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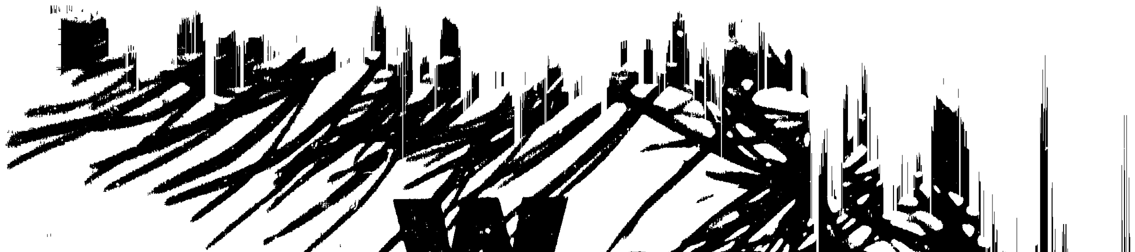
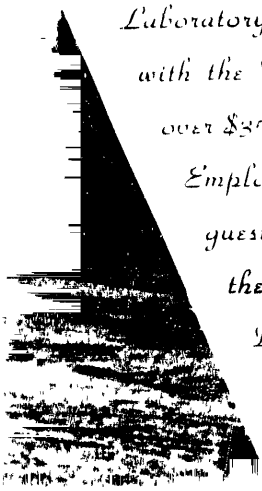


A WORD ABOUT BNL

Established in 1947 on Long Island, New York, on the site of the former Army Camp Upton, Brookhaven National Laboratory 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 with the U.S. Department of Energy. BNL's annual budget is over $350 million, and our facilities are valued at over $2.2 billion. Employees number about 3,300, and a comparable number of guests, collaborators and students come each year to use the Laboratory's facilities and work with the staff.



BNL's future is full of promise as we begin construction of a nuclear physics facility known as the Relativistic Heavy Ion Collider, or RHIC. In RHIC, the U.S. will have a unique facility with almost unpar- ... discovery.

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BROOKHAVEN TODAY

A WORD ABOUT BNL

Brookhaven was established in 1947 with a unique mission: to provide a Northeast-based center where scientists would have access to major research facilities not feasible at their own institutions.

We began fulfilling that mission almost immediately, and within a few years, experiments had begun at our first two "big machines" — the Brookhaven Graphite Research Reactor, the world's first reactor built specifically for peacetime research into atomic energy, and the Cosmotron, the first accelerator to break the 3-billion-electron-volt energy region.

Our philosophy of service to the scientific user community started out as a unique and bold initiative. Today, it has evolved into a committed and caring tradition, reaching users well beyond the Northeast and becoming a truly national resource.

Annually, some 3,300 scientists and students come to BNL from universities, industry and other government institutions to do research on our major machines. But, because of factors ranging from funding to fine-tuning, it is rare that our visitors find all our major facilities operating simultaneously. This special and exciting atmosphere did prevail, however, within a window of about a week last June, when all of Brookhaven's major machines were up and running at the same time.

Among these machines I count the four designated user facilities — the Alternating Gradient Synchrotron (AGS), the National Synchrotron Light Source (NSLS), the Scanning Transmission Electron Microscope, and the High Flux Beam Reactor (HFBR), which had just enjoyed a smooth return to an operating level of 30 megawatts after a two-year shutdown for a thorough safety review.

I also include two brand-new facilities, both investments in the future: the Accelerator Test Facility, the centerpiece of the Laboratory's Center for Accelerator Physics; and the AGS Booster, which had just completed proton commissioning — on time and within budget!

The Booster, of course, is an important link in the chain of accelerators that will provide the injection system for the Relativistic Heavy Ion Collider (RHIC) — the next important user facility that will carry out our fine tradition.

This was the first year that we received construction funding for RHIC — $13.5 million, and I am very pleased to see that funding has been increased to $50 million for 1992. It was a proud day for me in April when Presidential Science Advisor D. Allan Bromley, New York Senator Alfonse D'Amato and other luminaries joined the Laboratory community for the ceremonial beginning of the RHIC construction project.

Planned for completion when BNL celebrates its 50th anniversary in 1997, RHIC will open up exciting new research opportunities for those in the nuclear and high energy physics communities. The heavy-ion experiments that Brookhaven researchers are now conducting at the AGS and will continue at RHIC have great potential for unlocking secrets of the universe that have remained sealed since the Big Bang.

Like RHIC, our proposed upgrade for the HFBR has long had widespread support from the user community. Despite the fact that this relatively inexpensive project has been passed over for funding, we believe the upgrade is critical to maintaining the high quality of work done at the HFBR — the premier research reactor operating in the world today — and we will continue to press for and expect its approval.

As the HFBR is to neutrons, the NSLS is to photons — making it the world's foremost source of synchrotron radiation, as well as a shining example of academic and industrial participation. As tools for investigating basic energy sciences, the HFBR and the NSLS are wonderfully complementary. This Brookhaven concept, which provides users with a center for materials science they can find nowhere else, has gained worldwide appreciation and emulation.

While it gives me great satisfaction to look at the BNL site and see the vital user community we have established here, I am pleased to note that we are also responsive to the needs of those outside the Laboratory's boundaries:

- We are constantly looking for ways to transfer to industry BNL-developed technologies. And we have been leading the national effort to develop a compact superconducting x-ray lithography source to keep the U.S. competitive in the computer chip market.
- As a recognized expert in the field of superconducting magnets, Brookhaven has become a major player in developing the sophisticated magnets for the national Superconducting Super Collider (SSC). We're also exporting our detector expertise in collaborations such as D-Zero at Fermi National

Accelerator Laboratory and GEM for the SSC.

- Because Brookhaven is not a weapons laboratory, our objectivity and expertise are especially sought by the International Atomic Energy Agency in its effort to prevent the spread of nuclear weapons.

And with three new facilities, we have extended our boundaries to include many others:

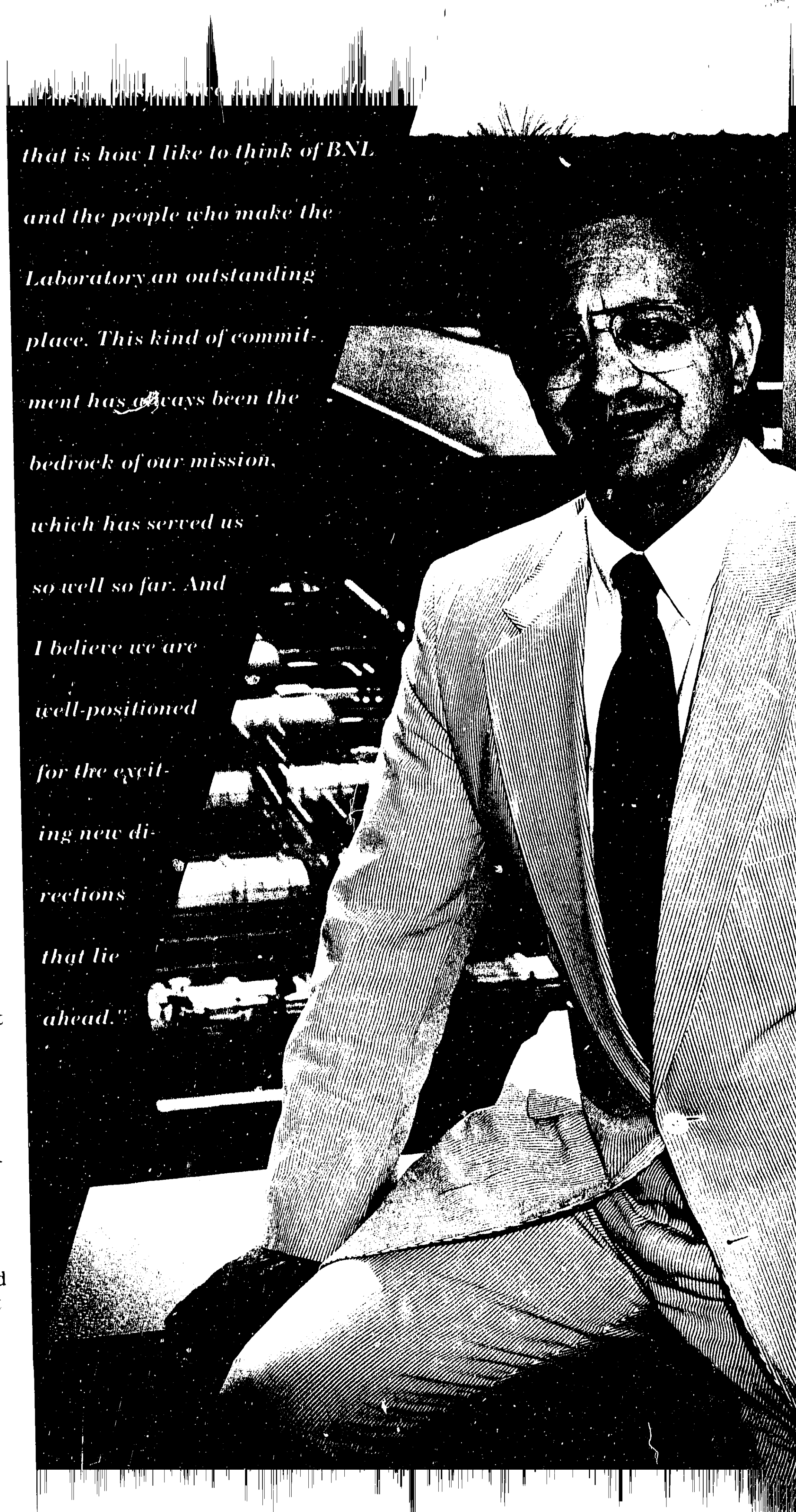
- The Radiation Therapy Facility, operated on site by University Hospital at Stony Brook, gives cancer patients from eastern Long Island a first-rate facility at which to receive the finest treatment available.
- The new Science Education Center will provide a focal point for the students of all ages who visit and work at BNL throughout the year.
- The Child Development Center opened in September to meet the needs of our youngest generation, as represented by the children of our employees.

