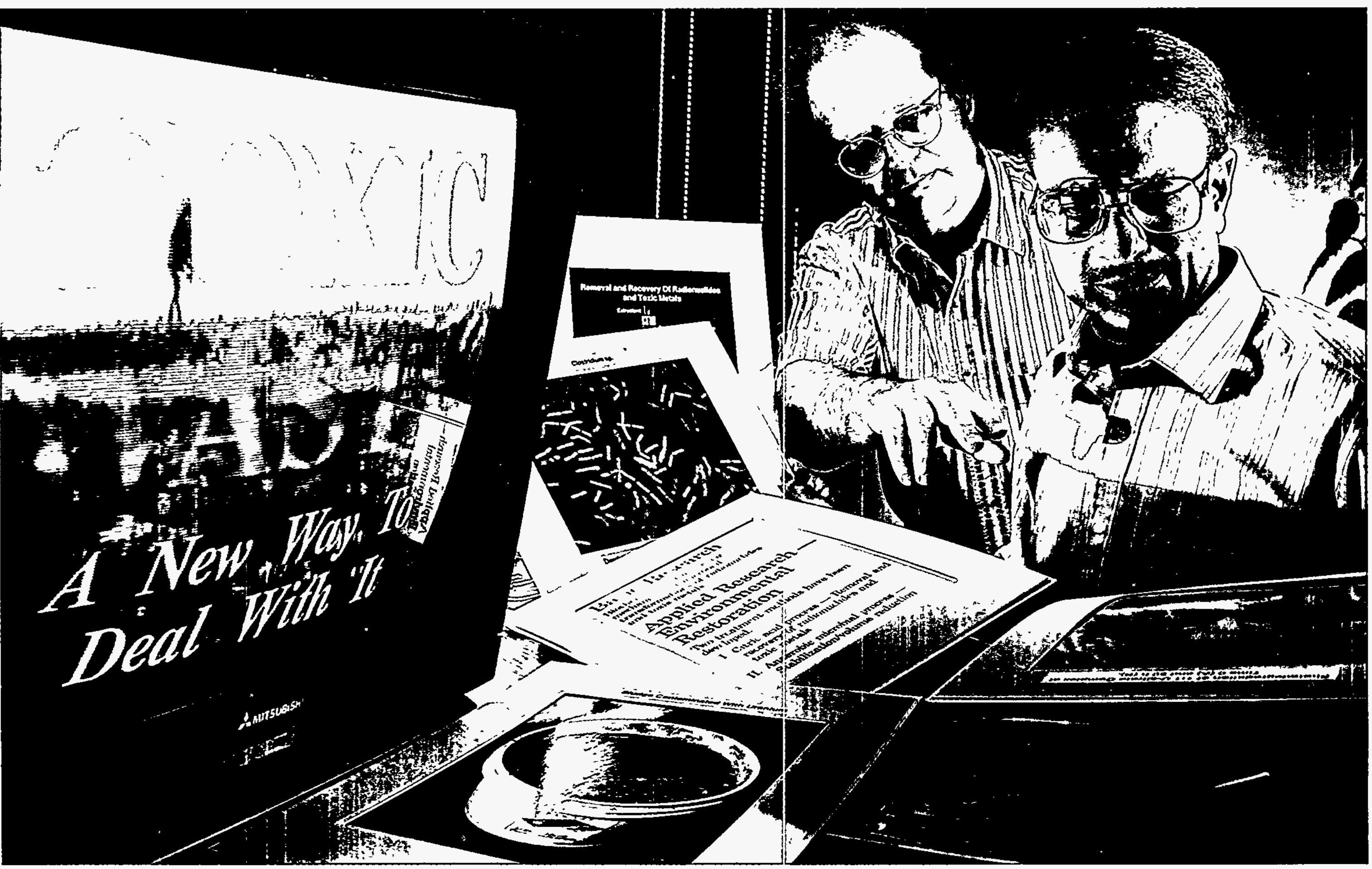
Spanning a spectrum of interests that includes the environment, health, energy science and technology, and mathematics, the Department of Applied Science puts basic research to work solving problems innovatively. Current projects include high-powered computer models of groundwater movement, measurements of carbon dioxide levels in both the atmosphere and the ocean, and development of devices to improve home-heating efficiency. Through cooperative efforts with industry, both the nation's economy and the frontiers of science are advanced.

Department of Applied Science

Tackling Toxics

Around the nation, the legacy of America's 20th century industrial and military prowess lingers in the environment, haunting soil and groundwater. At factories, landfills, power plants and weapons sites, radioactive and toxic elements contaminate soil, ash and other waste.

To fight the battle against pollutants produced by high technology would seem



to require a high-tech weapon. But, armed only with common citric acid, natural soil bacteria and sunlight, a team of microbiologists in BNL's Department of Applied Science has developed and proved a three-part method to remove radioactive and toxic hazards from the environment.

The process takes advantage of some very useful properties of each of the three agents. For example, the same citric acid that gives orange juice its tang and helps keep processed foods fresh is also sometimes used to remove hazardous metals from polluted materials. The acid binds up the hazardous elements, essentially "washing" them out of the mix.

Just as the human body easily processes orange juice's citric acid, turning it into carbon dioxide, water and energy, so do bacteria. Thus, they hungrily attack the citric acid-pollutant mix, in a process called biodegradation. The chemical-bond-breaking potential of sunlight completes the three-part process.

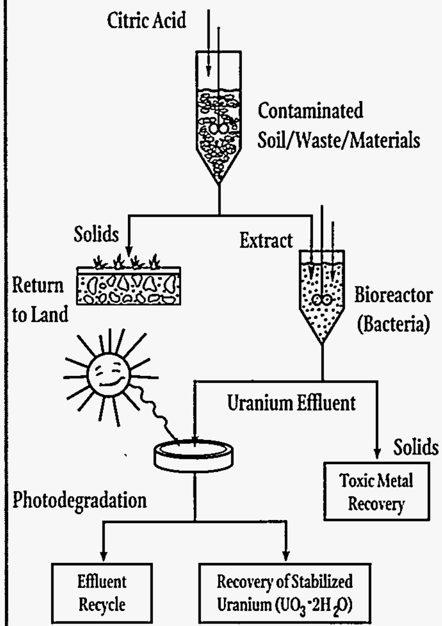
This year, the BNL-developed technique proved its ability, on the laboratory scale, to clean samples of radionuclide and toxic metal waste from several polluted industrial and military sites, including the U.S. Department of Energy's (DOE) Y-12 and Fernald facilities.

Also in 1994, the process was granted a U.S. patent and became the subject of a Cooperative Research and Development Agreement (CRADA), making it a good example of how basic research can yield marketable applications.

Reduce and Recycle

Our microbiologists have been working for several years to understand the basic mechanisms by which some species of bacteria biodegrade metal-complexing agents, including citric acid, that are used to strip toxic metals from waste in a process called chelation.

Cleveland Dodge (left) and A.J. Francis prepare a presentation on the environmental remediation technique they developed to clean up toxic waste.



BNL Remediation Process Using Citric Acid and Biodegradation

Citric acid is an effective chelating agent, but when used to clean up spills, it creates a witches' brew of citrates — compounds of citric acid combined with metal or radionuclide pollutants.

Fortunately, however, nature's cornocopia of life holds microbes that can digest citrates and leave the pollutants behind to be recovered.

After testing many strains of bacteria, our researchers isolated rod-shaped *Pseudomonas fluorescens*, a naturally-occurring soil microbe. It proved able to digest most citrates.

It is unable to break the bonds in uranium citrate, however — a property that turned out to be a plus rather than a minus.

Tests showed that after a few thousand hungry *P. fluorescens* were added to a flask of pollution-laden citric acid extract, the bacteria degraded the citric acid and precipitated most of the metals, while the uranium citrate remained in the liquid. The metals can be disposed of or, in some cases, recycled.

But what of the uranium citrate? Additional research showed that it can be further broken down by exposure to an ordinary light source, such as sunlight, creating acetic acid, carbon dioxide and water, plus uranium trioxide, a dark precipitate. This photodegradation, as it is called, allows the uranium oxide to be collected and disposed of properly.

During the process' development, the BNL researchers were able to determine the exact form of uranium oxide that precipitates, using BNL's National Synchrotron Light Source and spectroscopy equipment at the State University of New York at Stony Brook.

A Proven Procedure

The technique of biodegradation with *P. fluorescens* followed by photodegradation was granted a U.S. patent in March 1994. By then, a CRADA had already been signed with Forrester Environmental Services, Inc., a New Hampshire company, to test the process' efficacy on incinerator ash. Initial results showed that more than 90 percent of the lead in the ash was successfully removed.

We also began demonstrating the technique's promise on samples sent from uranium-contaminated sites. This work is supported by DOE, with the goal of applying the method to several sites under the agency's purview.

For example, a test on sludge from DOE's Y-12 uranium processing facility at Oak Ridge, Tennessee, showed that biodegradation followed by photodegradation removed a list of metals from aluminum to zinc. Removal percentages ranged from 93 percent for bárium to 87 percent for uranium to 99 percent for thorium.

Another test on citric acid extract containing heavy metals and uranium from DOE's Fernald site in Ohio, a former uranium enrichment facility, produced similar results.

In addition to tests on radionuclide-containing waste, the BNL process is expected to be useful on waste streams with only toxic components. This means it can be tailored to meet the needs of an individual site. Mine tailings, smelting and power generation by-products, as well as radioactively contaminated soil, wastes and incinerator ash, are all potential subjects for study and practical application.

Monitoring The Cornerstone Of the Carbon Cycle

A routine part of any medical checkup is taking the patient's pulse, to assess the health of his or her circulatory system.

But when the "patient" is the global carbon cycle, nature's largest and most important circulatory system, taking that pulse is much more difficult.

The cycle encompasses all forms of the crucial element carbon — in the atmosphere, in living things and in geological reserves. And the cornerstone of this cycle is the population of trillions of tiny ocean plants known as phytoplankton.

Together, these floating flora act as a vast "sink," or sponge, for the carbon dioxide (CO_2) produced when animals exhale and humans burn fossil fuels.

Through photosynthesis — the ability to turn CO_2 and sunlight into sugars and oxygen — phytoplankton provide food for themselves and breathable air for the organisms that need it. They are also the base of the ocean's food chain. But their main importance is in helping to maintain a balance of the "greenhouse gases" that regulate solar heat loss from the atmosphere.

In 1994, a new instrument for taking the pulse of this important population was added to the scientific "doctor's kit" by researchers in BNL's Department of Applied Science.

Called a Fast Repetition Rate Fluorometer, the instrument uses lightning-quick bursts of light and highly sensitive detectors to measure how efficiently phytoplankton are using light in the process of photosynthesis.

The fluorometer has had a busy first year, being used on several research cruises all over the world, including Antarctica, equatorial regions of the Atlantic Ocean, and the Chesapeake Bay.

On one cruise, in the southeastern Pacific, it helped confirm an important ecological theory relating to iron levels in the ocean. And a technology-transfer initiative with a Texas company blossomed into full production of BNL fluorometers in mid-1994.

Measuring a Telltale Signal

The fluorometer was developed by our researchers and built by our engineers over the past two years through funding from the U.S. Department of Energy's Global Change Program and the National Aeronautics and Space Agency.

Dissecting the instrument's name reveals much about its function. Fluorometers are a class of instruments used to measure the fluorescence emitted by photosynthesizing plants — when plants convert sunlight and carbon dioxide to sugars and oxygen, a small portion of the absorbed energy is wasted as fluorescence, with a signal that is inversely proportional to the photosynthetic efficiency.

The term "fast-repetition rate," meanwhile, indicates the instrument's design for exciting this fluorescence signal. By bombarding a sample of phytoplankton with repeated flashes of light carefully controlled for intensity and repetition rate, and then precisely measuring the resulting fluorescence, it is possible to calculate exactly how much of the light, as measured in photons, the tiny plants are able to use.

Calculations can then be made to derive different photosynthetic parameters. These include the effectiveness of light collection, also called the photon absorption cross-section, a measurement of the size and efficiency of the plant's "antenna" of light-absorbing molecules. Also calculated are the photosynthetic yield, which is a measure of photosynthetic work per photon, and the ultimate rate at which photons are converted to photochemical work.

Because these parameters are highly sensitive to such factors as nutrient availability, those measurements can produce an indication of nutrient conditions in the ocean and the general "health" status of the phytoplankton population under those conditions.

Pumping Iron

Answering this question of health was the main aim of a research cruise in the Pacific Ocean off the Galapagos Islands, on which the BNL fluorometer helped establish the answer to a question that has long puzzled oceanographers.

While phytoplankton are plentiful in many parts of the ocean, some areas have much smaller populations, despite the ample nutrients available. Until now, the search for the cause of this scarcity has not turned up a satisfactory explanation. But the Galapagos cruise, led by scientists from Duke University and Moss Landing Marine Laboratory in California, tested a recent theory that a lack of iron was at the heart of poor phytoplankton performance.

Several instruments, including our fluorometer, were used to quantify phytoplankton activity before and after the addition of ferrous sulfate, an iron compound, to a 50-square-kilometer area of ocean. Within one day, our instrument's precise detectors picked up an increase in phytoplankton activity, indicating that iron limitation had indeed been a cause of the area's low productivity.

These findings do *not* mean that fertilizing the ocean with iron could be a quick fix for the world's overabundance of CO_2, which is considered a major factor in global climate change and the heightening of the "greenhouse effect." But they are important to understanding the potential effects of anthropogenic, or human-caused, global change on the delicate balance among nature's linked cycles and, therefore, on the vital phytoplankton communities.

For example, iron is brought to the ocean by winds from land masses. If global warming due to excess anthropogenic CO_2 causes a change in wind patterns, that could affect

phytoplanktons' iron supply and thereby change the ocean's ability to absorb CO_2.

Cruising the World

BNL fluorometers aided scientists on several other cruises this year. In March, a submersible version was moored in the Chesapeake Bay near the Maryland coast, to collect data until our scientists returned in June.

Also that same spring, a German team brought one of our instruments to Antarctica to study factors affecting phytoplankton distribution at high latitudes.

Meanwhile, Environmental Monitoring Systems of Dumas, Texas, our partner in the fluorometer technology transfer program, began producing fluorometers commercially in mid-1994. The first model to be made, a moored variety similar to the one used in the Chesapeake, had potential buyers lined up well before the first batch of 10 rolled off the assembly line. More designs are planned, as our fluorometer continues to prove its worth to oceanographers around the world.

Zbigniew Kolber (left) and Paul Falkowski prepare the Fast Repetition Rate Fluorometer for yet another oceanographic cruise.