We recognize that all our endeavors must be accompanied by a deep commitment to a culture that emphasizes safety for our employees and protection of our environment. Safety in the workplace has become a focal point for improvement, and we have aggressive programs for tackling the remediation of the site and minimizing any waste that we produce. Though we are sometimes overwhelmed by the sheer number of reviews and regulations that must be coordinated in this effort, we are seriously engaged in addressing these concerns.

Eager, responsive and committed — that is how I like to think of BNL and the people who make the Laboratory an outstanding place. This kind of commitment has always been the bedrock of our mission, which has served us so well so far. And I believe we are well-positioned for the exciting new directions that lie ahead.

N.P. Samios

Nicholas P. Samios
Director



Full Speed Ahead on RHIC

Under bright blue skies on a crisp April morning, a crowd of nearly 500 people gathered at BNL to celebrate the beginning of construction of the Laboratory's Relativistic Heavy Ion Collider (RHIC). That day in April marked the inauguration of the RHIC project, which received Congressional authorization of construction funding beginning in fiscal year 1991. The collider will take six years to complete, with a construction budget of $397 million from the U.S. Department of Energy.

A WORD ABOUT BNL

The promise of RHIC

To catch a glimpse of the universe at the moment of its creation . . . and not just once, but over and over again. That is the promise of RHIC.

RHIC will be able to create matter at extremely high temperatures and densities, conditions so extreme that scientists hope to observe phenomena that have not occurred in the natural universe since the original "Big Bang." This will open the door to studies of the fundamental properties of matter in a state in which the primordial quarks and gluons are no longer confined as constituents of the nuclei of ordinary particles.

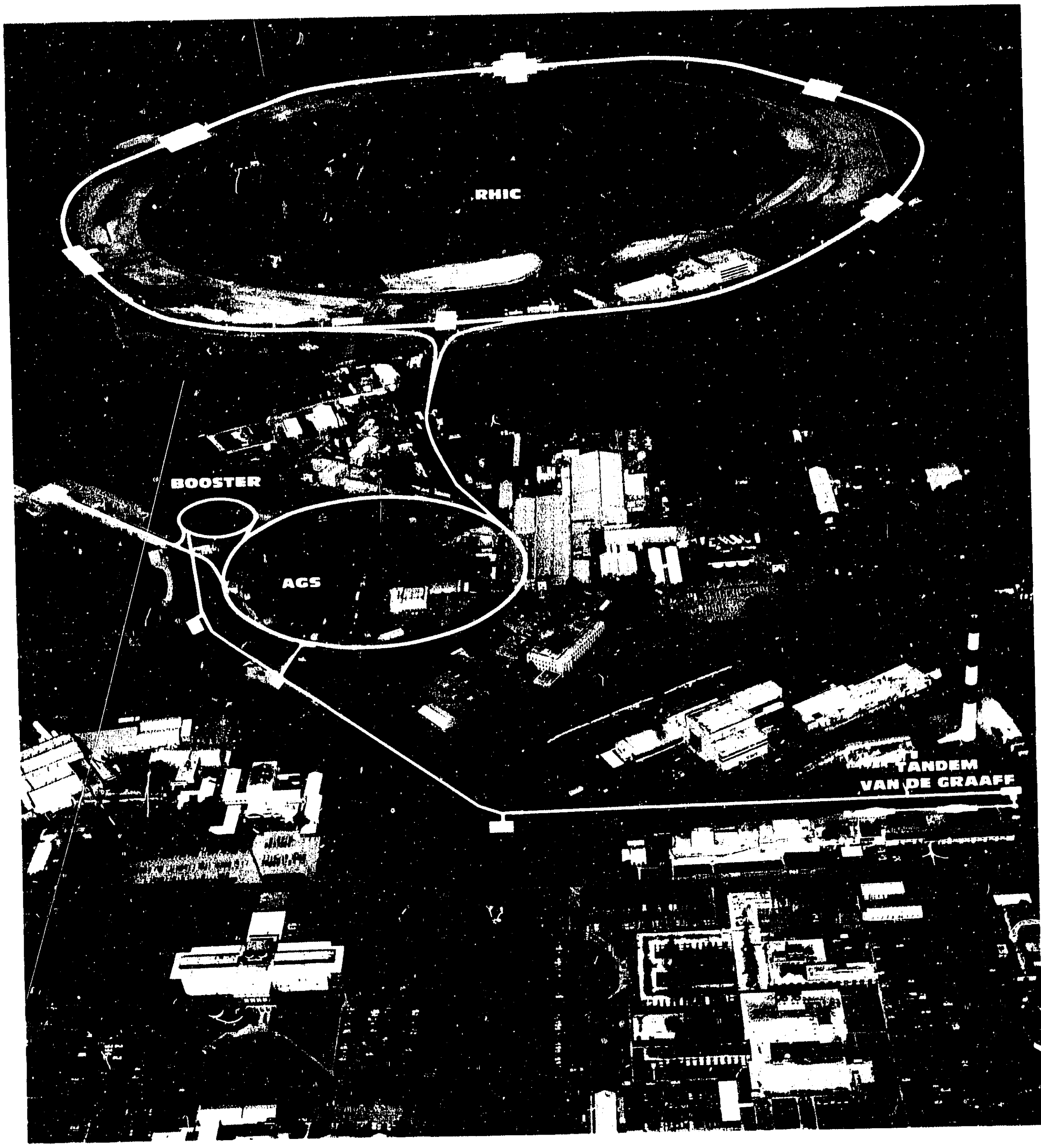
Such nuclear matter is called a quark-gluon plasma. It has never been seen before, and it offers physicists a whole new area of scientific study.

- Nuclear physicists are eager to explore a new frontier with the formation of quark matter. The transition from regular nuclear matter to quark-gluon plasma is a fundamental process predicted by modern theory. To test the theory, matter would have to be compressed to ten times the density of normal nuclei, or raised to a temperature one hundred thousand times hotter than the center of the sun.
- Particle physicists will study for the first time the behavior of quarks in an extreme state of matter and will be able to test the theory of strong interactions by observing systems in which large numbers of quarks interact with one another.
- Astrophysicists want to recreate the conditions that characterized the early evolution of the universe, as well as study the properties of nuclear matter with the high densities found in exploding stars.

A world class facility

In RHIC, the United States will have a unique world-class facility with almost unparalleled potential for discovery.

The traditional evolution of high-energy accelerators has been to probe deeper and deeper into the structure of elementary particles. With beams of electrons or protons,



The RHIC accelerator complex.

the higher the energy of the beam, the more powerful is the "microscope," as scientists search for new particles of ever-smaller dimensions.

RHIC will be the first high-energy accelerator to take a different approach. By colliding large particles (heavy nuclei) at high energies, RHIC will create a microcosm of the hot, dense plasma of quarks and gluons from which particles condensed immediately after the Big Bang. Thus, RHIC will be like a giant pressure cooker, producing temperatures and pressures more extreme than now exist even at the centers of stars.

In RHIC, two beams of heavy ions will speed in opposite directions around a pair of rings in a tunnel about 3.8 kilometers (2.5 miles) in circumference. Where the beams collide, at six different points around the accelerator, each collision will have a combined energy of 200 billion electron volts for each of the protons and neutrons contained in the colliding nuclei. Collisions that combine heavy nuclei at extremely high energies are the key to creating quark-gluon plasma. This cannot be done at existing high-energy accelerator facilities anywhere else in the world.

In 1983, the nuclear physics long-range plan prepared by the scientific community for the Department of Energy and the National Science Foundation cited RHIC as the highest priority new facility for the field. That recommendation was repeated in the 1989 long-range plan.

The Presidential budget proposal for fiscal year 1991 included fund-

Sharing a congenial moment during the RHIC ceremony in April are (from left) Senator Alfonse D'Amato, BNL Director Nicholas Samios, and Nobel laureate and Columbia Professor T.D. Lee.

ing to initiate RHIC construction, and Congress followed through by appropriating the first construction funds for RHIC. After a final review by the Department of Energy, the construction project was formally begun.

The project is considered especially cost-effective because RHIC will be placed in an existing tunnel at BNL, originally built as part of the Colliding Beam Accelerator project, which was cancelled in 1983.

THE ACCELERATOR COMPLEX

The RHIC tunnel is located in the northwest section of the Laboratory site. The RHIC accelerator complex, however, will include several BNL facilities to the south.

Heavy ions for RHIC will originate in Brookhaven's Tandem Van de Graaff, proceed into the Booster, and then into the Alternating Gradient Synchrotron (AGS), which will serve as the injector for RHIC.

When RHIC construction is completed and the entire chain of accelerators is linked together, that moment will be the fruition of many earlier years of hard work to modify existing facilities and build anew.

In 1986, the first link in the chain was forged when the Tandem was joined with the AGS via a newly constructed tunnel. The AGS, originally a proton accelerator, had already been modified to accelerate heavy ions.

Then, in 1988, the Booster project began. This small accelerator extends the range of ion species available to the AGS from the Tandem. Thus, the AGS will be capable of injecting into RHIC heavy ions as massive as gold, with an atomic weight of 197.

When RHIC is operating, over 100 bunches of heavy ions will be accepted in each of the two rings. Then, with both rings filled, the ions will be accelerated in a matter of minutes to the top energy. At that energy, the ion beams will coast around the rings in stable orbits for hours. For experiments, particles will be collided head-on at the rate of tens of thousands of collisions per second.

The tunnel configuration provides for six areas where the circulating beams cross and collisions take place. Four of these areas already have the necessary enclosures and support buildings to accept the first phase of research detectors. Two areas will be left undeveloped for a later phase.

RHIC EXPERIMENTS

In anticipation of RHIC start-up in 1997, an international community of nuclear and high energy physicists has already embarked on a program of experiments with very high-energy nuclear beams.

The first round of this research began in 1986, with fixed-target experiments at Brookhaven's AGS, as well as its European equivalent, the Super Proton Synchrotron at CERN. These programs are paving the way for experiments at RHIC, where colliding beams of heavy nuclei will produce much higher energies and offer unprecedented opportunities to study phenomena in the extreme state of matter — the quark-gluon plasma.

RHIC is designed to accommodate a varied program of heavy-ion experiments aimed at exploring this new regime. Some of the experiments will require the construction of large-scale detectors, which will

What's in a Name?

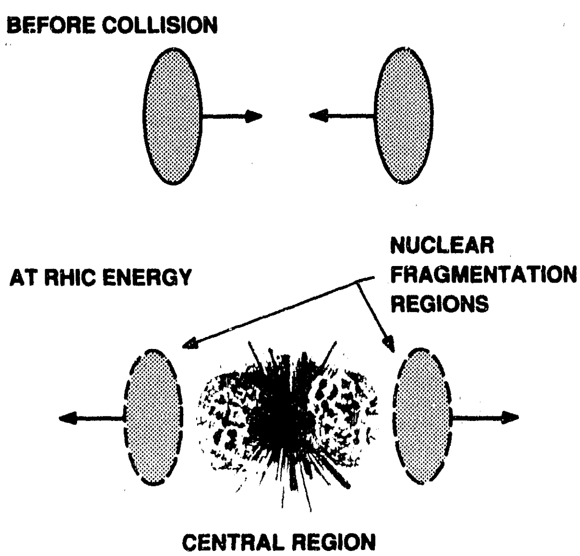
The name "Relativistic Heavy Ion Collider" seems a mouthful at first. This is what it means:

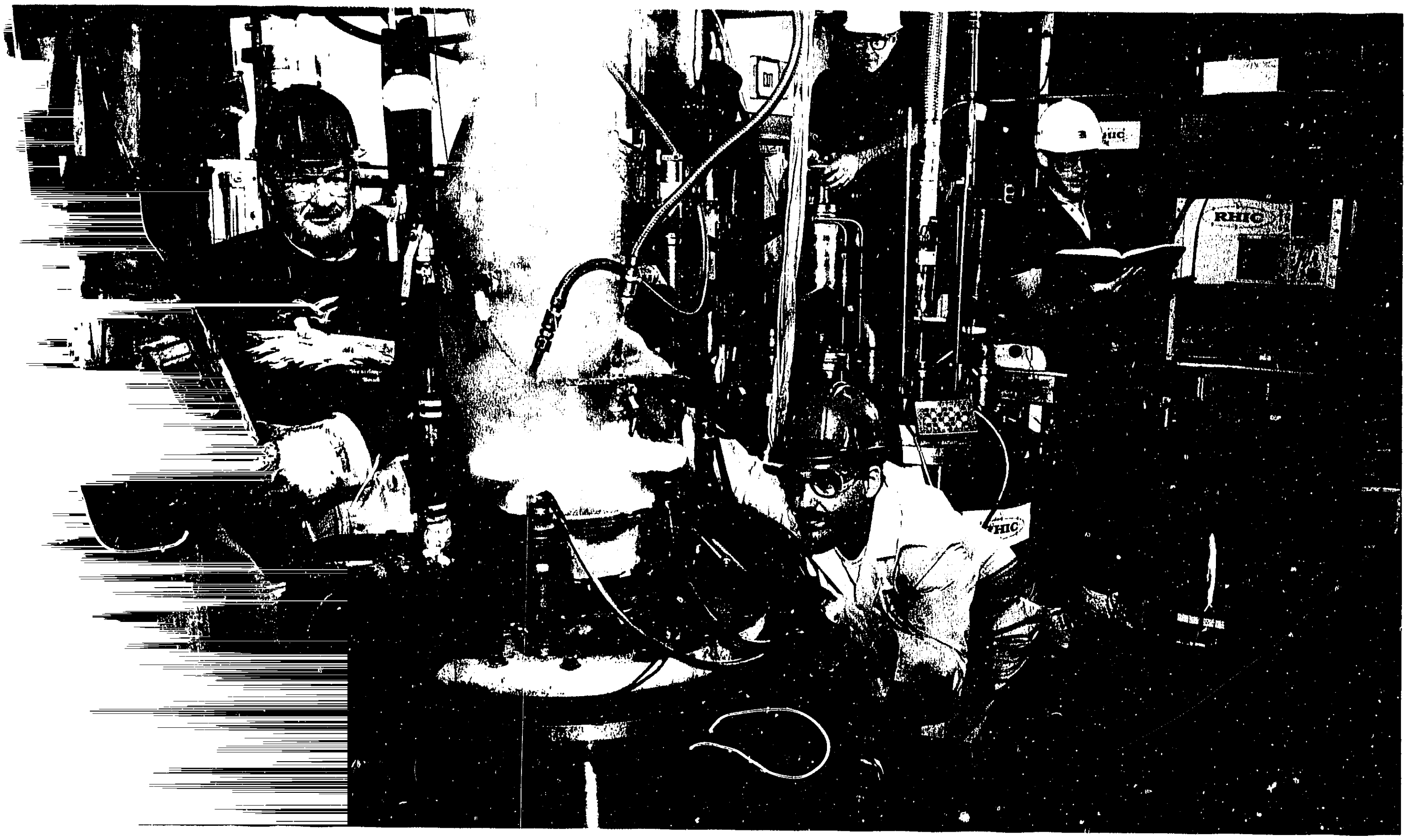
- Relativistic describes something traveling near the speed of light — in this case, heavy ions. At these speeds, the motion is described by Einstein's theory of relativity.
- An ion is an atom that has been stripped of its electrons, leaving only the nucleus. Heavy ions are so called because their nuclei contain many protons and neutrons.
- A collider is an accelerator in which two beams of particles circulate in opposite directions and collide at various points around a ring.

Putting the words together, they aptly describe RHIC's job: to collide beams of heavy ions at relativistic speeds.

On a Collision Course

This schematic shows expected results when two heavy nuclei collide at the high energies achievable in RHIC. As the two nuclei approach each other at nearly the speed of light, their normally spherical shapes are flattened due to the effects of relativity. During the collision, they will pass through each other, resulting in two hot, dense fireballs flying away from each other, leaving behind, in a central region, a state of matter in which extraordinarily high temperatures are reached. Such collisions should duplicate conditions that have not existed since the first few microseconds after the birth of the universe, conditions in which scientists hope to explore new forms of matter that directly reflect the fundamental and elusive properties of quarks.





In a testing laboratory where R&D work is carried out on superconducting materials for RHIC, (from left) Erno Ostheimer and Joseph D'Ambra test a sample of cable cooled in a cryostat to 4.2 kelvins. Working in the background are Richard McCluskey and Edward Sperry IV.

be among the most complex ever built and will be operated for many years by large teams of scientists. Other experiments will be carried out with relatively small detectors on a shorter time scale. Detector construction will account for about one-fourth of the project's cost.

In providing the first look at an uncharted domain of extreme nuclear temperatures and densities, RHIC detectors must be built to face new challenges: A single collision may produce as many as 10,000 high-energy elementary particles, and thousands of collisions will occur every second!

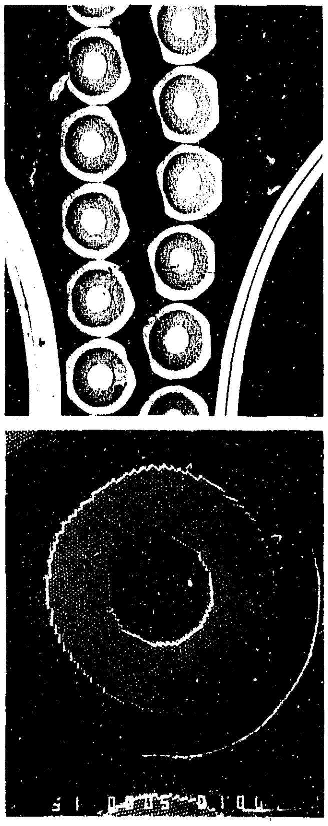
Hundreds of physicists are already engaged in preliminary designs for RHIC detectors. As the fiscal year ended, one detector concept, called STAR, was given conditional approval as the first large detector to proceed with a preliminary design.

Roughly six meters in diameter and resembling a giant cylinder, STAR will use a massive device called a time projection chamber to measure particles known as hadrons. The 20-odd institutions collaborating on STAR include U.S. and foreign universities and laboratories, with Lawrence Berkeley Laboratory and BNL playing major roles.

During the coming year, another collaboration will be organized to design a second large detector, to measure two other types of particles — leptons and photons. In addition, physicists will be considering smaller experiments whose physics objectives complement those of the large detectors.