Brookhaven's unique physical and chemical science resources and facilities are used by Medical Department scientists to develop new medical applications of nuclear technology and to understand effects of energy-related agents on human health. Researchers improve radiotherapy and nuclear medicine procedures, develop new radiopharmaceuticals and explore methods for noninvasive measurement of trace elements in humans, as well as the mechanisms of disease.

Medical Department

Wiping Out Cancer Cells

Suddenly, in May 1994, the news broke that Jacqueline Kennedy Onassis was gravely ill — and almost overnight, it seemed, she died. Her killer was one of the lesser-known deadly forms of cancer, non-Hodgkins B-cell lymphoma.

But there is hopeful news for patients stricken by this fast-acting cancer.

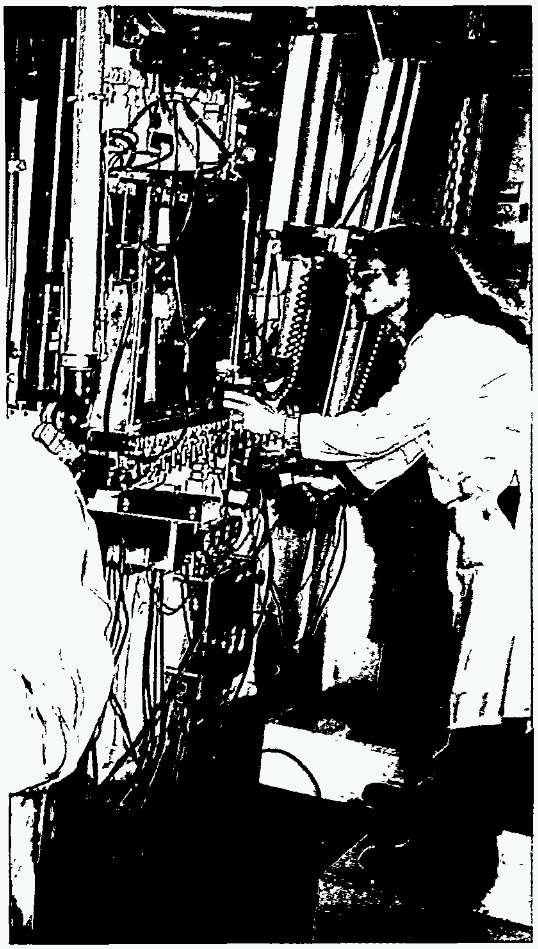
An isotope of copper — copper-67 — which was developed by scientists in Brookhaven's Medical Department, shows promise as a therapy for this lymphoma. Of the three patients treated so far in clinical tests at the University of California, Davis (UC Davis), one of our collaborating institutions, one patient did not respond to treatment, but one responded in part, and the third had his cancer go into complete remission. Work is continuing on adjusting treatment protocol and dosage, and it is hoped that patient response will improve considerably.

How does this promising therapy work? Copper-67 emits beta radiation, which has enough energy to kill tumor cells, yet stops short of damaging surrounding healthy tissue. Also, it emits gamma rays, which can be detected and used to reconstruct an image of the tumor site.

To produce it, however, requires considerable expertise and a sophisticated facility such as the Brookhaven Linac Isotope Producer (BLIP) at BNL. Our scientists are assisting the two or three other groups in the world working at comparable facilities, so that they can make more of this radioisotope. The complicated chemistry needed to attach copper-67 to antibodies and to other carrier molecules is also being investigated at Brookhaven and elsewhere, along with UC Davis.

Using the BLIP along with our High Flux Beam Reactor and cyclotrons — a unique cluster of facilities for such research — BNL scientists have also identified three other beta-emitting radioisotopes with gamma emission for radiotherapy of cancer: scandium-47, samarium-153 and gold-199. The latter was developed in partnership with researchers in the Biology Department.

All these Brookhaven-developed isotopes are expected to prove effective protagonists in the battle against various cancers.



At the Hot Laboratory (from left) Leonard Mausner, George Meinken, Suresh Srivastava and Slawko Kurczak are preparing copper-67 for lymphoma patients.

The Isotope Carriers

Developing the isotopes, however, is only part of our research. Their delivery to the tumor is an ongoing concern at Brookhaven and other laboratories worldwide.

In this effort, scientists are helped by nature, which provides antibodies, natural troubleshooters that rush towards a particular disease-causing intruder, or antigen, to destroy it. In 1975, a method of cloning antibodies was discovered in Britain, allowing the large-scale production of highly specific "monoclonal" antibodies. Since then, monoclonal antibodies have been developed against antigens of most common solid tumors and for various skin, blood and soft tissue cancers.

Monoclonal antibodies can be "labeled," or combined with radioisotopes; thus they can carry an additional weapon with which to attack their antigen foe. In addition, the tiny doses of radioactivity emitted from the isotopes over several days can be tracked and imaged. This allows doctors to "see" the tumor's position and size. So, radiolabeled antibodies not only scout out the way to the tumor, but also deliver a lethal dose of radiation to the tumor cells and signal how the treatment is working by showing changes in the tumor's size.

Experience has shown that radiolabeled antibodies are most effective at the earliest stage of a cancer or after a large tumor has been cut away and the area treated by conventional methods such as chemotherapy and external radiation. In both cases, the antibodies can track down and help eliminate the disseminated micrometastases and larger tumor cell clusters that will spread the cancer later.

Bound to Bind

Early studies of labeled monoclonal antibodies show that although they worked well in laboratory tests, many of them tend to break apart once in the human body. As expected, the "freed" isotopes were naturally attracted to the kidneys and liver, then excreted with little or no adverse effects on the patient. But the tumor remained unattacked.

After studying this problem and using new state-of-the-art binding techniques, our scientists developed a number of unique rigid chelating, or binding, agents. For several days, the active lifetime of the isotope, these two-armed agents hold the monoclonal antibody firmly attached to one arm and the isotope fixed to the other. The rigid format also retards the natural "chopping up" action taken by the body against the metal radionuclide and the antibody.

Four of these rigid chelating agents have been isolated and patented by our researchers. Some successful preclinical and clinical tests have been done at Brookhaven and at the University of Nantes, France, and more are expected to follow at Beth Israel Hospital in New York, the National Cancer Institute (NCI), and the State University of New York (SUNY) at Buffalo, all of which collaborate with Brookhaven in this work.

In one set of imaging tests in France using our chelating agents to hold monoclonal antibodies and an isotope of the element indium, there was a threefold reduction in the amount of "breakaway" indium taken up by the liver. Because of this, the indium that reached the tumor showed up clearly. Thus, for the first time, a liver tumor was successfully imaged.

The Brookhaven patent holders have already been approached by industry with a view to starting a technology transfer effort to make our chelating agents available commercially.

New Directions

Recently, advanced techniques for dividing up monoclonal antibodies have made it possible to isolate fragments or "single domain" polypeptides, which are often the business ends of the antibody that lead the rest to the tumor. We are collaborating with scientists from various other institutions, including the Wistar Institute, NCI and Yale University, to do research in this area, using our isotopes and chelating agents.

A recent focus has been our work on colorectal cancers, as well as on breast and ovarian cancers. In addition, we are developing antibody-based imaging agents for diagnosing life-threatening blood clots and other blood-vessel wall diseases.

License to Kill — New Boron Compound To Destroy Cancer

A new boron compound developed at Brookhaven promises to play a key part in treatment aimed at destroying the malignant cells of glioblastoma multiforme, an as-yet-incurable brain cancer.

Affecting about 7,000 Americans annually, this cancer gives a life expectancy of only nine months for 50 percent of its victims, with fewer than three percent surviving beyond five years.

In Brookhaven's Medical Department, however, researchers have high hopes for an experimental treatment called boron neutron capture therapy, which they have proven effective in animals with a similar brain cancer. Now, with clinical trials under way, the prospects for treatment of human brain-cancer patients with the therapy at BNL are extremely promising.

Boron Neutron Capture Therapy

In this therapy, a compound containing the element boron is administered to the brain cancer patient. The compound preferentially accumulates in malignant brain tumors, and so the boron enters the tumor rather than the normal tissue.

The tumor is then irradiated with low-energy neutrons produced at a nuclear reactor. Some of the boron nuclei absorb some of these neutrons and then self-destruct—releasing powerful, but very short-ranged, radiation. Because the boron is mostly concentrated in the tumor cells, the cancer can be destroyed without seriously affecting normal brain cells nearby.

Research on this therapy originally started at Brookhaven in the 1950s, but the clinical trials, as well as those done at the Massachusetts Institute of Technology at about the same time, were disappointing. The boron compound used then did not selectively accumulate in the tumor. Also, the neutron beam did not penetrate deeply enough into the patient's head to destroy the tumor without harming surrounding healthy tissue. So, the trials were halted, but our investigators and outside collaborators continued working to overcome these problems.

Key Improvements

With the 1980s came improvements in two key areas. First, our researchers showed that a then-obscure boron compound known as BPA compared favorably with other compounds for boron neutron capture therapy. In 1989, Brookhaven scientists received a nuclear-medicine research grant from the U.S. Department of Energy's Office of Energy Research to test BPA.

The tests proved that three to four times more BPA accumulates in tumors than in normal tissue. Rat tumor cells were shown to be more sensitive to the therapy than

First Patient

In September, the first patient in over 30 years received radiation treatment in the Brookhaven Medical Research Reactor, as part of the Medical Department's boron neutron capture therapy research program.

The patient, a 50-year-old woman, was treated under a U.S. Food and Drug Administration-approved protocol described as "single-patient use." The protocol was also approved by Brookhaven's Human Studies Review Committee, as well as the institutional review board at Beth Israel Medical Center, the Laboratory's collaborating institution. The procedure is the first experimental application of the improved neutron beam and new boron compound known as BPA — recent key improvements to the original work carried out in the 1950s to early 1960s, which had had disappointing results.

Further clinical experiments to determine the safety and efficacy of this therapy will be carried out in a few months, after the results of this first experiment are thoroughly evaluated.

Using a direct-current plasma atomic-emission spectrometer, (from left) Darrel Joel, Ben Liu and Jeffrey Coderre measure the boron concentration in a tissue sample.

was their normal brain tissue. Together, these factors produced a therapeutic ratio (tumor dose to normal brain dose) of 6:1, significantly higher than any obtained using other boronated compounds for this therapy elsewhere.

Using BPA in our studies of animals with gliosarcoma, a type of brain cancer, over 90 percent of the tumors were eliminated and the animals lived. After a year, further studies showed that little damage had been done to normal brain tissue.

Most animal brain tumors, being close to the surface, can be treated with the low-energy beam of neutrons used in the original tests. But human brain tumors being deeper, require a beam of higher energy. When the beam reaches the tumor, the neutrons have slowed into the low-energy range that can be captured by the boron compound.

The development of this intermediate-energy neutron beam is the second key to the success of this therapy at Brookhaven. Pioneered by our researchers in the 1980s, the beam, as one of only three in the world, is the most intense.

Recently, the beam intensity has been improved still further by a rearrangement of the fuel elements in the reactor that supplies the neutrons. And a second upgrade has been started that will radically decrease a patient's exposure time — from 30 to 40 minutes down to 2 to 3 minutes.

Clinical Trials

Approved by the Brookhaven Human Studies Review Committee and the U.S. Food & Drug Administration, clinical trials began this fiscal year with a study of the distribution of BPA in patients who took the compound orally, prior to brain-tumor surgery, and the results were encouraging.

Next, after improvements in the therapy of animal tumors when BPA was given intravenously, the biodistribution of BPA was studied in patients who received the compound intravenously, in a collaborative effort involving the Beth Israel Medical Center of New York City.

Meanwhile, our Medical Department scientists continue their research. By the end of the fiscal year, we will be well on the way to determining the highest dose of neutrons that can be tolerated without causing damage to normal brain tissue and the best dose of BPA to match the neutron intensity. With this information, a solid protocol can be established for the complete treatment trials soon to begin.

Chemistry Department

The broad range of research in the Chemistry Department has a single goal: the fundamental understanding of the properties of nuclei, atoms and molecules. Using the special facilities, apparatus and techniques available at Brookhaven, chemists discover detailed structural and spectroscopic information on solids, liquids and gases, and the dynamics of physical and chemical change.

New BNL Imaging and Neuroscience Center

A brand-new building will soon be making its mark on the BNL landscape — part of the new Brookhaven Center for Imaging and Neuroscience.

Funded jointly by the U.S. Department of Energy and the National Institutes of Health, the building is expected to be completed in early 1995. It will house an ex-

tremely powerful — four-tesla — magnet, which will be used for magnetic resonance imaging (MRI) research.

The four-tesla MRI facility will be one of three complementary imaging methods on which will be founded the center's work on understanding the relationship between mental and physical processes in the human brain.

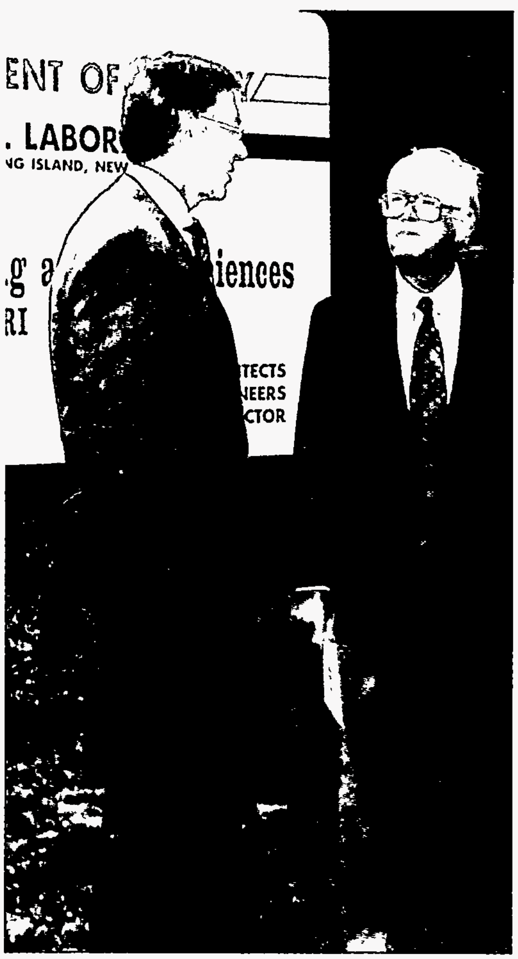
The other two-thirds of the center will be the positron emission tomography, or PET, facility, which has gained world renown since beginning operations at BNL in the 1970s, and the Medical Department's Single Photon Emission Computed Tomograph (SPECT), which started research in the mid-1980s.

A Unique Opportunity

The new center will provide a unique opportunity to combine PET, MRI and SPECT in coordinated research, getting new, invaluable cross references. Also, it will further strengthen interaction between the Medical and Chemistry Departments.