Presidential Science Advisor D. Allan Bromley addresses the crowd gathered for the ceremony to celebrate the beginning of RHIC construction.

Robert Hughes, President of Associated Universities, Inc., speaks at the RHIC ceremony.



Super Cable for Super Magnets

All RHIC magnets will use superconducting cable, which is made from niobium-titanium alloy — a special material that loses electrical resistance at a temperature close to absolute zero.

In fiscal year 1991, when Congress appropriated the first installment of the $397-million construction budget for RHIC, the Laboratory was able to start tracking down some of the major purchases from industry that will be required as the construction project progresses.

The first major contract was signed in September 1991, for the purchase of superconducting cable from Oxford Superconducting Technology in New Jersey. Oxford's cable will be used specifically in RHIC dipole magnets, which will be the first type to be procured from industry.

The cable consists of 30 strands of individual wires, each containing about 3,600 niobium-titanium filaments embedded in copper. A single filament is 6 microns in diameter — roughly one-eighth the size of a human hair.

A cross section of a portion of a cable (top) shows two rows of wires, magnified 32 times in the photomicrograph, which was taken with an optical microscope. The filaments show as gray circles and the white is the copper matrix. A closeup of a wire (bottom), magnified 150 times by a scanning electron microscope, reveals the individual filaments.

A WORD ABOUT BNL

Industry to Build RHIC Magnets

For the latest generation of particle accelerators such as RHIC, perhaps the greatest challenge lies in designing the superconducting magnets needed to bend and guide the particles as they whiz around a tunnel at close to the speed of light. But while superconducting magnets are difficult and expensive to build, they are far superior in field strength and overcome the problem of the prohibitive power costs of conventional electromagnets.

Laboratories in the United States and around the world have devoted decades of work to superconducting magnet technology, and this dedication has paid off. The technology is now well in hand.

RHIC will use about 1,700 superconducting magnets. Of that number, industry will build about 1,200, based on BNL's prototype full-scale magnets, which have successfully passed performance tests. The balance will be built by the Laboratory, as they are special purpose magnets. Commercial studies of the RHIC magnet design have found the RHIC magnet technology to be well-suited for transfer to industry.

In November of 1990, BNL held a three-day workshop to familiarize industry with the magnet technology, with particular emphasis on the dipole magnets. Over thirty companies came from all over the world to learn about the magnets and gather detailed written material and drawings. Following that, BNL sent out requests for proposals to build dipole magnets, and various companies replied with formal proposals. By year's end, the Laboratory had completed technical evaluation of the proposals.

These dipole magnets will be built using superconducting cable. In September 1991, BNL signed a $6.5 million contract with a New Jersey company to manufacture and supply over 548,000 meters (1.8 million feet) of cable — a major step toward RHIC commissioning.

◄ RHIC Project Head Satoshi Ozaki is seated on the flatbed truck bearing the RHIC dipole magnet that was exhibited during the RHIC ceremony. This 9.7-meter-long magnet produces a powerful and uniform magnetic field inside the central pipe where the heavy ions will travel. When the magnet is operating, its iron structure and the superconducting cable contained within are cooled by liquid helium to 4.3 kelvins (452°F).

BROOKHAVEN'S BIG MACHINES

The essential ingredients for scientific breakthroughs are many — top-notch researchers with keen insights, careful procedures, precise timing, and reliable, state-of-the-art facilities. These ingredients are abundant at Brookhaven. Besides its first-class researchers, BNL is home to four world-renowned scientific facilities. The sophisticated capabilities of Brookhaven's big machines are essential for experiments in many diverse fields, from physics and materials science to biology and chemistry. The National Synchrotron Light Source, the Alternating Gradient Synchrotron, the High Flux Beam Reactor and the Scanning Transmission Electron Microscope are the big machines that attract approximately 3,000 visiting researchers to Brookhaven each year. They come from industry, academia and other laboratories all over the world to work independently or in collaboration with BNL researchers. Brookhaven encourages collaborative research with industry, and the Laboratory's 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 BNL by entering into a proprietary user's agreement with the Laboratory.

National Synchrotron Light Source

NATIONAL SYNCHROTRON LIGHT SOURCE

Since it began operations in 1982, the National Synchrotron Light Source (NSLS) has been an important resource for scientists in a variety of fields, including physics, chemistry, biology, materials science and various technologies. The world's largest synchrotron radiation center, the NSLS produces a broad range of radiation, from infrared and ultraviolet light to x-rays.

In steadily increasing numbers, researchers have been using this synchrotron radiation for purposes as diverse as exploring the surfaces of catalysts to determining the concentration of lead in human bones. In 1991, some 2,610 researchers from 376 institutions used the facility.

ALTERNATING GRADIENT SYNCHROTRON

An international community of researchers performs a variety of physics experiments at the Alternating Gradient Synchrotron (AGS).

The most versatile accelerator in the world, the AGS can accelerate protons to 33 billion electron volts (GeV), polarized protons to 22 GeV and heavy ions up to 14.6 GeV per nucleon. The AGS also provides the most intense beams of kaons ever available for research. This year, 740 researchers from 92 institutions performed experiments at the AGS.

HIGH FLUX BEAM REACTOR

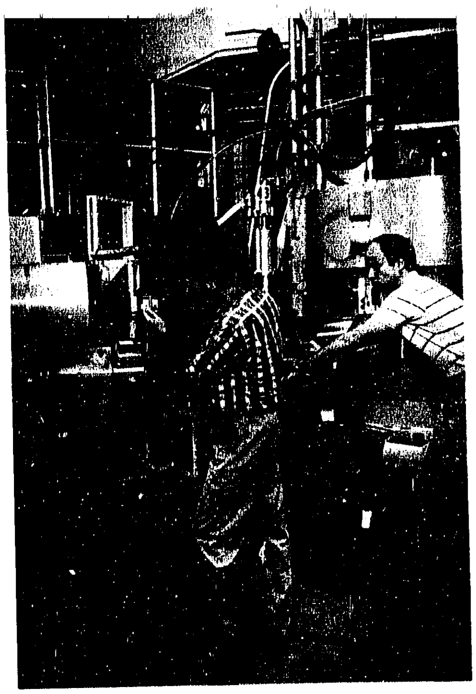
One of the world's most advanced research reactors, the 26-year-old High Flux Beam Reactor (HFBR) resumed operations this year after a two-year hiatus for safety reviews.

As many as 250 researchers from universities, industries and other laboratories are expected to return to their research at the HFBR. The reactor produces neutrons that are used as probes for experiments in numerous fields, including biology, chemistry, physics, and metallurgy.

SCANNING TRANSMISSION ELECTRON MICROSCOPE

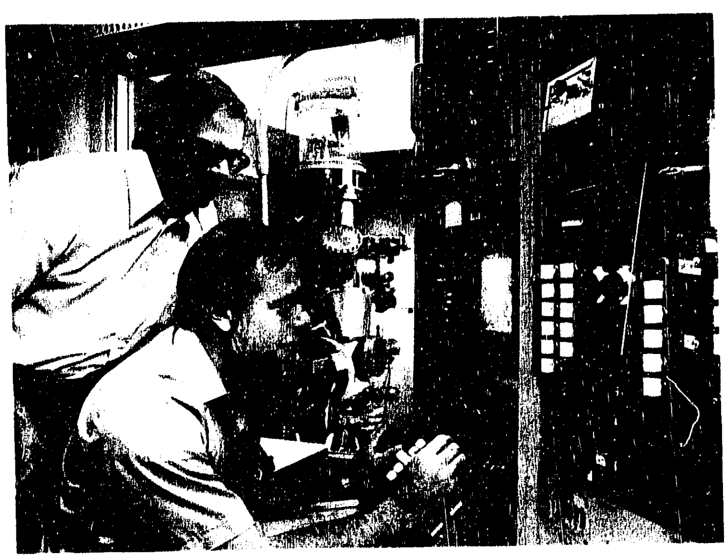
Brookhaven's Scanning Transmission Electron Microscope (STEM) can easily image single heavy atoms. One of only three high-resolution microscopes in the world with that capability, it is used to view biological specimens without adding heavy metals to the sample for staining or shadowing. Researchers also use STEM to measure masses of proteins, nucleic acids and complexes of the two.

The microscope can magnify specimens up to 10 million times, with a resolution of 2.5 angstroms. Sixty scientists from 37 institutions used STEM in 1991.

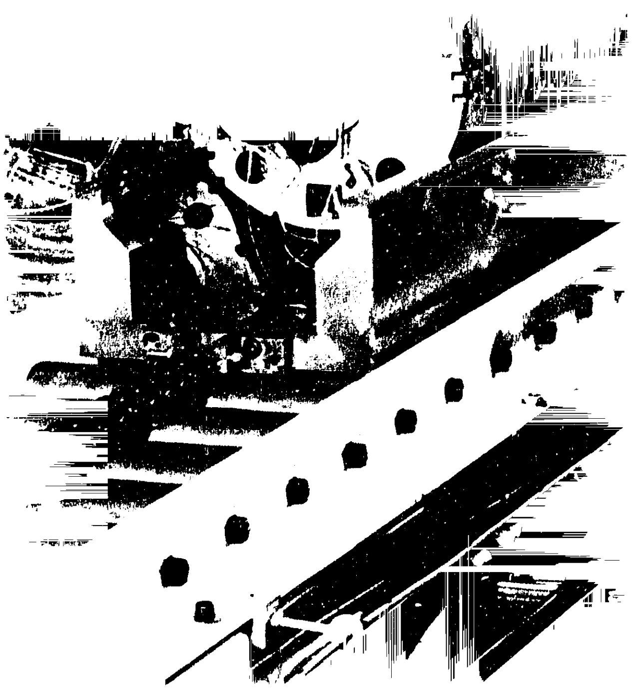


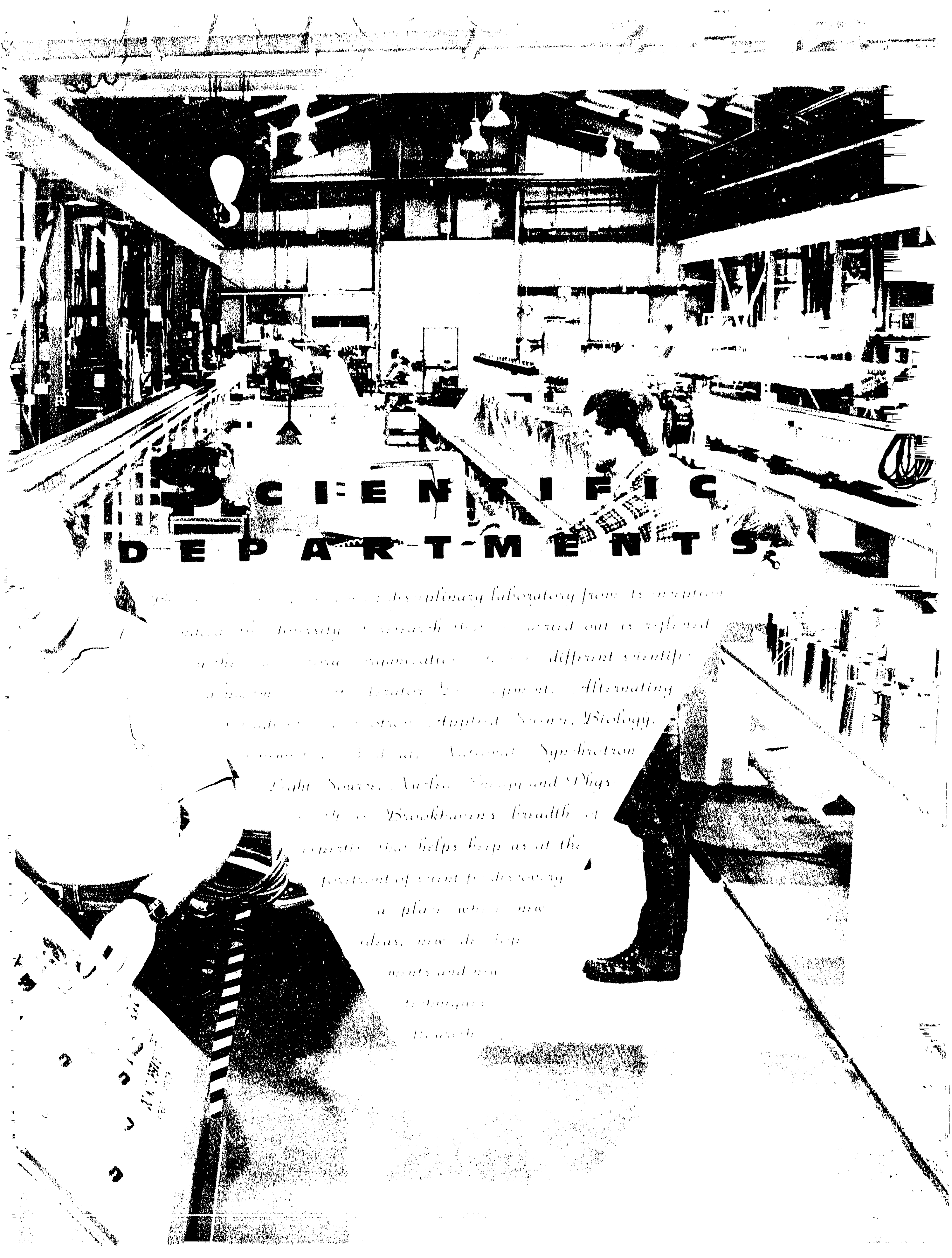
◄ High Flux Beam Reactor

▲ Alternating Gradient Synchrotron



◄ Scanning Transmission Electron Microscope





SCIENTIFIC DEPARTMENTS

[illegible] disciplinary laboratory from its inception [illegible] diversity [illegible] research [illegible] carried out is reflected [illegible] the [illegible] organization [illegible] different scientific [illegible] Accelerator [illegible] Alternating [illegible] Applied Science, Biology, [illegible] National Synchrotron Light Source, Nuclear [illegible] and Physics [illegible] Brookhaven's breadth of expertise that helps keep us at the forefront of scientific discovery [illegible] a place where new ideas, new developments and new techniques [illegible] research [illegible]

Alternating Gradient Synchrotron Department

The Alternating Gradient Synchrotron (AGS) — heart of Brookhaven's high energy and nuclear physics programs — is operated by the AGS Department. In recent years, with the completion of a transfer line between the Tandem Van de Graaff and the AGS, heavy ions up to the mass of sulfur have joined protons and polarized protons as the particles drawing researchers from all over the world to carry out experiments here. Now, with the Booster commissioned for protons and with heavy ions up to the mass of gold on the way, another new age of physics experiments is rising on the AGS horizon.

Booster Boasts Made Good

Milestone after milestone has been reached on schedule by the Alternating Gradient Synchrotron (AGS) Department in building the new Booster, a small but powerful accelerator.

And on June 13 came yet another milestone — proton commissioning was successfully completed. A proton beam in the Booster was accelerated to the planned top testing energy of 1.2 billion electron volts.

Under construction since 1986, the Booster is only one-quarter the size of the AGS, which has a one-half-mile circumference. But by preaccelerating the particles going into the AGS, the Booster will increase the intensity of the AGS's proton and polarized proton beams and enable the larger machine to accelerate heavy ions up to the mass of gold.

New Science Ahead

These new features have been eagerly awaited by scientists in the AGS Department and by the hundreds of researchers from outside institutions who perform their experiments each year at the AGS.

For example, rare-kaon decay experimenters are drawn to the AGS because it is the world's most intense source of kaons, which are made when a proton beam hits a special target. The Booster will combine multiple bursts of protons

The Booster team.

At Building 89, Wenzel Rowan and Marco Donno handle the receipt of a delivery to BNL.

The Great Suppliers

At Brookhaven, you may need a hundred tons of construction material to build a tunnel, or a half million small steel plates to build magnets, or three boxes of No. 2 pencils for the office. Whatever the item and about 80,000 requests are made annually it will reach its destination through the Supply & Materiel Division.

The receiving and shipping section of Supply & Materiel deals with about 50,000 individual receipts a year and handles outbound shipments that might include completed magnets going for testing at another laboratory 1,000 miles away, or instruments destined for medical research in the Marshall Islands, over 7,000 miles away.

If a required article is one of the 15,000 individual lines maintained in the stockroom, it will arrive within a day or two of being ordered. The division also delivers such items as dry ice and liquid nitrogen on site, and provides off site delivery and pickup services for emergencies.

As new property comes on site, it is identified, classified and tagged, joining the approximately $300 million of controlled property owned by Brookhaven and inventoried by Supply & Materiel. Services such as moving office furniture, storing equipment and repairing office machines are also the concern of the division.

The Booster Champs

Both expertise and enthusiasm drove the many AGS groups who worked in close coordination to complete the Booster. Teams included Power Supply, Mechanical Engineering, Mechanical Services and Booster Ring Component Production Facility staff, Power Room, 200-MeV Linac, Experimental Area Operations Installation, and Computer Controls. Numbering approximately 100, these AGS staffers were joined in their task by staff from the Accelerator Development and Physics Departments, and the Central Shops, Contracts & Procurement, Plant Engineering, and Safety and Environmental Protection Divisions.

As the day of Booster commissioning grew closer, the smooth running of each of the last few Booster tests became more and more exhilarating. For example, once all the magnets that would focus the beam were in place and the vacuum system was completed, the Booster team tried circulating the beam.

After only one full turn in which a small correction to the injection trajectory was made, the beam was successfully circulated. Even better, the "horizontal tune," a machine characteristic that demonstrates that the magnets, power supplies and alignment of components are as designed, was as predicted (diagram A).

The next step, accelerating the beam to top energy, proved the efficacy of the Booster's radio-frequency (rf) system, which increases the beam's energy. During the test, more than 95 percent of the beam reached top energy as rf was increased (diagram B), and about 65 percent returned to injection energy as the rf was decreased — a most satisfactory result.

The last major step was to extract the beam from the Booster ring for transfer to the AGS. This was accomplished just before the AGS was closed for its annual maintenance checkup.

Now that the Booster is fully operational for research with protons, Brookhaven researchers and other scientists are at work, with new science beckoning them from the new, boosted AGS.

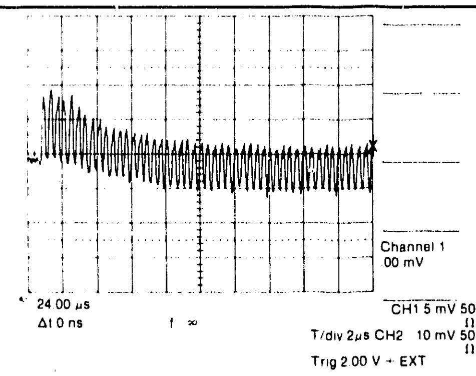


Diagram A. Waveform from an oscilloscope in the AGS main control room, showing protons spiraling around the Booster.