The PET and SPECT techniques use injected radiopharmaceuticals to study metabolic processes and the movement of drugs in the human body. PET research at BNL has included studies of schizophrenia, Alzheimer's disease, brain tumors and substance abuse.

MRI gives clear, detailed pictures of soft tissue deep in the body, but the picture is obtained differently from PET. MRI uses the response of the body's own protons to an exterior magnetic field to produce an extremely clear picture of their spatial distribution. This has led to MRI's being quite commonly used in general medicine to diagnose damaged tissues invisible to x-rays.



At the site of the proposed MRI facility are (from far left) BNL's Joanna Fowler, David Schlyer, Alfred Wolf, Nora Volkow, Charles Springer, James Decker of the U.S. Department of Energy, and Robert Hughes, Associated Universities, Inc.

A Forefront Investigative Tool

Now, recent technological advances have greatly speeded up MRI's image-making. Images are formed so swiftly that they can be used in forefront research on cognitive neuroscience — making MRI a worthy partner for PET.

For example, PET shows blood flow to the active parts of the brain by detecting the increased delivery of the injected labeled water, which diffuses out of blood vessels to all parts of the brain. MRI shows blood flow by detecting rising blood oxygen levels in the active part of the brain.

This is possible because the amount of oxygen carried by hemoglobin in the blood changes the hemoglobin's magnetic properties, and MRI is sensitive to these changes. Also, when a part of the brain is used, more blood flows to it. Yet initially, little of the extra available oxygen seems to be consumed. Therefore, blood oxygen levels rise in an area of mental activity — and this can be detected by MRI.

Four Teslas for Research

Because MRI can detect these functional changes, scientists often refer to this use as *functional* MRI, or fMRI. When powered with a large magnet with a field strength of four teslas, fMRI gives the high spatial resolution images that have made it a top-ranking technique for the latest neuroscientific research.

The exacting research to be done at BNL will require such a four-tesla magnet. Clinical work in this country is accomplished using magnets of two teslas or less. But our scientists will be doing fMRI studies, distinguishing between tissue regions at least as small as one to two millimeters.

Only three other four-tesla MRI facilities are operating in the world, all in the U.S. and all federally approved for research. fMRI is a totally noninvasive technique, and, since the signals come directly from functional changes in the subject, together with information on the structure of the active region, researchers get an excellent picture of what is happening.

The Brookhaven four-tesla instrument will also be important for pursuing *relaxographic* MRI. This new, fundamental form of MRI was developed by researchers from the State University of New York at Stony Brook, who will be working with our chemists at the new center. Relaxographic MRI potentially produces, for example, extraordinarily clear, living maps of the precise position and volume of cells in different parts of the brain or other organs.

With the added advantage of collaborative work with PET and SPECT, we expect to carry out valuable studies in the rapidly developing field of neuroscience.

Top Research With Catalysts

Most people hate to paint ceilings — but the job became much less messy when manufacturers came out with dripless, epoxy-containing paint. And think of epoxy resins — how much cheaper and easier they make it to repair boat hulls.

The epoxidation process involves a complex chemical reaction that, in the presence of a suitable catalyst, converts the starting material to a product with the desired properties. So, understanding this fundamental process is useful for everyday applications. This kind of understanding is generally achieved by doing basic research in a laboratory.

In the Chemistry Department at Brookhaven, our chemists do basic research on the surfaces of catalysts. Since catalysts are complex systems, the research is done on models that are easier to use in experiments, yet give similar results. This information can then be helpful in the more complicated system.

Our researchers probe the exposed surfaces of simple metals and compounds that have molecules adsorbed on them — that is, attached to their surface — to see how the bonding interactions are affected. They study how bimetallic alloys react when heated or cooled, with or without the aid of a catalyst. The role of alkali metals as catalytic promoters is also examined, as well as ways to prevent the accumulation of byproducts made in the reactions, which may have a slowing-down effect. Any of this knowledge is likely to be useful to industry.

So, when our chemists find out some new information, it becomes part of a general base of understanding that industry can draw on to create specific products or change or improve existing ones.

To do these extremely precise investigations, several techniques are used, all focused on revealing the relations between the structure and reactivity of a sample.

In electron spectroscopy, for example, the sample is bombarded with x-rays. Electrons are emitted, and their energy measured to obtain information on the detailed makeup of the sample. Vibrational spectroscopy, on the other hand, follows the changes in the spectra that result from an experiment to show what kind of species will be adsorbed on the surface of a sample. In yet another technique, thermal desorption, the sample is steadily heated while researchers monitor the species that are produced.

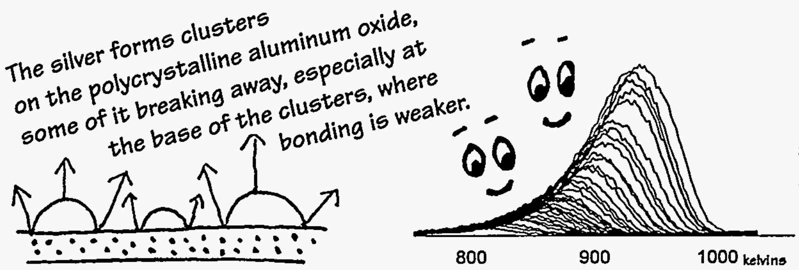
Since each technique sheds light on a different aspect of what happens in the sample, each makes a unique contribution to the final all-round understanding of the process. A consistent picture of how a molecule interacts with a surface on a molecular scale should emerge in the near future, allowing engineers and others to design and tailor catalysts to fit new market needs.

Jan Hrbek positions a crystal sample to prepare for an ultrahigh vacuum experiment.

A Chemical Quest

Industry uses silver supported on aluminum oxide in a polycrystalline form.

When it's heated... The Industrial Case

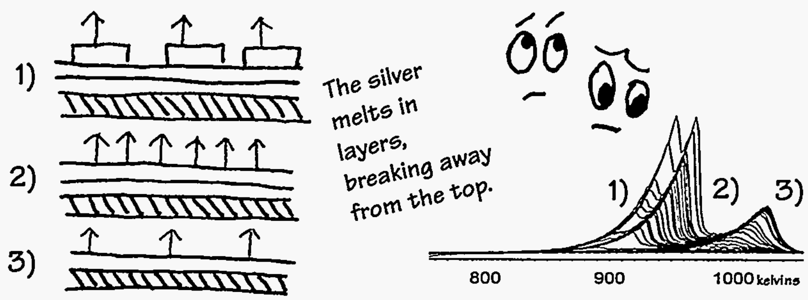


But — what happens to the supported silver under other conditions? Engineers need to know.

Polycrystalline aluminum oxide is hard to use in experiments. It's too powdery.

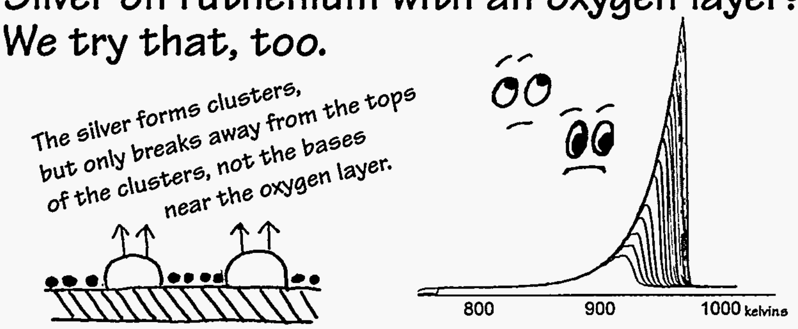
So, our chemists seek another form of supported silver that acts in a similar way, yet is easier to use in experiments.

We try heating silver on ruthenium.



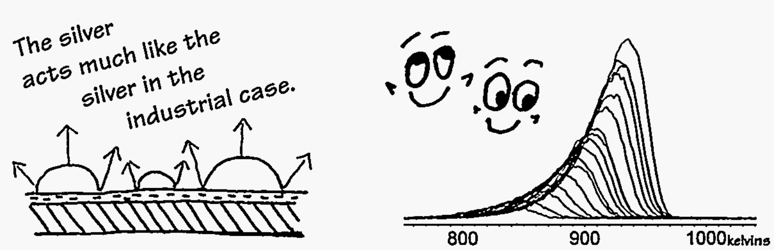
But the results are not similar to those of the industrial case.

Silver on ruthenium with an oxygen layer? We try that, too.



These results are not like those of the industrial case, either.

So, we try silver on a thin film of aluminum oxide on ruthenium.



A good model!

What's next? This form of silver on aluminum oxide thin film can be used in many experiments to model the industrial case. Basic research can make a difference in everyday life!

by Liz Seubert

Technology initiatives, waste and environment, safety and arms control—these are the Department of Advanced Technology's principal fields of expertise. Reflecting a response to national needs, in addition to nuclear-energy work, many programs are expanding into areas of increasing technical diversity.

Department of Advanced Technology

Untying Traffic Tie-ups With ATOP

Like most United States' highways giving access to major cities, the Long Island Expressway—known locally as the world's longest parking lot—is a rush-hour nightmare. Traffic can be brought to a standstill by a single breakdown several miles ahead. Now, however, scientists from Brook-

haven's Department of Advanced Technology, with colleagues from Polytechnic University, have proved for the first time that it is possible to predict, and therefore help prevent, the worst traffic jams.

To achieve its goal, the team developed a package of powerful computer software called ATOP, for Advanced Traffic Occupancy Prediction.

ATOP includes a number of different information sources and analytical techniques. It draws on current data on the state of the highway as well as historical traffic flow patterns, then feeds the information through sophisticated statistical computer routines. The result is a forecast of traffic volume entering and exiting an area of the highway.

Then, using conservation equations, ATOP simulates the movement of the traffic through the highway system. All the while, more information on actual traffic movement pours into the computer model so that the resulting prediction can be continually updated.

Information Helps Safety

Working closely with the researchers at Brookhaven are members of the staff of the INFORM system, which is run by the New York Department of Transportation, sponsor of ATOP. INFORM, part of the Intelligent Vehicle Highway Systems program, is an advanced traffic management system that collects and evaluates roadway data, but lacks ATOP's predictive capacity. Since ATOP will eventually communicate directly with INFORM, such cooperation is an essential part of the project's success.

With ATOP to predict delays on the road ahead, drivers could help eliminate traffic jams by changing to a less congested route. Also, in areas where little or no new highway capacity is expected to be funded in the near future, "intelligent" transportation systems like ATOP could take on even greater significance. If traffic is running smoothly, pollution is less and fewer accidents may occur.

So, not only should ATOP increase efficiency by reducing congestion, but also, it may help to decrease environmental impact and increase public safety.

Real Time Model

Already, INFORM has a system of computerized signs in place on the Long Island Expressway and the Northern State and Sagtikos Parkways. The signs alert motorists to the state of traffic ahead, but they only tell drivers what is currently happening, not what they can expect by the time they get there.

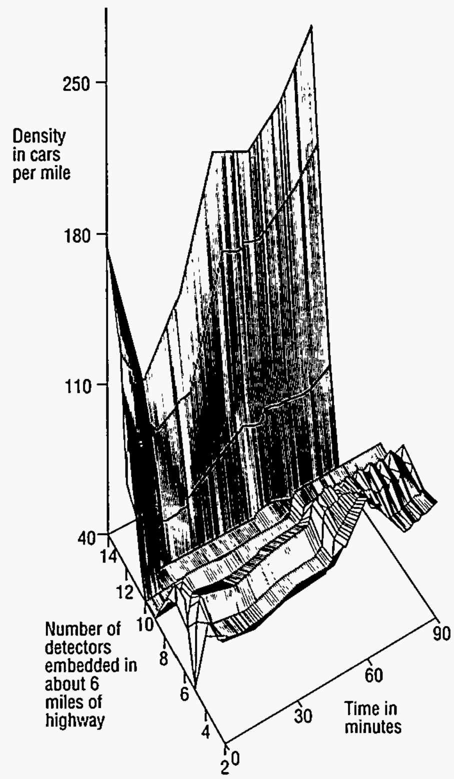
That's where the unique ATOP advantage would help. Using extensive experience in nuclear engineering, physics and statistics, the ATOP team has developed a simulation model that is the first of its kind. The model not only operates in real time — as things happen — but also includes software that runs even faster than real time, to give a prediction.

Info for INFORM

To make ATOP work, first, a signal from a vehicle passing over INFORM's system of detectors embedded in the roadways goes to the INFORM center. There, it is combined and analyzed with data from the entire highway. Then, the ATOP team's software is applied to INFORM to add in the speed of the vehicle and the density of surrounding traffic, both obtained from the detectors' readings, as well as weather, accident and construction information.

Private Sector Potential

ATOP's implications extend beyond messages to the motorist already on the road. Up-to-the-minute traffic predictions, if distributed to TV and radio stations and cellular phone companies, could help motorists in planning a trip.



This ATOP traffic simulation shows predicted congestion along a highway over a 90-minute period.

At the INFORM highway-monitoring center, soon to include an ATOP traffic simulator, are BNL's Ali Azarm (left) and (from right) Robert Hall, Elizabeth Selcow and David Stock, with INFORM director Robert Rosendahl. Also on the ATOP team is Said Mughabghab.

Sealing — With Penguins!

When do penguins act as seals?

In real life, the answer is never. But Brookhaven's Department of Advanced Technology penguins are unusual specimens. Small, bronze-like statues, they are samples made from used testing material to display the new sealant compounds being investigated by our scientists. These penguins represent the polymer materials we have designed to surround and contain underground contamination, sealing it in to prevent leakage.

Around the United States are certain sites where chemicals or other contaminating materials were dumped, or waste was buried long ago in containers that are beginning to fail. Through the action of rainwater, the contaminants at these sites threaten the environment by seeping out and spreading underground. Yet completely removing them may be too expensive to be practical.

Capping over the contaminated site with clay has not proved to be totally effective. This is because the moisture under the cap can draw the contaminants toward the cap boundary, to join with other moisture on the way to the groundwater.

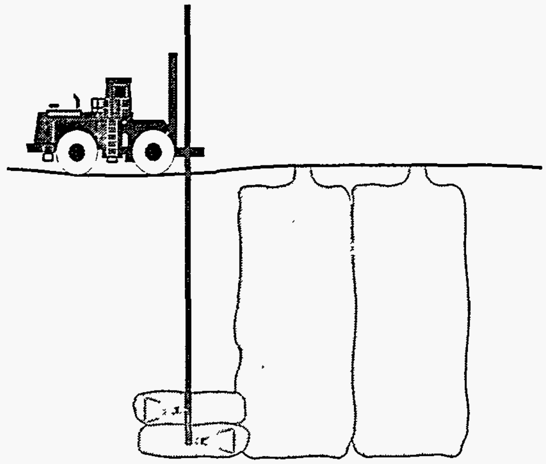
Another solution is to surround the contaminants with underground barriers, which are constructed by pumping liquid grout into the soil and letting it set. Barriers can block the natural water, vapor-and-gas, or transpiration pathways that carry contaminants with them. Also, barriers can be made to direct contaminants to sumps where they can be collected. Thirdly, barriers can provide time to clean up a contaminated site.