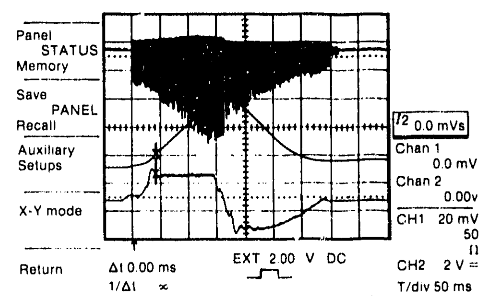


Diagram B. Waveform from oscilloscope showi the bunched beam signal (top trace) in the Booster reaching its peak testing kinetic energy of 1.2 GeV at the same time that the main magnet current (center trace) peaks.

SCIENTIFIC DEPARTMENTS

preaccelerated to 200 million electron volts in the AGS's linear accelerator, or linac, and boost them to 1.5 billion electron volts — increasing the intensity of the AGS proton beam fourfold. So kaon researchers will get four times more data in the same experimental period.

Spin-physics specialists will also benefit, because the polarized proton beams they need for their experiments will be increased by a factor of 20.

The AGS is already equipped to accelerate some heavy ions, which are atoms stripped of their electrons. From their source, the Tandem Van de Graaff accelerator, oxygen and silicon ions have been passed into the AGS through a beam transfer line constructed in 1986.

Due to its much higher vacuum, however, the Booster will be able to accelerate much heavier ions. The new range will span ions all the way up to gold, with its atomic mass of 197, in contrast to the present maximum — silicon, with 28. The AGS will then be capable of accelerating all these heavier ions for its own fixed-target heavy-ion research program. Creating even greater opportunities for new discoveries, it will be ready to inject heavy ions into RHIC, Brookhaven's Relativistic Heavy Ion Collider, now under construction.

A Central Shops Division welder, Walter Ducoing, joins mandrel segments.

A Muon measure

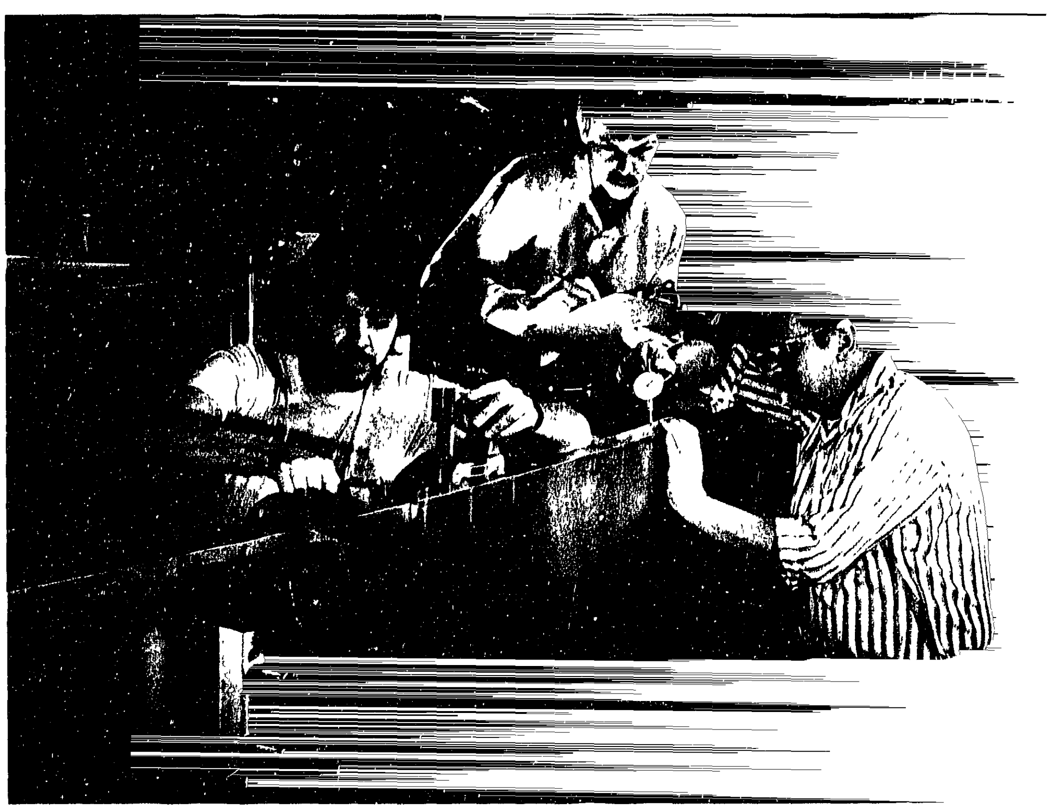
Four super-big superconducting coils — at 14 meters in diameter, the world's biggest — are being built by engineers and technicians of the Alternating Gradient Synchrotron (AGS) Department and the Central Shops Division. The coils will help drive a gigantic magnet being built at the AGS. It will be used in a new experiment, E821, to measure a minute part of muon magnetism.

As well as giant coils powering a huge magnet, E821 has an impressive list of collaborators — an indication of the intense interest of the scientific community in this project, which may reveal new information about the W boson and the photon. These particles carry the weak and electromagnetic forces, two of the four forces known to control all matter.

Brookhaven scientists have thus been joined by others from Boston University; City College of New York; Cornell University; Fairfield University; Heidelberg University; the Institute of Nuclear Science, Novosibirsk, U.S.S.R.; KEK in Japan; Los Alamos National Laboratory; Riken University, Japan; Tokyo University; and Yale University.

The focus of all these scientists is on muon magnetism. A muon, formed when pion particles decay, is an electrically charged particle that spins on its own axis and acts like a tiny magnet. Each muon has a

Surveying the coil mandrel position are (from left) Joe Domiano, Lou Snydstrup and Steve Kochis.



The coil-winding facility for the muon g-2 experiment, with (clockwise from center front) Joe Domiano, Zion Armoza, John Benante, Lou Snydstrup, Chien Pai, Irving Polk, Zygmunt Twardowski, Steve Kochis, Mike Tartakovsky, Jim Cullen and Gerry Bunce

magnetic axis that usually matches the direction of the spin axis. When a muon passes through a magnetic field, however, its magnetic axis changes direction by a minute amount — only about 12" for each turn of the muon around the whole storage ring.

It is this shift in direction, called g minus 2 (g-2), that the experiment will measure. Most of the shift is due to effects caused by photons. The W boson is expected to contribute a few parts per million (ppm) of the total, however, so to get the W contribution, the measurements have to be incredibly precise.

Already, during the 1960s and '70s, g-2 was measured to a precision of 7.2 ppm of itself in a series of experiments at CERN, the European high energy physics laboratory. Results of these experiments helped establish muon behavior and the validity of the quantum theory of electricity and magnetism.

Now, however, a number of refinements are possible. First, a greater intensity of muons will be available from the AGS with the new Booster in operation (see preceding story). Also, a new technique will take muons from decayed pions in an external beam line and inject them right into the storage ring. This is more efficient by a factor of seven than the method used at CERN, in which pions were put into the storage ring, where some decayed to give muons. Altogether, about 1,000 times as many events will be available for analysis as were obtainable at CERN.

To use these extra events effectively, the AGS experimenters will need to know the magnetic field about 20 times better than before. They will use a nuclear magnetic resonance probe system, being built at Heidelberg and Yale, to measure the field inside the 42-meter circumference of the storage ring. To measure more accurately, the probes have been designed to be carried on an internal trolley. Thus the whole field will be able to be mapped without ever being turned off.

The most visually spectacular of the new refinements will be the mammoth superconducting magnet to be used as the muon storage ring. In contrast to the 40 separate nonsuperconducting magnets used at CERN, it will help make the mag netic field more uniform by its unending continuity and the lack of resistance in the superconducting coils, which will reduce heat and cycling problems.

By December 1992, the magnet itself is expected to be complete, with its magnetic field uniform to 1 part in 10,000. After that, the magnet will be studied and adjusted so that the magnetic field is ultimately uniform to 1 part in 1,000,000.

Apart from the magnet, there remains a tremendous amount more to get ready. Brookhaven scientists are already working on a number of other systems needed for the experiment, and their collaborators are busy, too.

For example, Boston and Yale are designing the detector system, and KEK is building a superconducting nonferrous magnet to bring the muons close to the ring. Novosibirsk is building beam transport components and has started an experiment that will improve the theoretical prediction of the g-2 measurement for comparison with the Brookhaven results.

And everyone is looking forward to the first run, scheduled for December 1993.

The Coil Makers

Making the first giant superconducting coil was an experiment in itself.