But conventional concrete is susceptible to cracking and degradation, so the question arose: what should the barriers be made of? At the request of the U.S. Department of Energy's (DOE) Office of Technology Development, scientists and engineers in Brookhaven's Environmental and Waste Technology Center have been playing a key role in research on barrier development.

Best Barriers

After investigating and identifying the regulatory issues and basic assumptions associated with installing barriers, our researchers started developing barrier materials and testing them for durability and performance under typical conditions at DOE waste sites.

Barrier materials have to be compatible with both the soil and waste conditions specific to each site. Each site, therefore,



Column jet grouting

must have its own barrier material, which consists of soil from the site mixed in varying proportions with, for example, a sulfur polymer or a polymer compound. Samples of each possible barrier material are rigorously tested for such characteristics as permeability to water and chemical resistivity to acid, base and solvent conditions.

Ingenious Installations

Another problem to consider is the method of installing the barrier. In the process called jet grouting, the grout is injected into the ground through rotating tubes that are slowly withdrawn as the high velocity jet mixes the soil and grout into a column about one meter in diameter. The grout sets in the soil, forming the barrier, which is made continuous by overlapping the injection zones (see diagram).

When the soil is closely packed, the SoilSaw™ method can be used. It works by the sawing action of a long beam with multiple jets along it, which is connected to an excavator equipped with high pressure pumps that force the grout out of the jetting nozzles of the beam. As the beam saws up and down in the ground, the jets spray the grout, which hardens into a barrier. As soon as the beam reaches the desired depth and cutting angle, the excavator moves backward, pulling the beam along the path where the barrier is needed (see diagram).

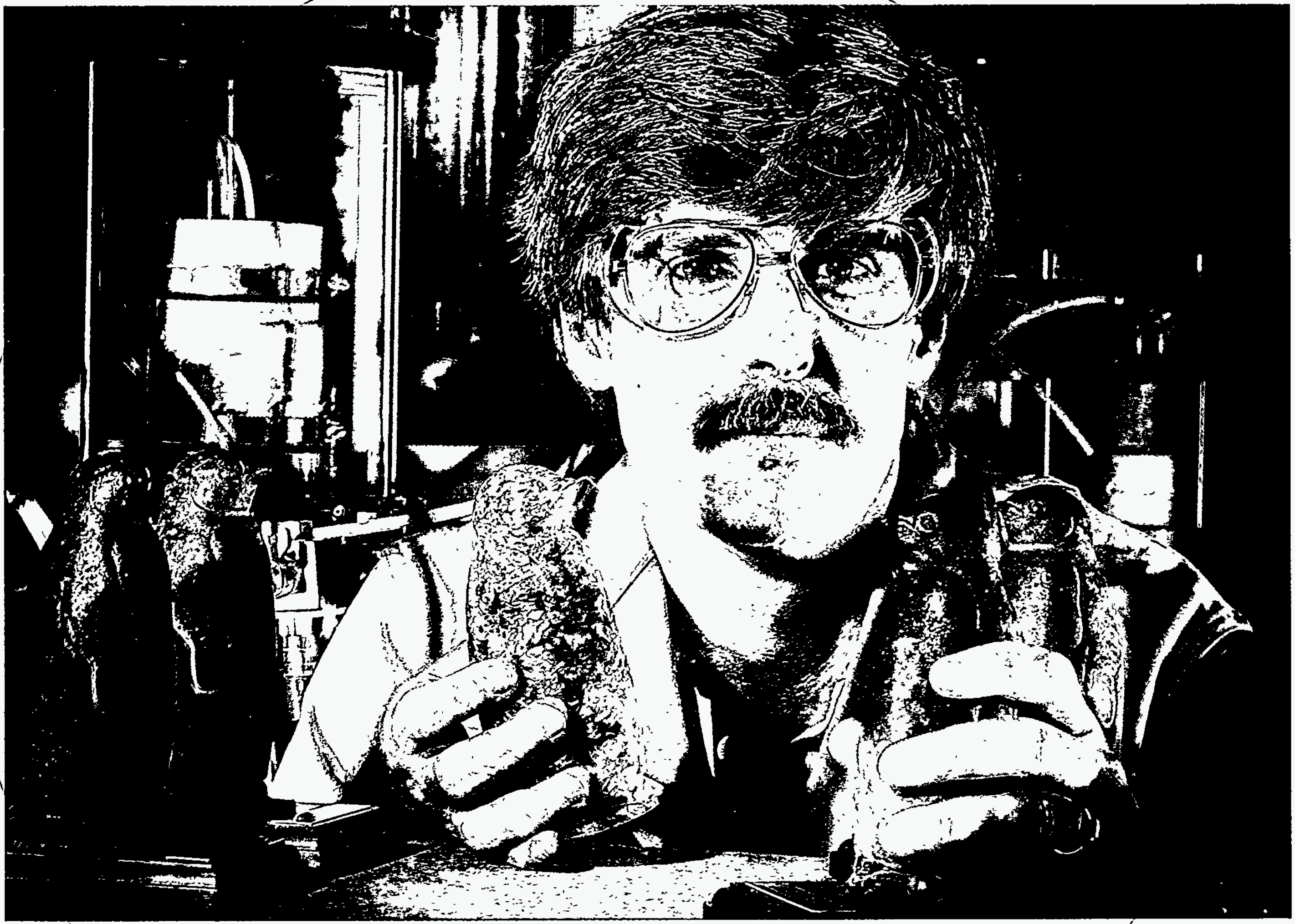
Praiseworthy Polymers

After testing many possible compounds, our researchers found that, for applications

A Tech-Transfer Success

Polymer concrete was developed at the Laboratory in the mid-1960s, when it was made by removing moisture from ordinary hardened concrete in a vacuum, then impregnating the concrete with a liquid chemical called a monomer, such as methyl methacrylate. The monomer was then hardened, or polymerized, by either radiation, a heat and radiation combination, or heat and a chemical catalyst.

Our scientists continued to refine the material and developed several versatile new versions of it. One type was designed for the rapid repair of airport runways — a polymer concrete that could be cast in place. More recently, the basic technology was successfully transferred to industry, and several polymer concretes are now available as repair and replacement materials in architecture, highway construction, electrical utility, and the oil and gas industries — and now, in containing underground contaminants.

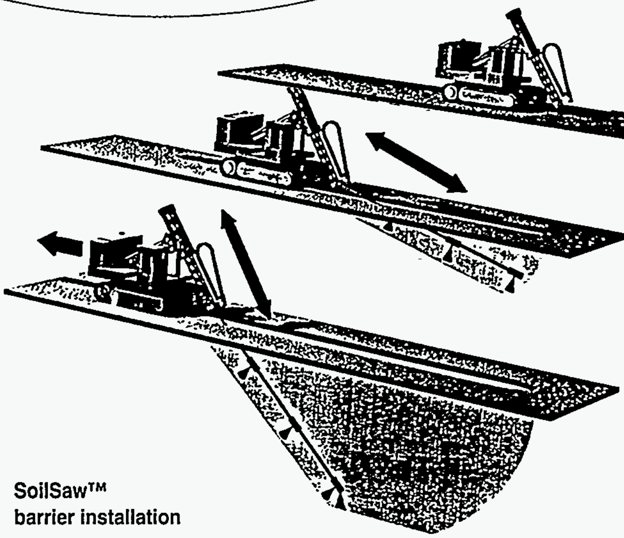


where impermeability, high strength and long-term durability are required, certain polymer compounds give excellent results. These compounds are impermeable to gas and liquids and resistant to radiation, acids and alkalis. Also, their compressive strength is double that of ordinary concrete, and they have four to five times concrete's tensile strength.

Using polymers that are available commercially, we have now completed 18 barrier materials that can be used to solidify radioactive, mixed-radioactive, chemical and other hazardous waste.

In addition, we have established a valuable data base on how the many materials we tested react as sealants under specific conditions.

John Keiser holds some of the penguin-shaped samples of new barrier compounds developed at BNL.



SoilSaw™ barrier installation

Interdepartmental Research

When a technology comes along that can be used by many at BNL, the cooperation that springs up to bring that technology's promise to life is astounding. Such was the case this year with asynchronous transfer mode (ATM) networking. From demonstrations of how our scientists are already using this revolutionary communications approach, to plans for future applications, ATM brought researchers together in true interdepartmental cooperation. The cooperative network stretched into industry and other research institutions as well.

The Information Superhighway: If You Build It, They Will Come

One of 1994's most-used phrases was "information superhighway." But while this worldwide computerized communications network is only an abstraction for most people, it is already a reality for researchers in several of BNL's departments and divisions.

This year, the Laboratory took an active role in incubating new ideas on how to use high-speed, high-tech communications equipment to enhance scientific and medical research.

Through interdepartmental cooperation led by the Computing and Communications Division (CCD) and involving researchers in the Applied Science, Medical and National Synchrotron Light Source departments, and the Relativistic Heavy Ion Collider Project, we continue to ride the very leading edge of an exciting and rapidly evolving technology known as asynchronous transfer mode (ATM) networking.

Always Transmitting More

Capable of ATM-voluminous amounts of data in the blink of an eye, ATM networks differ from the traditional information superhighway infrastructure. They transmit "fast packets" of data between communicating systems, using high-capacity circuits that provide guaranteed bandwidth for that transmission — rather than relying on telephone cables where data transmission is slow and prone to interruption.

Even in its infancy, ATM technology allows "real-time" — as it happens — communication of data, video images and sound.

Using fiber-optic cables, ATM networks can now transmit data on the information highway at a pace that would violate any normal highway's speed limit: 155 million bits of data per second. In the future, this number will go into the gigabyte (billions of bits) per second range.

And with increases in data capacity and the number of connections on the way, our researchers have set their sights on the vast expanse of communications potential that lies beyond today's horizon. Connections to colleagues around the state and across the nation are no longer a futuristic vision, but a very near reality.

Meanwhile, the companies whose equipment, cable and technical assistance provide the means for this communication are gaining a solid understanding of their technologies' potential.

Today's Catch: FISHNET

The first on-ramp to the infohighway connecting BNL with other scientific institutions has a fishy name: FISHNET, for Fiber-optic, Island-wide Super High-speed NETwork. But there's nothing fishy about it.

Proposed in 1992 by a committee of scientists from BNL, the State University of New York at Stony Brook and Cold Spring Harbor Laboratory, FISHNET began linking BNL and Stony Brook in early 1994. It uses fiber-optic cable, ATM switches, software and technical support provided by several Long Island companies, including Cablevision Systems Corporation and the Long Island-based Data Systems Division of Northrop Grumman Corporation.

During a demonstration coordinated by CCD in February 1994, physicians at Stony Brook's University Medical Center conversed face-to-face with one of our physicists through a FISHNET video link. All watched as a patient at Stony Brook went through preliminary preparations for radiation therapy. Then, complex instructions for positioning her later in the Radiation Therapy Facility at BNL's Medical Department were sent directly and swiftly over the line.

Meanwhile, other physicians at Stony Brook viewed images of patients' coronary arteries, made at the transvenous angiography facility at BNL's National Synchrotron Light Source.

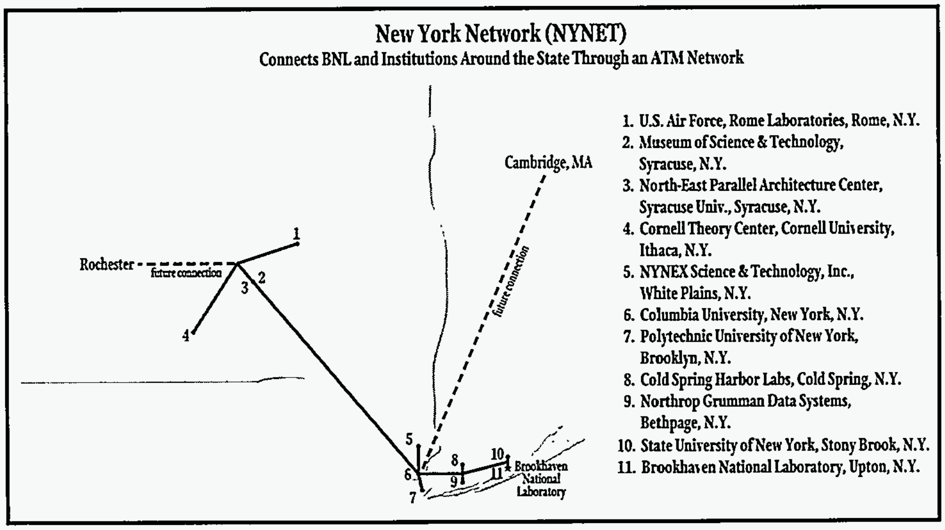
This kind of real-time medical data and image transmission saves physicians, scientists and patients travel and waiting time, and holds great promise for teleconferencing meetings and morning chart rounds.

Also at the FISHNET demonstration, our Applied Science researchers saw that the "movie" created by their computer model of groundwater pollution movement can be visualized from a remote site — in this case, the data were transmitted 30 kilometers from a supercomputer at Stony Brook to BNL.

The model will eventually be used on a powerful massively parallel supercomputer at Oak Ridge National Laboratory in Tennessee, and the results transmitted to environmental restorers elsewhere to help them plan the best course of cleanup action.

A NYNET State of Mind

ATM is not limited to Long Island — BNL also became part of a statewide ATM network this year when NYNEX expanded its NYNET network to the Laboratory.



When completed, NYNET will connect many of New York's research institutions, including Columbia University, Cold Spring Harbor Laboratory, Cornell University and Syracuse University.

This year, NYNEX laid fiber-optic cable to BNL and provided a high-performance router so that the high-speed link can connect to the more traditional technology of our existing network.

Local Networks, Too

While ATM technology has linked the Laboratory to places throughout Long Island and around New York State, with potential to go even further, another ATM project is connecting points within the BNL site.

ATM's ability to transmit voluminous quantities of data almost instantaneously makes it the likely choice to form the backbone of a communications system at the Relativistic Heavy Ion Collider now under construction.

Through prototype ATM links supported in part by seed funds from the Office of Scientific Computing of the U.S. Department of Energy, accelerator physicists, seated in the control room or at a remote workstation, can already monitor the longitudinal profile of particle bunches whipping through the ring at BNL's Alternating Gradient Synchrotron.

The particles travel near the speed of light, so after only three seconds, millions of bytes of diagnostic data, representing millions of intensity measurements, are gathered.

These data then need to be transmitted just as quickly to a workstation that can handle such a bulk of information. ATM can eliminate this potential bottleneck in a way no other technology can.

Lucian Wielopolski, Medical Department, confers in real time with radiology colleagues 30 kilometers away at a demonstration of a fiber-optic computer network.

Research Divisions

Critical to the success of the Laboratory's scientific programs are activities in the four research divisions: Computing and Communications, Instrumentation, Reactor, and Safety and Environmental Protection. These divisions collaborate with the scientific departments in support of ongoing research. The work requires innovative ideas, techniques and instrumentation, since science is by nature always reaching out to new frontiers.

Reactor Division

With the operations of two world-class research reactors under its purview, the Reactor Division facilitates scientific investigation for some 300 BNL staff and visiting scientists each year. Physicists peer into the dynamics of superconductors and other materials at the High Flux Beam Reactor, while researchers develop cancer therapy at the Brookhaven Medical Research Reactor. To expand these research horizons, user facilities are constantly being upgraded. Meanwhile, the division's staff expertly handles challenges and works diligently to keep quality standards high.

The Power To Examine Powders

Powdered sugar. Baby powder. Face powder. All of these everyday items have one thing in common: They consist of lots of small crystals — a powder.

Even things that we think are solid, such as ceramic coffee mugs, are actually made of powders that have been pressed into a solid form.

Many less-familiar inorganic substances used in scientific research and industrial production also are used in powder or packed-powder form. Among other properties, they may dissolve or combine with other substances more readily, or otherwise be a more efficient form for practical use.

Solving Structures

To find out more about powders and their properties, some scientists use beams of subatomic particles known as neutrons. These energetic probes allow researchers to determine, or solve, the atomic structure of the tiny individual crystals that make up the powder, and thereby glean information about its chemical and physical properties.

The technique is called powder diffraction, named for the way the neutrons are diffracted, or scattered, as they pass through the powder sample. The pattern made by the neutrons reveals the nature of the atoms they have encountered in their path.

This approach has been used for several decades where neutrons are available for research, including at BNL's High Flux Beam Reactor (HFBR). In fact, powder diffraction had once been labeled a "mature field," with few new advancements in diffraction techniques expected.

Until now.

A new powder neutron diffractometer built at HFBR beam line H1 began to generate impressive results in 1994, allowing scientists to "solve" the structures of many complex compounds.

The instrument was built through cooperation among BNL, the Georgia Institute of Technology and many industrial, academic and governmental organizations. Principal funding to construct it was from the U.S. Department of Energy's Office of Basic Energy Sciences as the first stage in an ongoing effort to upgrade the user facilities at the HFBR.

Based on its success, dozens of researchers have signed up far in advance to examine everything from high-temperature catalysts to metals used in basic solid-state research at other HFBR beam lines.

Mighty Monochromator

The new high-resolution neutron powder diffractometer lives up to its name: It yields higher-resolution images than any reactor-based neutron powder diffraction facility in the world and allows scientists to solve some structures that can't even be discerned using the more well-known combination of powerful x-rays and single crystals.

The instrument's unique monochromator, or neutron-deflecting mirror, makes the difference. Built by engineers in our Physics Department, it maximizes the low density of the neutron beam that hits the sample, resulting in high-resolution results. This allows researchers to detect previously unnoticed subtleties in their samples' structures, while reducing the "noise" signals that, like static on a radio, can crowd out valid, useful signals.

Small (30 centimeters high) but crucial, the monochromator is made up of many thin wafers of the element germanium. Thirty of these wafers stacked atop one another make a packet, and 24 of those packets put together make the monochromator.

Because the germanium packets are deformed, making a mosaic crystal which deflects neutrons, the monochromator can be fine-tuned to deliver neutrons depending on the energy needs of individual researchers.

With this and other improvements, structures can be solved even if their smallest repeating unit, called a unit-cell, has a volume as large as 10,000 cubic angstroms.

The BNL powder-diffraction monochromator's impressive capabilities have made it the inspiration for powder diffractometers planned for several sites in Europe.

Complexity Becomes Crystal Clear

After neutrons are focused by the monochromator and scattered from the sample, they are snatched up by an array of helium detectors inside a semicircle of boron shielding. As the instrument rotates, computers record the neutron "hits." Then, they turn these readings into one-dimensional representations of the crystals' three-dimensional structure.

Using these images, scientists can see, for instance, active sites — places where the juxtaposition of several atoms allows the crystal to latch on to other substances or catalyze a chemical reaction.

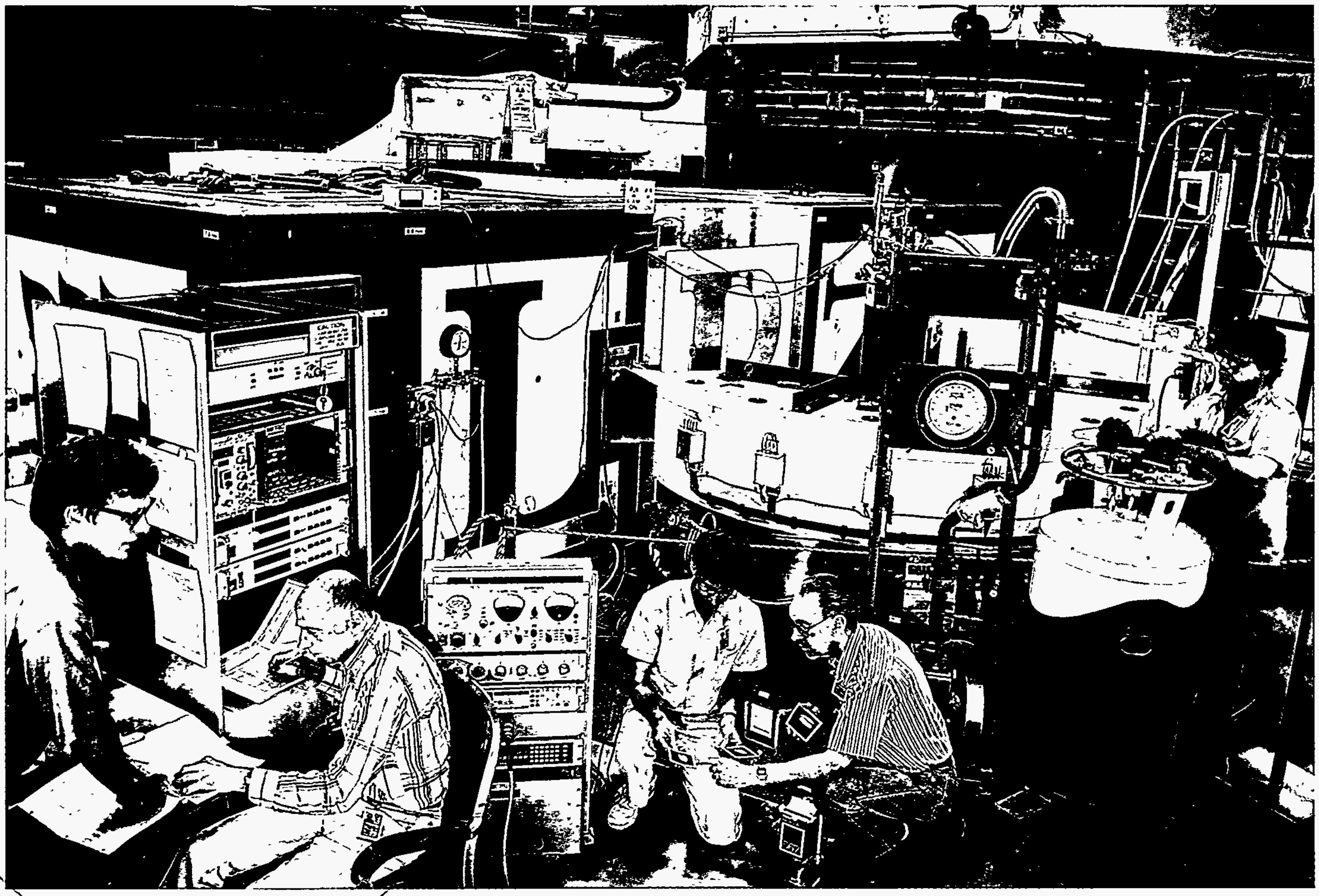
Powders used as catalysts in industry make good subjects of study by diffraction. This year, the BNL instrument allowed one team of industrial researchers to actually see the channels in their catalyst's crystal structure through which oxygen moves in the course of a chemical reaction. And others studying sponge-like zeolite structures could visualize the myriad "cages" that typify these materials.

Analysis by neutron powder diffraction can also tell scientists how pure their powders are, in order to assess the efficiency of their manufacturing processes.

And solid-state physicists, including those working at other HFBR beam lines, can learn more about the structure of a sample. Then they can use this information like a road map in their effort to gain insight into the sample's dynamic properties.

But most important, our instrument allows both basic and applied science researchers to examine powders in the form in which they are used. Combined with the power and finesse of the improved monochromator, this capability shows how the "big science" of the HFBR can contribute to the "little science" of individual projects.

At HFBR beam line H1, (from left) Tom Vogt, Laurence Passell, Shu Cheung, Paul Schaedler and James Biancarosa tend to the neutron powder diffractometer.



Safety and Environmental Protection

○ ○ ○ ○ ○ ○ ***The Safety and Environmental Protection (SEP) Division's goal — providing technical support to Laboratory staff in environmental, safety and health issues — blends well with its emphasis on partnership with those it serves. SEP monitors both the Laboratory's environment and the people and workplaces within it. It coordinates the review of design and construction plans, conducts readiness surveys of new or modified facilities, and works with departments and divisions in assessing their health, safety and environmental plans.***

Partners In Excellence

The SEP Vision:

"Partners in environmental, safety and health excellence with the BNL community in pursuit of world-class research."

Ensuring the safety and health of BNL's employees and visitors, and the environmental quality of the Laboratory's site and neighboring areas, is a nonstop challenge.

This year, the division responsible for these important duties adopted a new philosophy to help it meet that goal: partnership.

By viewing itself as a service provider working in close cooperation with its customer — the BNL research community — the Safety and Environmental Protection (SEP) Division strives for ever-increasing quality in safety, environment and health service.

Effective communication and joint problem-solving are just two important components of this customer-provider relationship, whose purpose is to help fulfill the Laboratory's mission of high-quality research without compromising the safety of employees, the public and the environment.

Other important factors each SEP employee seeks to keep in mind include:

- BNL's unique climate of open scientific cooperation, swiftly changing research goals and customized equipment to meet those goals demands a special approach to safety, one that does not seek to fit this singular community into a standard industrial safety mold.
- Science's yearly cycle of funding ups and downs requires cost-effective safety and environmental recommendations with minimal impact on research and operating programs.
- Because the Laboratory's world-class user facilities attract thousands of short-term industrial and academic visiting scientists each year, environment, safety and health efforts must effectively guard their safety while protecting their most precious commodity: time.

The following four SEP employees exemplify how individual staff members fulfill their division's mission on a personal basis, working in partnership with the researchers and other BNL staff they encounter.

Andrea Epple
Radiation Safety

Scientists come to BNL's High Flux Beam Reactor (HFBR) to perform research in their specialties. But it takes a broad knowledge of many safety fields to protect the health of all who work at the HFBR. SEP's Andrea Epple supervises a team of technicians who conduct both radiological and industrial-hygiene surveys at the HFBR. She also assists Reactor Division staff in scheduling those technicians to cover jobs such as fuel handling and the removal of irradiated scientific samples from the reactor's core. Interacting daily with scientists, technicians, maintenance workers and management, Epple's team also ensures that all staff have the training and equipment they need to work safely and in accordance with proper procedures.

Steven Kane
Safety Engineer

More than 1,500 superconducting magnets, each cooled to 4 kelvins (—269° C), will cooperate to bend and focus ions speeding around the Relativistic Heavy Ion Collider (RHIC). Safety engineer Steven Kane's charge was to design a welding material that will hold those magnets together while withstanding such super-cold, or cryogenic, conditions without fracturing — thus allowing for decades of nuclear physics research. After extensive testing, a strong and fracture-resistant alloy was developed by incorporating high levels of nickel, chrome, manganese and nitrogen, while virtually eliminating the weakening effects of oxygen. Magnet production using the alloy and a state-of-the-art welding machine built especially for RHIC began in June.

Bill Sells
Hazardous Waste Collection

In addition to noteworthy scientific results, BNL research sometimes creates hazardous waste by-products. Since strict regulations govern the handling and disposal of any waste that contains radioactive isotopes or certain chemicals, Bill Sells uses his extensive experience and training to help save researchers time and effort by safely collecting this waste from dozens of appointed areas all around the Laboratory. Several days a week, Sells retrieves clearly labeled bags, canisters and jugs, checks their documentation and transports everything to the hazardous waste management area, where he aids in preparing it for proper disposal. Sells, who also cleans the respirators used to protect workers' health, calls this the "cradle to grave" control of hazardous waste.

Jim Vaz
Fire Alarm System Manager

The BNL site is home to hundreds of visitors and their families who live in on-site housing, as well as billions of dollars in world-class scientific equipment and other property. The site fire alarm system, crucial to protecting all of this from fires and other emergencies, was redesigned in 1994 by Jim Vaz, in collaboration with BNL's Plant Engineering Division. Now, main and backup computers run software custom-designed for the unique emergency-alert demands of the site. Linking 3,500 alarm points in 170 buildings via 2,000 kilometers of cable, the system speeds graphic alarm information to the Laboratory's full-time fire/rescue group almost instantaneously, allowing faster response and better protection.

De[illegible]

Television has become one of the most powerful ways to communicate — so it's no wonder the Safety and Environmental Protection (SEP) Division calls on the Laboratory's video production group for help in getting its messages to our employees and visitors.

Using colorful graphics and upbeat music to accompany safety information in the weekly GLANCE program and training videos they produce, the video group helps SEP specialists educate its audience on safety issues. Topics range from how to handle bottled gases to the proper way to climb ladders. At right, Alex Reben (left) and Ray Axmacher put together one such piece in the editing room.

Other Photography & Graphic Arts (P&GA) Division employees also help SEP to fufill its mission of excellence in environment, safety and health practices in partnership with the rest of the BNL community.

Typesetters, graphic designers and printers produce periodic safety bulletins, environmental reports, site maps, safety information for visitors, and even colorful stickers that keep the BNL emergency number handy to every phone. Photographers aid in investigations of accidents by capturing the scene on film.

P&GA helps not only SEP, but the entire Laboratory as well, performing high-quality work in preparing communications materials. Newsletters, reports, conference proceedings and brochures are produced there from start to finish — from the preparation of photographs, charts and drawings, to typesetting, composition and page design, to the final stages of printing or photocopying and binding.