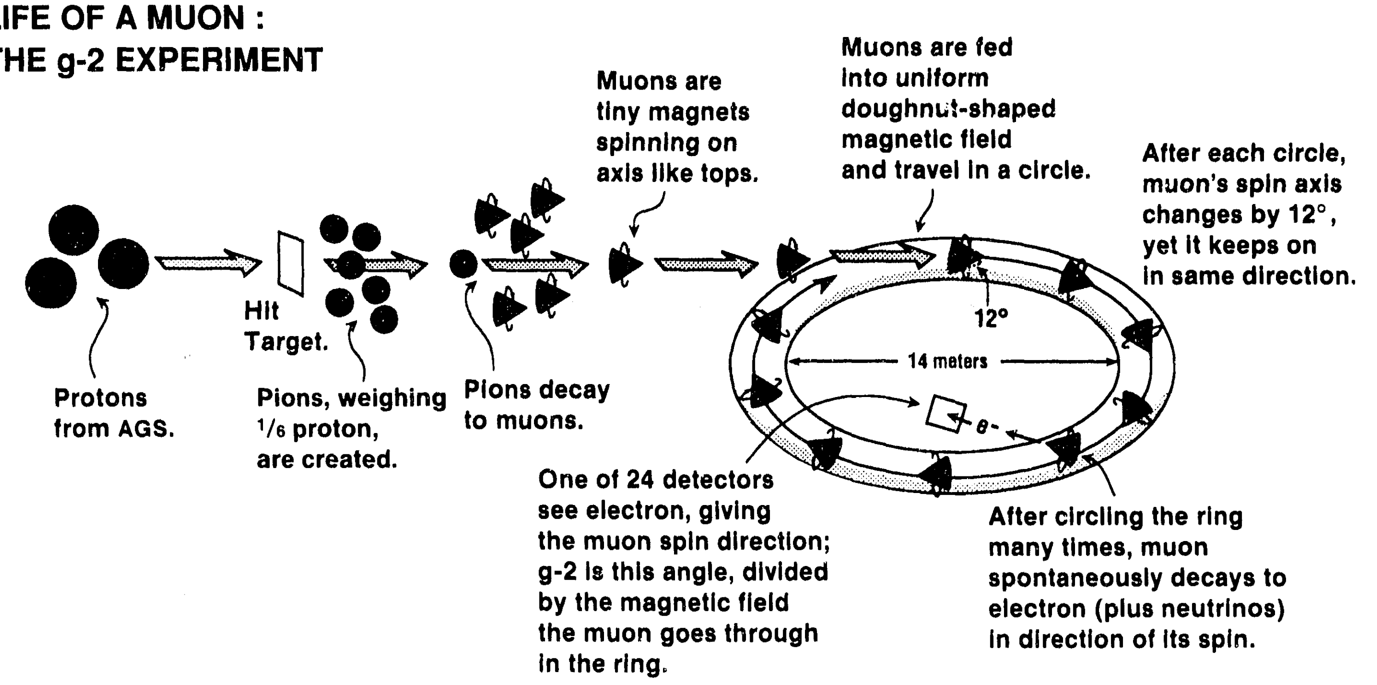
First, a special winding machine was designed and built to double as a milling machine. Then 12 curved aluminum sections, each 12 feet long, were built, placed end to end and welded to form a ring. A cooling tube was added, and the result — called a mandrel — was machined to very tight tolerances.

Once ground insulation was applied to the mandrel, the winding machine came into its own. Slowly rotating, the winder uncoiled conductor material from a central spool, wrapped it in epoxy-laden insulation and fed it into the inside diameter of the mandrel, where it was held by air-activated clamps that rose and fell automatically as the next of the 24 layers was added. After that came more insulation, coil covers, more clamps and a 90-minute period at 250°F to cure the epoxy.

By taking extra care in the welding and by machining everything in situ, the apparatus builders achieved extraordinarily accurate results. For example, there were variations of only 0.012 of an inch over the 7-meter ring radius on the first coil.

After finishing the coils, part of the experimental team will make the cryostats to keep the superconducting magnet cooled to 4.5 kelvins. Others will begin assembling the huge iron magnet yoke to the specifications needed for the all-important uniformity in the magnetic field.

LIFE OF A MUON : THE g-2 EXPERIMENT



ACCELERATOR DEVELOPMENT DEPARTMENT

The physicists and engineers of the Accelerator Development Department (ADD) focus on research and development in such areas as accelerator physics, cryogenic and vacuum technology, and applications of superconductivity, in order to create and expand the capabilities that will help shape a new generation of high energy and nuclear particle accelerators. With the Laboratory's Relativistic Heavy Ion Collider's new status as a stand-alone project, the department is mainly responsible for BNL's contribution to the national high-energy accelerator initiative, the Superconducting Super Collider in Texas, as well as the general advancement of technologies essential to particle accelerators.

SHEPHERDING HEAVY IONS

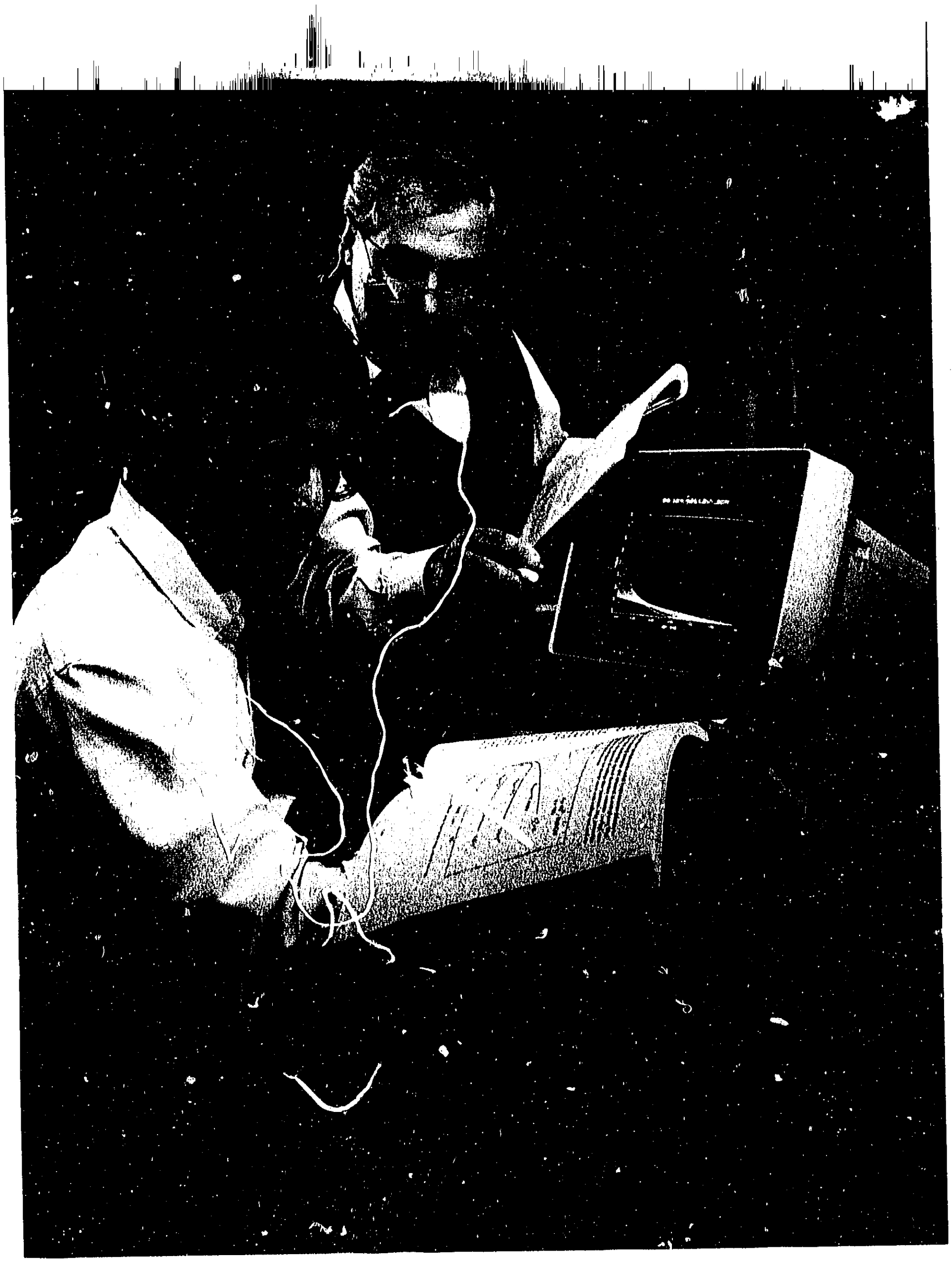
For many hundreds of years, shepherds have used sheepdogs to gather sheep into controllable flocks to move them to another pasture.

Now, in a joint effort between Brookhaven's Accelerator Development Department and Fermi National Accelerator Laboratory (Fermilab), physicists are developing a new "shepherding" technique called stochastic cooling, which promises to improve the way particle accelerators can work.

In this kind of shepherding, the "sheep" are particles. And the "sheepdogs" are electromagnetic fields, which can capture stray particles and force them back to their places among the tight bunches of similar particles traveling round an accelerator ring.

When scientists study what happens when bunched beams of accelerated particles collide with each other in a collider ring, they prefer working with the smallest possible beams. Densely packed beams allow more head-on collisions to occur, thereby creating the best conditions to observe an event. Also, if the particles are bunched in tight groups rather than flowing evenly through each other, it is easier to record the exact time of an event. This is especially true in the developing fields of heavy ion and antiproton particle experimentation.

Unfortunately, accelerated particles have electric charges that repel



◄ Jie Wei (left) and Alessandro Ruggiero discuss their research on stochastic cooling, in which electromagnetic fields are used to keep heavy ion or antiproton particles in bunches as they speed round an accelerator.

each other. Their natural tendency is to spread out, increasing the beam size. In addition, as they are accelerated they get heavier, and it is more difficult to control their spreading.