The division completes all of this work with a unique combination of old-fashioned craftsperson's pride and state-of-the-art computer technology. New printing presses and document copying machines increase speed and efficiency, while desktop computers aid designers, illustrators and typesetters in expressing their ideas on paper.

Instrumentation Division

Inventing and developing new methods and tools to make high-precision measurements for scientific research and providing unique solutions to specific problems in experiments are the primary activities of the Instrumentation Division. The staff develops new techniques in areas such as nuclear particle detectors, low-noise hybrid and microelectronic circuits, microstructures, and laser and optical metrology, and also provides special services in vacuum-deposition and optics technology, electron microscopy and printed circuit board fabrication.

Record-Breaking Neutron Detectors

Last year, the world record in spatial resolution, or pinpoint accuracy, for two-dimensional thermal neutron detectors was set at 400 microns by a Brookhaven-developed instrument.

This year, the record was broken — by the very same detector (top, far right).

The latest record sets the detection precision at 300 microns — an extraordinary standard of accuracy. This success was due to the combination of expertise, careful, precise construction and innovative use of advanced technology that characterize the work of the Instrumentation Division's scientists and technicians.

Neutron detectors are used in scientific experiments to track neutrons after a beam of those particles has been directed onto a sample of the substance under study. Because neutrons are scattered in different patterns, depending on the target's internal structure, the contrasting patterns give scientists information about the structure of the sample.

First, Know Your Detector

The modern two-dimensional position-sensitive neutron detector is a high-pressure — up to ten times more than normal atmospheric pressure — gas-filled chamber containing three parallel layers of wire planes, connected to readout electronics. Because the detectors extend in two dimensions over areas as large as 2,500 square centimeters, they can image the neutron patterns around a sample all at once. Thus, experiments that once took literally months can be completed in a day or two.

The active gas in the chamber is helium-3, a rare, expensive isotope of helium chosen for its high interaction rate with neutrons. A neutron interacting with a helium-3 atom produces a proton and a triton. These energetic particles create tracks of ionization — electrons and positive ions — in the gas. The electrons from the tracks are attracted, with applied electric fields, to the center wire plane in the chamber. As they approach the high field of a wire, they collide with gas molecules and multiply, forming an electron avalanche that produces localized signals on the two outer wire planes.

Brookhaven's Innovations

Our researchers developed an extra-sensitive method of reading out the signals, so that a smaller avalanche could be detected. This allows background signals from x-rays and gamma rays, which are commonly found in neutron experiments, to be more easily distinguished and discounted.

The proton and triton produced by a neutron-helium-3 reaction are emitted in opposite directions, and their positions are recorded by the extremely sophisticated readout electronics invented at Brookhaven. This system, called centroid finding, locates the center of two tracks' positions to indicate where the neutron was absorbed.

Because the proton is more energetic than the triton, however, it flies further. Therefore, the neutron's recorded position is slightly displaced from its interaction position. To help resolve the problem, high-pressure propane was added to the helium-3. The propane is insensitive to background radiation, but tends to stop the flight of protons, making the positions being recorded much closer to the actual point where the interaction took place. This lessens the error and plays a major role in the detectors' excellent resolution.

The more helium-3 atoms in the detector, the more likely is an interaction with an incoming neutron. But, for good spatial resolution, the chamber has to be thin, with less depth for the gas. So, our scientists developed operating modes permitting a high helium-3 pressure, bringing the thermal neutron efficiency up to 80 to 90 percent. In addition, by meticulous design and workmanship, the wire size was reduced to a minute 12 microns, which further improved the spatial resolution.

Yet another reason why the Brookhaven neutron detectors work so well is our invention of an efficient internal circulating gas purifier. This clears the helium-3 and propane of decomposition products that poison the chamber, keeping our detectors in excellent condition even after 15 years. One "oldie" detector that has completed its experimental tasks at Brookhaven has emigrated and is now at work in the laboratory of a collaborator in Australia, still with the original gas filling.

An equally vital part of neutron-scattering detection lies in data acquisition. To achieve our state-of-the-art standards, we build special-purpose processors with very large memories. These instruments can record the vast amount of information coming from 512 horizontal and 512 vertical locations, store it and then send it out over high-speed systems to workstations where the final analysis is done.

Because the data are not only collected in space, but also in time periods, researchers get a "moving picture" of what is happening to their samples. In this way, for instance, a biologist can "see" the changes in molecular structure that occur if a stimulus is applied to a muscle being studied.

Our scientists continue to develop and construct more of these advanced research detectors, fulfilling the steady demand for them at BNL and laboratories abroad.

At left, BNL's world-record holding neutron position-sensitive detector. Below are some neutron-detector team members: (from left) Mary Anne Kelley, Neil Schaknowski, Seymour Rankowitz and Joachim Fischer.

Computing and Communications Division

The Computing and Communications Division keeps Brookhaven on the leading edge of scientific and administrative computing technology and communications capability. Its innovations extend into high-speed networking, data-processing facilities and tools, maintenance, programming and communications infrastructure. In addition to supporting the Laboratory's staff, the division's programmers and technology specialists also contribute their expertise through original projects, including the AMTEX collaboration to help the American textile industry compete globally.

The Well-Dressed Computer

Wherever shoppers in today's department stores turn, "Made in the USA" labels are sure to catch their eye.

On towels, shirts, sheets, dresses and more, the assurance that American workers grew or made the fiber, spun the threads and stitched the finished products has become more and more important to many people who wish to support the country's textile industry as it faces global competition.

"Buying American" may help increase textile manufacturers' sales. But detailed information about each purchase that could help companies to make competitive decisions for the future — such as size, color and style — often never leaves the warehouse of the retail store.

All that may change over the next few years, thanks to work begun in fiscal year 1994 by a team of computer scientists in our Computing and Communications Division (CCD). It's part of the AMTEX (AMerican TEXtiles) collaboration among national laboratories, universities and many levels of the textile industry, designed to spur an exchange of expertise in a massive technology-transfer agreement.

From the southern cotton farm and the midwestern factory to the West Coast sailmaker and the New York fashion design house, AMTEX visualizes the U.S. textile industry in its mission statement as a "dominant global force in providing high value products to the world market in an environment of industry growth, environmental responsibility, profitability and worker satisfaction."

Information on Demand

Followers of fashion know how quickly the tide can turn in the worlds of clothing and home decor: What's "in" one season can be "out" the next. Meanwhile, the companies that make fashion items may need many months to get their styles ready for consumers.

Thus, the more timely sales data available to guide planning for the future, the less waste and lost profits there will be. And the fastest way to transfer that information from stores to manufacturers and on to fiber producers is through computers.

With that in mind, the largest and first slice of the huge AMTEX pie centers around a computer system called Demand-Activated Manufacturing Architecture, or DAMA.

The key phrase to remember in relation to DAMA is "electronic marketplace." Through computer-based communication, analysis and simulation systems, DAMA aims to link the scattered components of an entire industry in order to streamline decision making. Quickly transmitted information on consumer demand will drive the industry more than ever, decreasing inventory, overproduction, shipping costs and consumer prices.

Our computer scientists have already begun developing software relevant to DAMA's and AMTEX's goals, our overall aim being an information infrastructure on which the electronic marketplace can be built.

Switching Swatches Swiftly

For designers, the look of a finished product is of paramount importance — but it used to be that only a trained eye could attempt to predict how a garment or home furnishing design would look in different fabrics and colors.

Soon, however, designers who already use computers to create such items will have a new tool, which will allow them to compare materials and hues without having to sew a stitch. Our computer scientists are creating a graphical showcase equipped with an array of textures and colors that can be selected at the click of a button.

The software already incorporates computer images from the library of the Parsons School of Design in New York City and is well on its way to becoming a working part of AMTEX.

Pilot programs and demonstrations, to familiarize managers at member companies with computer tools, also got under way this year. For example, a CCD-developed program called Zipper is being developed for textile company managers as a tutorial on navigating the Internet, the vast, complicated and immensely useful "information superhighway."

Another Kind of Fashion Model

Easier communication among layers of the textile industry is only one part of BNL's contribution to AMTEX projects related to DAMA.

We are also working with models — not the Paris-runway variety, but the complicated, supercomputer-based kind.

In order to forecast the implications of their actions, textile and clothing company managers must now combine many variables and huge amounts of data — it's no wonder that even then, their best guesses aren't always accurate. If they had a way to simulate the effects of various decisions, however, they could plot a course for the future more carefully.

That's where our expertise comes in. Work has already begun on a sophisticated software-based model of the textile industry, taking into account many variables and depending on feedback from some of the managers who will use the finished software.

That software will respond instantaneously to the executives' "what ifs" — "what if" they make fewer of one product, or "what if" the cotton farmers have a bad year. They can play out each scenario in the safety of a computer "learning lab," applying only the most valuable strategies. Multimedia tools, such as CD-ROM and video capabilities, as well as sophisticated and vivid computer graphics, will all be incorporated into this project.

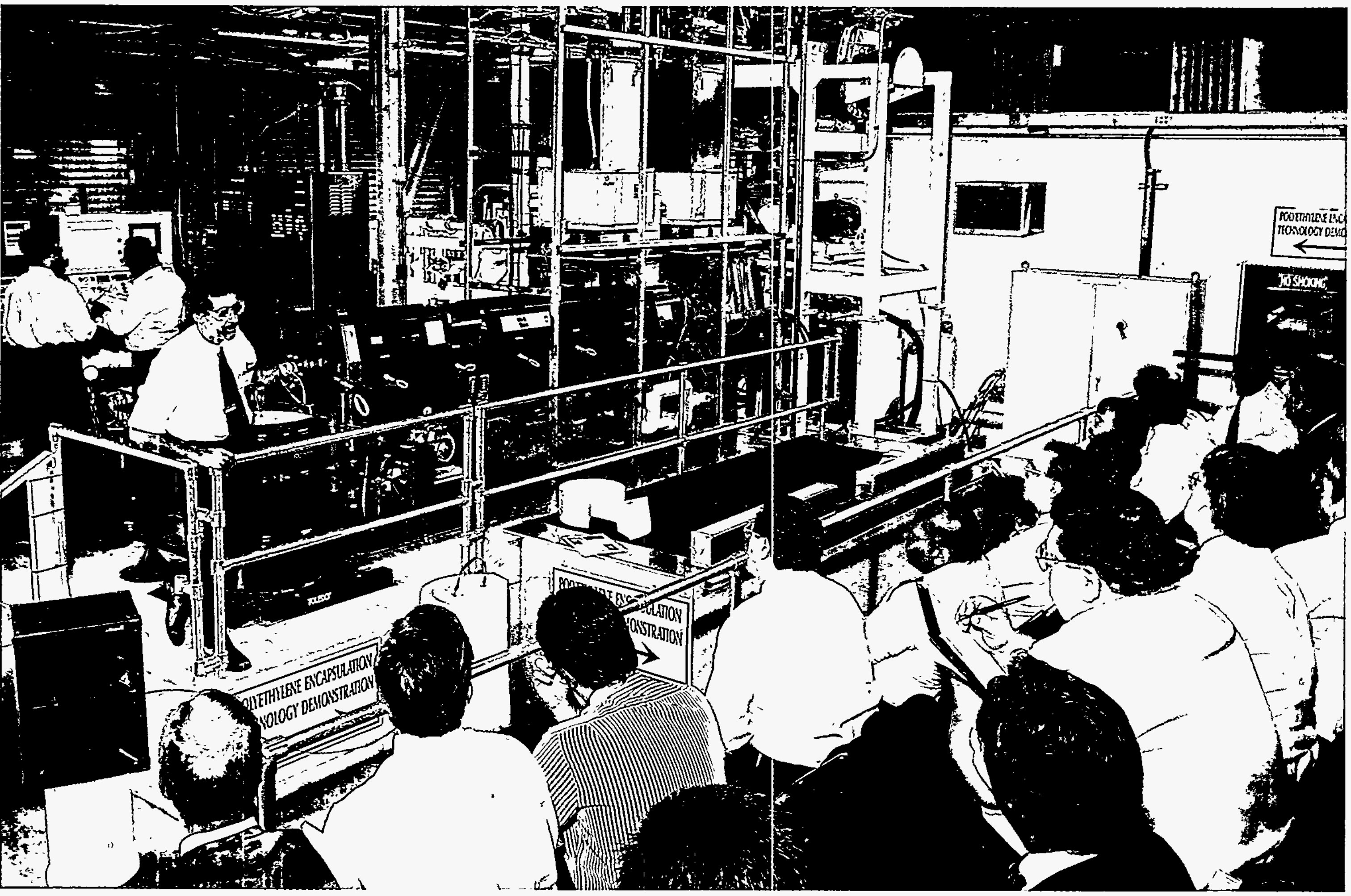
Textile company executives around the country will not only receive CCD's contributions to AMTEX — as part of a continuous feedback loop, they'll be asked for their suggestions to improve them as well. Through this kind of mutual effort, AMTEX's collaborators, including our computer scientists, envision continued success for textiles "Made in the USA."

Under the AMTEX banner, (clockwise from lower left) Alison Tilp, Sven Travis, Harold Berry, Paul Kessler, Arnold Peskin and (center) Barry Arbeit display a garment custom-made and monogrammed for Kessler at a demonstration of Demand-Activated Manufacturing Architecture.

Laboratory Profile

The following pages summarize activities that have taken place at the Laboratory during fiscal year 1994. Included in this section is a description of numerous conferences, meetings, workshops and symposia held at BNL throughout the year; a listing of honors won by Brookhaven staff; and a year-end report on the Laboratory's budget. Also highlighted are a number of programs that are under the administration of BNL support divisions and various offices.

Meetings



A demonstration of polyethylene encapsulation of radioactive, hazardous and mixed waste drew 85 industry and government observers to BNL's Environmental and Waste Technology Center on September 13-15.

Just as broad as the range of disciplines represented at Brookhaven is the range of topics for meetings, conferences, workshops and symposia that are held here each year. Among fiscal year 1994's gatherings were the following:

Scientists from BNL's Alternating Gradient Synchrotron (AGS) and National Synchrotron Light Source (NSLS) Departments hosted nearly 60 scientists for an **Orbit Correction and Analysis Workshop** December 1-3, regarding the orbits of particle beams.

The **High Energy Physics Advisory Panel** (HEPAP) to the U.S. Department of Energy (DOE) met at BNL January 28-29 to discuss, among other topics, the future of U.S. high energy physics in relation to the Large Hadron Collider at Europe's CERN laboratory.

A February 3 workshop detailing **Advances in Infrared Microspectroscopy With the NSLS** brought 32 researchers to see preliminary applications in that field at the NSLS.

DOE nuclear facilities were the subject of an **Aging Management/Life Extension Workshop** sponsored by the Department of Advanced Technology, held March 30-31 with 80 participants.

The **Oil Heat Technology Conference** hosted on March 24-25 by the Department of Applied Science drew more than 200 attendees, who even ate a lunch cooked on an oil-powered military field stove.

More than 300 technology teachers from around the state converged on BNL April 28-29 for the 31st **Conference of the New York State Technology Education Association.**

The Long Island chapter of **ASM International,** a professional organization for materials scientists and metallurgists, met at BNL on April 20 and sponsored a metallographic polishing contest for local students.

Museum administrators from all over the state visited BNL as the Museum Programs in the Public Affairs Office hosted the annual meeting of the **New York State Science and Technology Museum Consortium** on May 9.

At the annual **AGS/RHIC Users Meeting,** held June 14-15, more than 200 attendees discussed intensity records, the future use of the AGS as injector for RHIC and the possible use of the Relativistic Heavy Ion Collider (RHIC) for proton physics.

A large gathering — more than 550 in all — of synchrotron scientists and engineers from 25 facilities worldwide attended the quadrennial **International Conference on Synchrotron Radiation Instrumentation** July 18-22, co-hosted by the NSLS and the State University of New York at Stony Brook.

The 17th meeting of the **U.S./Russian Federation Joint Coordinating Committee for Research on Fundamental Properties of Matter** was held at BNL on August 25, and the 25 participants set the stage for the continuation of collaborative scientific work between the two nations.

B-physics, the study of bottom quarks, and its potential exploration at RHIC and elsewhere were discussed at a **B-physics workshop** held at BNL September 23-24.

More than 120 physicists working on the cutting edge of particle detection using calorimeters met at BNL for the **Fifth International Conference on Calorimetry in High Energy Physics** from September 25-October 1.

Lectures

Aside from the usual packed calendar of scientific seminars and lectures in each of BNL's departments and divisions, several special lecture series and seminar programs aim to reach a broader audience.

AUI Distinguished Lectures — In this series sponsored by Associated Universities, Inc. (AUI), two speakers addressed topics of general interest: physicist Wolfgang K.H. Panofsky, National Academy of Sciences and director emeritus of the Stanford Linear Accelerator Center; and chemist F. Sherwood Rowland, University of California, Irvine.

Brookhaven Lectures — The series' 34th year featured: Gerry Bunce, Alternating Gradient Synchrotron (AGS), measuring muons magnetically in the g-2 experiment; Jeffrey Coderre, Medical, boron neutron capture therapy; Robert Crease, BNL historian, early BNL history; George Hendrey, Applied Science, effect of elevated carbon dioxide on ecosystems; John Larese, Chemistry, using neutrons to study layering and melting; Paul O'Connor, Instrumentation, custom-integrated computer chip circuits; Ann Reisman, Advanced Technology, deterring nuclear weapons proliferation; and Douglas Wallace, Applied Science, ocean uptake of carbon dioxide.

Pegram Lecture — Robert Serber, emeritus physics professor at Columbia University and a major participant in the development of the first atom bomb, gave three lectures, describing "Peace and War" during three eras of his career, including work at Brookhaven.

Brookhaven Women in Science Seminars — Lecturers in this series were: Cornell University medical professor and physician Lila Wallis, jointly with the Medical Department; and University of Washington College of Medicine professor Barbara Trask, jointly with the Biology Department.

Donald Van Slyke Lecture — For this Medical Department lecture, the speaker was R. Michael Blease, National Institutes of Health, discussing gene therapy as a potential treatment for some diseases.

Aditya Sambamurti Memorial Lecture — The third year of this series featured physicist Thomas Roser, AGS, discussing the use of Siberian snakes to accelerate polarized beams at the AGS.

Honors

Thomas Butcher, Philip Cerniglia and Roger McDonald (Applied Science) captured an R&D 100 award from *Research and Development* magazine in December 1993, for the Flame Quality Indicator they developed to monitor oil-burning home-heating devices.

This owl perches on an OWL, or Oilheat Watchguard Light, the version of BNL's Flame Quality Indicator being field tested by Energy Kinetics, Inc.

This year, honors went to the following:

The **Clinical Laboratory** of the Clinical Research Center was awarded a two-year accreditation by the Commission on Laboratory Accreditation of the College of American Pathologists in February 1994, and was congratulated for "excellence of services provided."

The **Energy Management Group** of the Plant Engineering Division was presented with its second consecutive In-House Energy Management Award from the U.S. Department of Energy (DOE), in October 1993.

Sixty-seven Brookhaven employees were awarded the Laboratory's Spotlight Award throughout the year, in recognition of extraordinary short-term efforts that responded to department or division needs.

Robert Bari (Advanced Technology) was elected to the American Nuclear Society's board of directors in June 1994.

Eva Bozoki (National Synchrotron Light Source, or NSLS) was honored at Brookhaven Town's Women's Recognition Night in March 1994, for developing modeling-based control, including orbit control, for the NSLS.

Michael Brennan (Alternating Gradient Synchrotron) was one of two recipients of the Laboratory's Distinguished Research & Development Award in December 1993, for work in rf accelerator systems, including a low-level rf system for the AGS Booster.

Ernest Courant (retired, AUI Distinguished Scientist emeritus) was made an honorary professor of physics at the University of Science and Technology of China in July 1994, for contributions to accelerator development.

Joseph Hanson (Photography & Graphic Arts), **Bruce Penn** (Advanced Technology), **Alfred Roebuck** (Physics), **Ralph Sanders** (Alternating Gradient Synchrotron) and **Neal Tempel** (Biology) won the Laboratory's Brookhaven Award in December 1993 for their key contributions in support areas and outstanding service to BNL through performance and achievements.

Hugh Isaacs (Applied Science) garnered the H.H. Uhlig Award from the Electrochemical Society in October 1993, for outstanding achievement in the use of synchrotron x-rays to study corrosion *in situ.*

Art Jens (Central Shops), **John Scharpeger** (Supply & Materiel), **Richard Skelton** (Alternating Gradient Synchrotron) and **Roy McWilliams** (Plant Engineering) were recognized on a national level by the U.S. Department of Energy in May for their pollution-prevention activities.

Walter Kato (Advanced Technology) received an American Nuclear Society leadership award in June 1994 — one of eight awardees out of 16,000 members — for leadership contributions.

John Millener (Physics) was made a fellow of the American Physical Society in November 1993, for his work on the structure of light nuclei.

Gen Shirane (Physics) was awarded one of the Laboratory's two Distinguished Research & Development Awards in December 1993, for his use of neutron scattering in solid-state physics, including research on superconductors.

Joseph Taylor (Associated Universities, Inc.) shared the 1993 Nobel Prize in Physics with his colleague **Russell Hulse** for discovering the first known binary pulsar and thereby providing indirect proof of the existence of gravitational waves as predicted by Albert Einstein.

Doris Tooker (Director's Office) and **James Wegrzyn** (Applied Science) were given Federal Laboratory Consortium (FLC) awards in May 1994 for technology transfer activities: Tooker received the FLC's Northeast Regional Coordinator's Excellence Award, and Wegrzyn the FLC's Excellence Merit Award.

Ernest Warburton (Physics) received the American Physical Society's Tom W. Bonner Prize, and the congratulations of President Bill Clinton, in December 1993 for experimental and theoretical work relating to light nuclei.

Administrative Actions

Michael Bebon was appointed Assistant Director for Management and Physical Plant in February 1994.

Michael Brooks became the Deputy to the Associate Director for Reactor, Safety and Security in October 1993.

William Gunther was made Head of the Office of Environmental Restoration in September 1994.

Ernest Henley began a term as Chairman of the Board of Associated Universities, Inc., in October 1993.

Lance Junker assumed leadership of the Reactor Division in December 1993.

Joel Sussman became the Head of the Chemistry Department's Protein Data Bank in February 1994.

Karl Swyler began serving as Manager of the Office of Educational Programs in October 1993.

Laurence Trueman was made Acting Associate Director for High Energy and Nuclear Physics in August 1994.

William Willis assumed the newly created position of Assistant to the Director for the CERN Collaboration in May 1994.

Administration

Personnel Statistics

In 1994, employment at the Laboratory decreased slightly due to voluntary retirements, layoffs necessitated by tight budgets, and attrition.

Employment Statistics

	1994	1993	1992
Scientific Staff*	584	604	598
Scientific Professional Staff	619	639	622
Nonscientific Staff	2,064	2,106	2,144
Total	3,267	3,349	3,364

* Includes research associates and visiting staff.

Percent of Total Employees

Minorities	17.3	17.3	17.0
Women	23.4	24.3	22.7

Some 4,400 guest researchers, ranging from students to senior research appointees, took advantage of Brookhaven's world-class research facilities in 1994. These guest researchers came from 450 U.S. and 295 foreign institutions.

Controlling Support Costs

The operations of two support divisions were reviewed for cost-cutting ideas in 1994 by a Director-appointed committee set up to examine all of the Laboratory's nonscientific organizations by criteria similar to those used in a scientific department review.

The Plant Engineering and Staff Services Divisions were asked to present data on the number of employees, costs, tasks, trends, accomplishments and goals within their organizations. The committee's report to the Director reviewed costs and operations and made recommendations for improvements, cost reductions and effectiveness in management, and the two organizations were asked to provide a response and action plan. Previously, the Safety and Environmental Protection Division and several offices with connected functions had been reviewed in 1993.

This pragmatic approach to support operations review is expected to extend to all nonscientific offices and divisions, and help the Laboratory make better use of its resources and funding.

TRISTAN Fire Response

During the early hours of March 31, several departments and divisions mustered a quick and efficient response to an electrical fire involving radioactive material at the TRISTAN experimental station within the High Flux Beam Reactor (HFBR) building. No injuries or measurable emissions of radiation to the environment occurred, and, except for a shutdown of the reactor and evacuation of the building, general Laboratory operations continued as normal.

Emergency personnel from three divisions — Reactor, Safeguards & Security and Safety and Environmental Protection answered the call and addressed the low-level radioactive contamination found in the building and on seven individuals who had been inside. The response team gathered later in the year to review its actions, and a U.S. Department of Energy (DOE) investigation of the event identified needed improvements, primarily in the area of experiment review. Operation of the reactor resumed in early June.

A Willingness to Volunteer

The Brookhaven community showed its giving spirit throughout 1994, volunteering time and resources to help those in need. A record-breaking total of $103,441 was raised for the United Way's affiliated service groups in a campaign that garnered special recognition from the Long Island United Way committee.

The Laboratory's employees also helped fill the pantry of a local food shelf, donating 22,190 pounds of food and other necessities in monthly drives. Swimmers at the on-site pool raised a record $6,759.04 for the American Cancer Society by completing sponsored laps at July's Swimarathon, and two American Red Cross blood drives at the Laboratory collected 954 units of blood.

Technology Transfer Flourishes

With 17 new Cooperative Research and Development Agreements (CRADAs) leading the way, 1994 was another banner year for the Office of Technology Transfer (OTT), which seeks to bring the Laboratory's scientific and technological ideas to the open market through cooperation with U.S. businesses large and small.

Other accomplishments during the year included the issuing of one exclusive and 38 non-exclusive licenses by Associated Universities, Inc. (AUI), and the continued success of 31 proprietary user agreements with companies performing research at Laboratory user facilities. Through extensive outreach work, OTT targeted specific industries, as well as small businesses and minority/women-owned firms, for potential technology transfer. The office also participated in a DOE/national laboratory effort to improve the Work-for-Others process, to enable the Laboratory to perform research for university and private-sector sponsors.

Computer-Learning Outreach

A Laboratory-sponsored program that has introduced more than 700 local children and adults to computers celebrated its 10th anniversary in 1994 and began planning to add two new learning sites to its two existing ones. The six-week classes are coordinated through the Office of Equal Opportunity. The partnership, which includes AUI, DOE, local school districts and local community organizations, helps students become comfortable with using computers and prepares them for a workplace that is increasingly computerized.

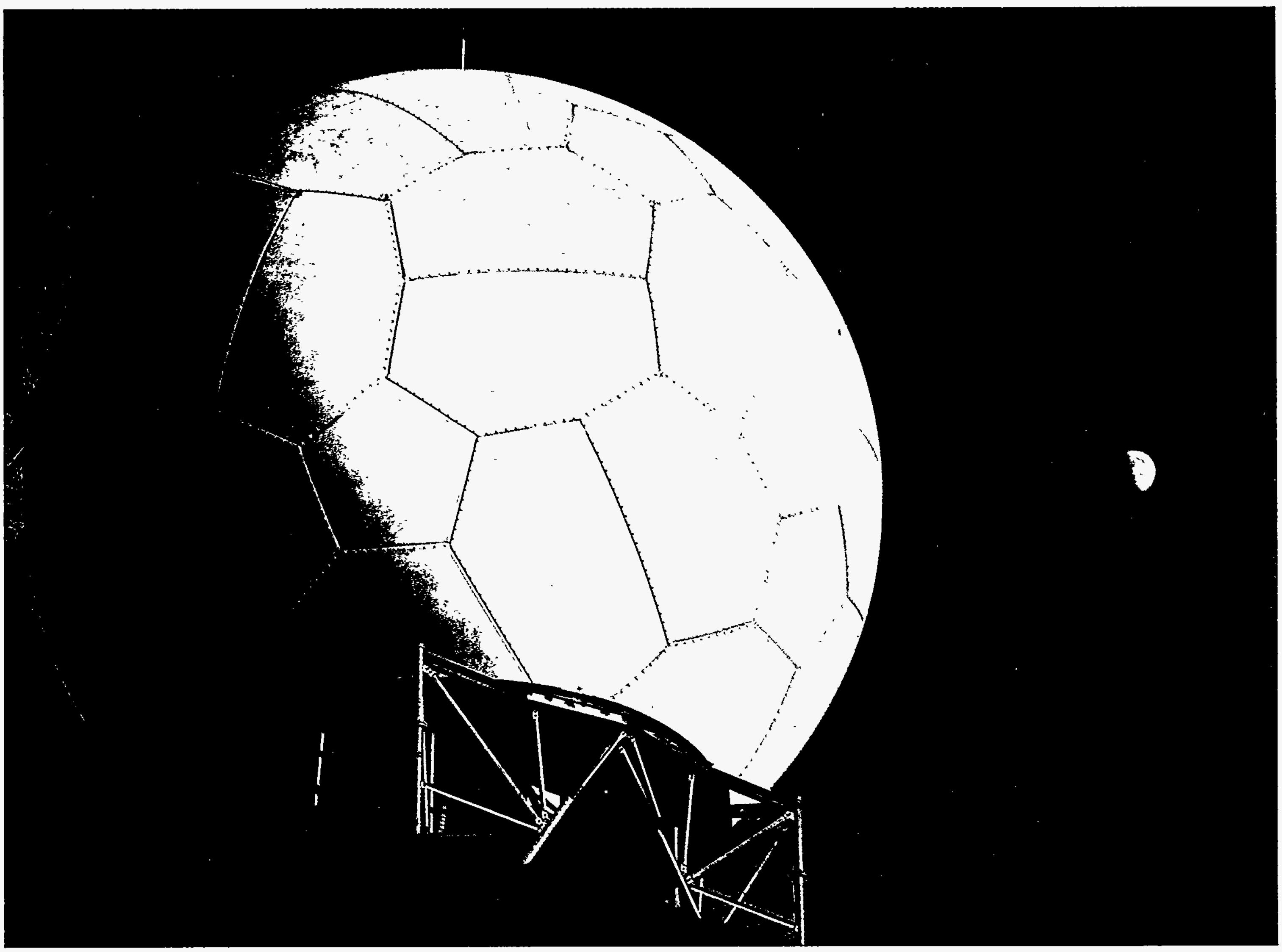
Salary Freeze; Reduction in Force

Salaries at Brookhaven were not increased in 1994, following a DOE action. At the same time, budgetary constraints led to a reduction in force of almost 100 employees through a combination of voluntary and involuntary layoffs and early retirements. This number was below the expected reduction due to reassignments and attrition. Some affected individuals were able to move to other positions within the Laboratory, while the Personnel Office assisted others in finding jobs outside BNL.

Summer Teachers

A group of 25 Long Island elementary and middle school teachers spent several weeks at the Laboratory in June and July learning about the physical sciences and applying their knowledge to the development of classroom techniques. They were

In October, the National Weather Service opened a $4 million forecast office on the Laboratory site, featuring a sophisticated, spherical Doppler radar unit in addition to other meteorology equipment.



the first teachers to come to Brookhaven under the Summer Teacher Enhancement Program sponsored by the National Science Foundation, and the first elementary school teachers to participate in a program run by the Laboratory's Office of Educational Programs (OEP). Besides visiting laboratories and facilities, the teachers learned about science-education equipment and techniques that they can bring to their classrooms in a way that makes students part of a research or engineering team.

In addition to the Teacher Enhancement participants, more than 2,500 teachers, precollege students and college undergraduates participated in various OEP programs throughout the year.

Healthfest Success

The Laboratory's first Healthfest was held in October 1993 to reinforce the importance of health, fitness and safety among Brookhaven's employees. Informational lectures, a health, safety and fitness fair, a fitness walk and a "fun run" helped the message get through. The event was sponsored by the Director's Office and organized by the Central Shops, Occupational Medicine, Plant Engineering, Safeguards & Security, and Safety and Environmental Protection Divisions, the Public Affairs Office, and several fitness-related clubs of the Brookhaven Employees Recreation Association (BERA).

Computerizing the Three P's

A new computer system to handle the "three Ps" of Brookhaven's administration — payroll, personnel and personnel budgeting — came on line in 1994. Beginning with the payroll office of the Fiscal Division in January, the new software gave employees a modernized payroll stub and the ability to have their paychecks deposited in any bank electronically. The annual salary review process was successfully converted to this program in June. By 1996, the system will allow staff in several divisions to handle information more efficiently and quickly, and to meet DOE requirements for labor-cost distribution and cost accounting.

Record Year for Museum

More people than ever before — 33,800 in all — participated in museum programs offered by the Public Affairs Office in 1994. These included over 9,400 visitors who came on Summer Sunday tours of the BNL Science Museum, which also played host to 5,780 younger and 6,088 older school children, and 1,000 college students, throughout the year.

Also in 1994, the museum programs office once again organized a science fair that was funded by the Office of Educational Programs and attracted entries from 720 budding scientists in kindergarten through grade 6, as well as a model bridge contest in which 304 high school students tested the strength of the basswood bridges they had built.

Recycling Effort Picks Up

In October 1993, mixed paper was added to the already long list of items that Brookhaven employees recycle, and a former refuse collection truck was converted for use in picking up the new stream of recyclable material from around the site. This was one more addition to the Plant Engineering Division's highly successful program to recycle cans, bottles, cardboard, metal, construction waste, batteries, tires, and white and computer paper. Thanks to the concern and cooperation of Laboratory employees, more than 1,000 tons of these materials were recycled in 1994, as Brookhaven's staff continued to "Rethink, Reuse, and Recycle."

New Voice Mail, Phone Systems

The Laboratory's centralized telephone voice mail system became even more convenient in November, when a more powerful computer took over that task. The Octel Maxum system, installed by the Computing and Communications Division, can handle 2,000 users — twice the capacity of the previous system — and can be expanded. For the 1,373 Brookhaven employees who now use it, the system offers better sound quality, more versatility and additional advanced features.

Also in this fiscal year, BNL signed a contract for an entirely new phone system with Rolm-Siemens Communications Inc.

LIRI Helped by Grant

The Long Island Research Institute (LIRI) — a not-for-profit Long Island institution whose creation several years ago was sponsored by Cold Spring Harbor Laboratory, the State University of New York at Stony Brook and Brookhaven — received $1.1 million in federal Technology Reinvestment Program (TRP) money in 1994, to be used to help Long Island's small businesses.

True to the nature of TRP grants, this one will aid some of the region's 500 small defense-related manufacturers in diversifying their product line into the civilian market by commercializing technologies developed on Long Island. LIRI was founded to foster the commercial development of advanced technologies developed at Long Island's leading research institutions and large defense manufacturers.

Special Bulletins, Radio Show Debut

Communicating the news of BNL's scientific achievements to the Laboratory community and the general public is a main duty of the Public Affairs Office. In 1994, Brookhaven's communicators introduced two new ways of accomplishing that mission: single-topic special editions of the Brookhaven Bulletin and a science series for local radio stations. The first special edition Bulletin delved deeper into cancer therapies developed at the Laboratory, while the second presented a roundup of research at the National Synchrotron Light Source. In the radio series SCIENCE ON AIR, four Brookhaven scientists took to the airwaves each month in two-minute stories produced with the assistance of the video group of the Photography & Graphic Arts Division.

Improvements to On-Site Housing

Many of the thousands of visitors who come to Brookhaven to perform research find a "home away from home" in the Laboratory's own on-site housing community of apartments, efficiencies and dormitories. In 1994, a major renovation of the 19 multiple-unit apartment buildings continued, much of it funded by DOE's In-House Energy Management Program. By 1999, each of the apartments will feature new insulation, wiring, siding, windows and furnishings, making the 1940s-era dwellings more comfortable, attractive and energy-efficient.

Making reservations for one of those apartments, or for any of the more than 433 accommodations on site, became easier and more efficient for both guests and staff this year, when the housing office in the Staff Services Division acquired a computerized property management system designed for resorts and hotels with large numbers of guests and high turnover.

First AUI Patent Royalties Distributed

Several research groups received the fruits of past scientific and technology transfer efforts in 1994, as AUI distributed $250,000 in patent royalties to the Biology, Medical and Applied Science Departments. Under AUI's patent-licensing agreement with DOE, a portion of the royalties from the licensing of patents on Brookhaven-developed inventions is poured back into the Laboratory. This year's distribution of funds, the first ever, will support new scientific research, educational efforts, technology-transfer activities and other programs within the inventors' departments. These endeavors are approved by Laboratory, AUI and DOE management.

BERA Update

More than 50 Laboratory employees and guests kicked up their heels in 1994 when a Country/Western Dance Club was added to the organization roster of BERA. Two filled-to-capacity sessions of weekly classes were held, and included instruction in popular line dances and traditional couples dancing.

Superfund

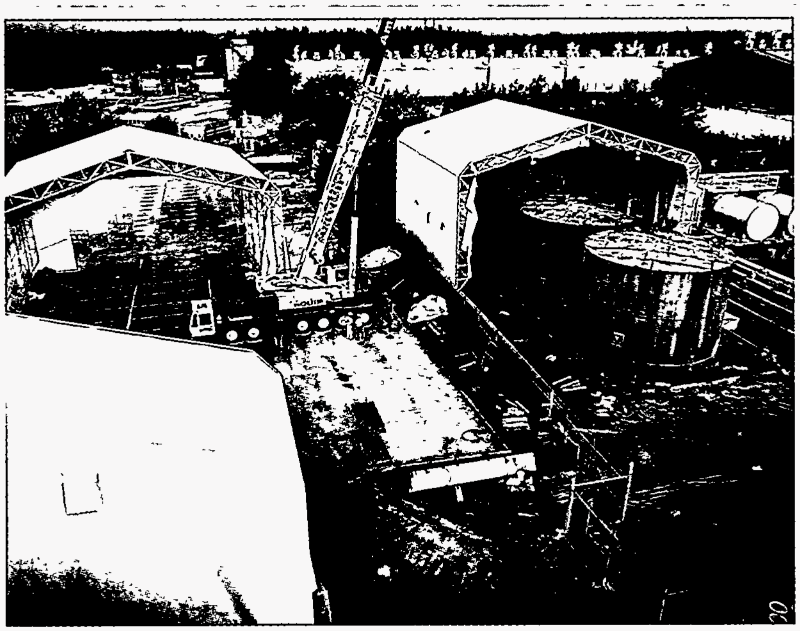
BNL is on the federal roster of sites that are considered high priority for cleanup under the federal Comprehensive Environmental Response, Compensation and Liability Act, commonly referred to as Superfund. The Laboratory's Office of Environmental Restoration is responsible for short-term removal actions to remove known sources of environmental contamination, as well as for long-term investigation and cleanup of areas of concern, where the nature, magnitude and extent of contamination are unknown.

The first major removal-action project was begun in fiscal year 1994: the dismantling of eleven large steel tanks that once held low-level radioactive waste. Under a giant structure erected to contain radioactive dust and rust, the tanks were dismantled, cut into pieces and packaged for disposal off site. The removal action began in August and was expected to be completed months later.

Another removal action was carried out this year. During construction of an addition to an existing building, mercury was found in soil being excavated for a storm drain. Construction was halted while 265 tons of soil were removed.

A public meeting was held in November 1993, to inform the community of, and solicit comments on, proposed studies of specific areas in the southeast section of BNL property. These areas are grouped together and are called Operable Unit I. The primary areas of concern in Operable Unit I are BNL's two inactive landfills, as well as the waste-management facility. Also to be addressed is an area of groundwater contamination, which had been initially remediated by a spray-aeration technique. Operable Unit IV consists of the Laboratory's steam plant and a 1977 oil and solvent spill at that location. In that unit, progress this year included the removal of the underground storage tank that had leaked in 1977, as well as removal of contaminated soil surrounding the tank.

All remediation work is approved by New York State, the U.S. Environmental Protection Agency and the U.S. Department of Energy.



Financial Report

In fiscal year 1994 (FY94), Brookhaven's total budget was $414.2 million, an increase of 3.5 percent over FY93.

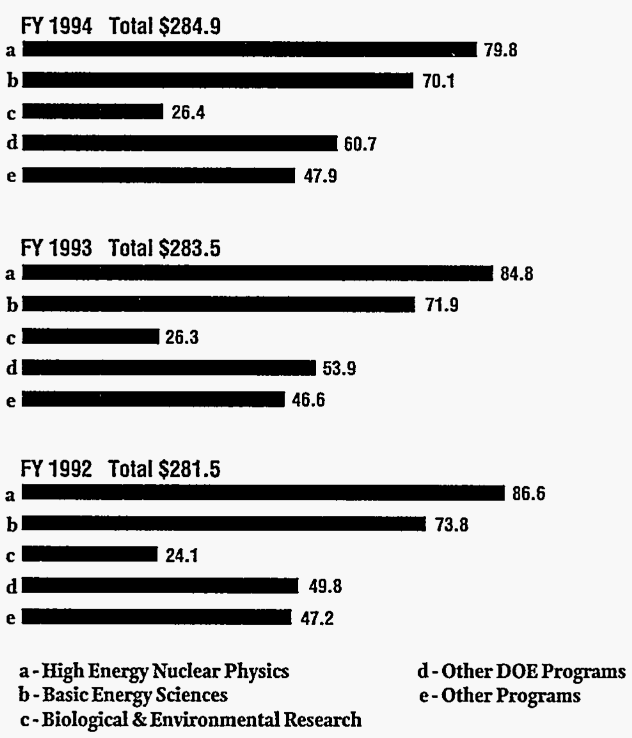
BNL's budget is divided into three areas:

- Operating funds support the Laboratory's various research programs. These funds pay the costs of salaries and wages, fringe benefits, materials and supplies, and energy associated with the research programs. In FY94, operating funds added up to $284.9 million.
- Capital equipment funding, which amounted to $22.8 million in FY94, provides for major instrumentation, scientific apparatus, computers and office equipment.
- Construction funds are used for building projects. These monies increased by 9.3 percent in FY94, to $106.5 million, largely due to funding of $78 million for the Relativistic Heavy Ion Collider. Environmental restoration and waste management (nondefense) projects received $6 million for the waste minimization facility upgrade, and $1.1 million for a laboratory floor drain collection system. Infrastructure improvements included one new start, the fuel storage and transfer facility, funded for $700,000 in FY94.

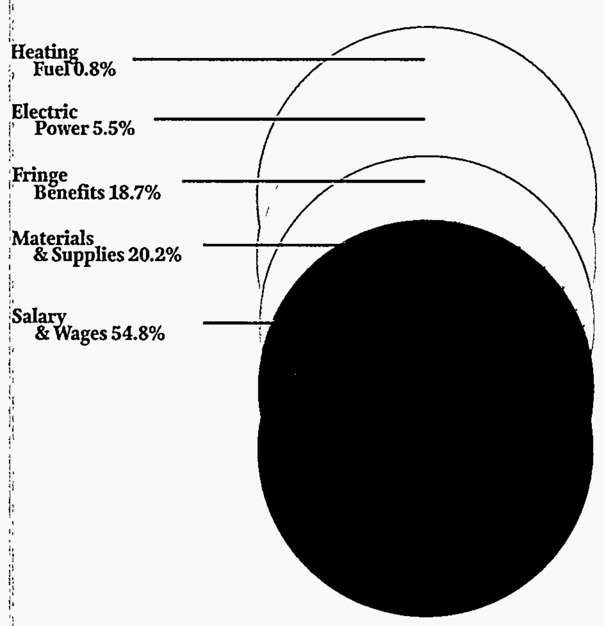
Other ongoing facilities projects supported by the U.S. Department of Energy (DOE) were the potable water system upgrade ($2 million), and phase I of roof replacement ($1.9 million). Program-related construction included an upgrade of the Brookhaven Linac Isotope Producer, funded for $5.8 million in FY94.

As in previous years, the principal source of BNL's funding was DOE, which accounted for about 83 percent of the operating budget and for all of the capital equipment and construction funds.

BNL Operating Funds (millions of dollars)



BNL Cost Elements



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