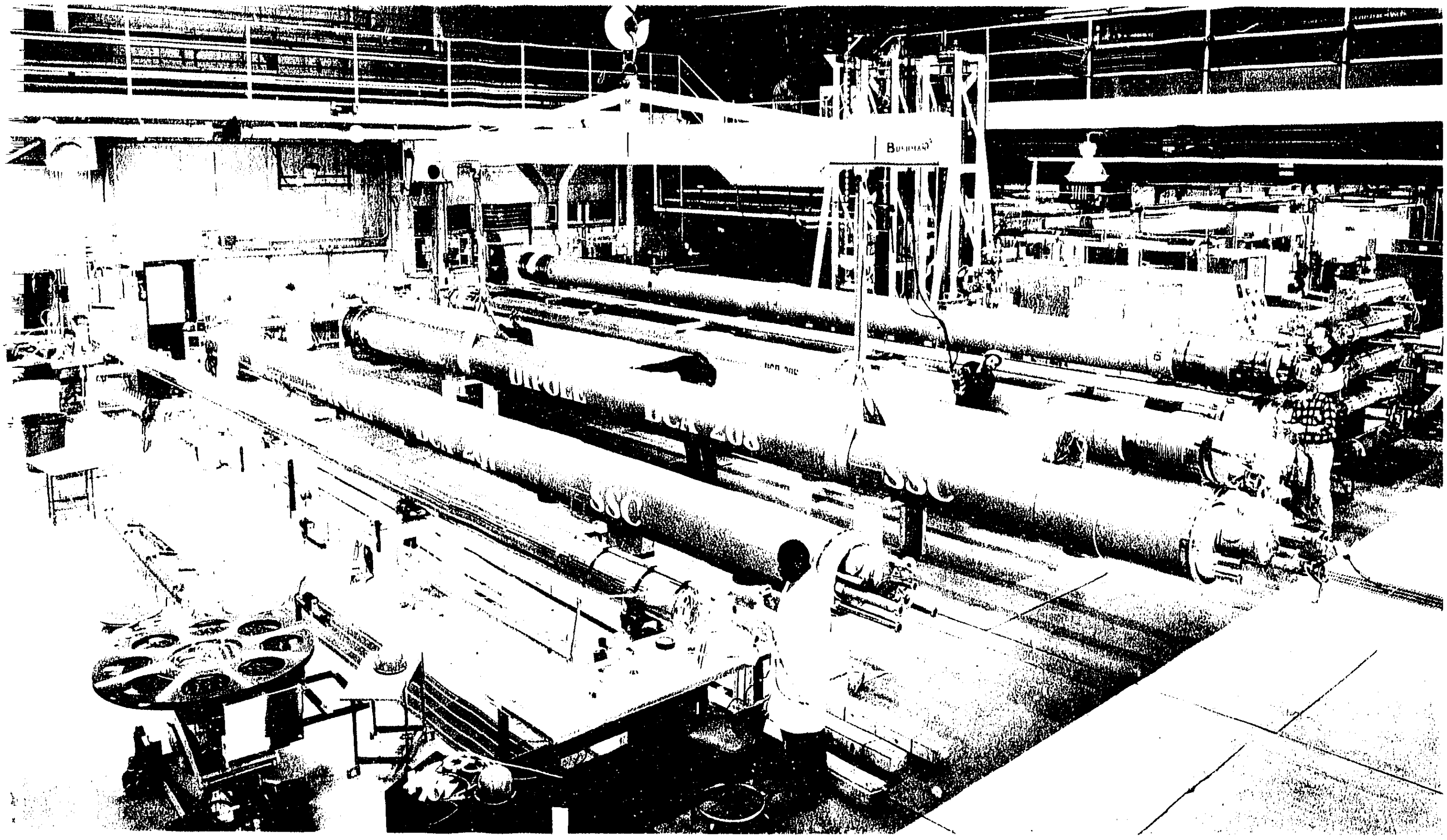
At present, bunched particle beams are guided around an accelerator ring by radio frequency systems. This technique does not fully control the area occupied by the bunches — only its length or its height, but not both, because cost sets a limit on the maximum voltage that can be used.

Research indicates that stochastic cooling of bunched beams — a technique that reduces the randomness of the bunched particles' motion — may be an exciting alternative. Samples of the accelerated particles are chosen randomly and then "watched" by an electromagnetic field as they go around the ring. Signals are sent ahead so that action can be taken to force any stray particles back into a tight bunch.

The technique has already proven valuable in collecting and "cooling" continuous beams of antiprotons at both Fermilab and CERN, the European high energy physics laboratory. But it was thought to be considerably more difficult to apply stochastic cooling to bunched beams. Problems to be overcome included achieving the very high frequencies needed for the field to be sensitive to the stray particles, as well as finding a way to signal their presence ahead.

Recently, however, the joint BNL-Fermilab effort has demonstrated how practical this method is. Stochastic cooling experiments with antiprotons at Fermilab — using the techniques originally proposed by Brookhaven — have been successful.

At this early stage, however, the experiments are on a comparatively small scale. Expanding the present capability to the higher frequencies and longer signal distances that will be needed for Brookhaven's Relativistic Heavy Ion Collider is a chal-



In the magnet assembly area at Brookhaven, Gregory Strickland (foreground) of the Westinghouse Electric Company, Inc., works on magnets for the Superconducting Super Collider, which will be built in Texas.

lenge that, once met, will be a major breakthrough in accelerator physics.

THE MAGNIFICENT DIPOLES

By the turn of the century, ten thousand powerful settlers will have surrounded the town of Waxahachie in Texas. Right away, they will herd millions of whirling particles inside double rings 87 kilometers (54 miles) in circumference.

The "settlers" are ten thousand superconducting magnets. They will guide, bend and focus two beams of protons traveling in opposite directions at nearly the speed of light in the national high energy physics venture, the Superconducting Super Collider (SSC).

Where the beams collide, showers of subnuclear particles will emerge, including, perhaps, some that have never before been seen. Scientists believe that these results will lead to a deeper understanding of the ultimate structure of matter.

Sited near Dallas, the SSC will be the centerpiece of U.S. high energy physics research — and scientific laboratories around the country are at work to make this happen.

At Brookhaven, scientists, engineers and technicians in the Accelerator Development Department (ADD) are building some of the first SSC dipole magnets.

Designed by a collaboration from Brookhaven, Fermi National Accel erator Laboratory (Fermilab), Lawrence Berkeley Laboratory and the SSC Laboratory, each of these 15-meter-long magnets will bend the protons around the vast circumference of the SSC ring.

So many dipoles will be needed — approximately 8,000 — that once the initial prototypes have been completed, the magnets will be made by industry. The ADD team has therefore been joined by staff from Westinghouse Electric Company, Inc., who will transfer the Brookhaven prototype techniques back to Westinghouse.

A similar program is under way at Fermilab with a team from General Dynamics, Inc., the lead industrial firm selected, with Westinghouse, to make the pre-production SSC magnets.

The magnets have generated another collaboration with industry — a research and development effort between the Du Pont Company and Brookhaven to make better insulation. As a result, Du Pont's new Kapton CI insulation will cut processing time, lessen magnet failure due to electrical short circuits and, because of smaller size variations in the coils, will contribute to a more uniform magnetic field.

Since the shape of the magnetic field is responsible for guiding the particles on their minutely accurate pathway, absolute uniformity is imperative in the SSC's magnet construction. This calls for the very highest standards in design and fabrication.

To establish these standards, the SSC Laboratory in Texas has been supporting research and development programs at national laboratories, including Brookhaven. This multilaboratory approach has led to many improvements in the technology of giant magnet building.

At Brookhaven, the ADD and Westinghouse teams are expertly assisted in making SSC prototype magnets by welders, machinists, and other skilled workers from Brookhaven's Central Shops Division.

First, niobium-titanium superconducting cable is made into a set of coils, in the middle of which is the magnet aperture, where the beam circulates inside a beam tube. Originally, this aperture was four centimeters wide. Later, it was enlarged to five centimeters so that the SSC would be able to operate with less disturbance to the proton beams.

The coils are surrounded by a stainless steel collar and an iron yoke. When current flows, every linear inch of collar must withstand over a ton of magnetic force that is created in the coils.

Because the magnets are superconducting — that is, they have no resistance to the flow of electricity — they operate on only a small fraction of the power needed for conventional magnets. To become superconducting, however, the niobium-titanium coils must be maintained at a super-low temperature of 4 kelvins, or −370°F. The coils and yoke are therefore surrounded by supercritical helium inside a cryostat, a refrigerating system that encloses the whole magnet like a giant, elongated thermos.

Once the magnet is made, it is tested by ADD staff in Brookhaven's superconducting magnet testing facility. Not only the finished magnets, but also the superconducting material itself is tested in another materials facility, which is often used by other institutions from the United States and abroad.

In obtaining the materials and components for the magnets, ADD staff members are greatly assisted by Brookhaven's Division of Contracts and Procurement, and Supply & Materiel Division (see sidebar, p. 19). The cooperation and expertise of staff from these divisions make the work of magnet building run more smoothly. And technicians, engineers and scientific staff can proceed more quickly to the national goal: an operating SSC.

Physics Department

Researchers in the Physics Department study the fundamental constituents of matter and seek to understand the forces through which these constitutent interact to form nucleons, nuclei, atoms and ordinary matter. Specialists in theoretical and experimental high energy physics, nuclear physics and solid state physics investigate a wide range of phenomena. Using such Brookhaven facilities as the High Flux Beam Reactor, the National Synchrotron Light Source and the Alternating Gradient Synchrotron, they probe the most submicroscopic building blocks of matter — quarks and leptons, study nuclear matter under conditions of extreme temperature and density, and investigate macroscopic effects that include, for example, high-temperature superconductors.

LEGS RUM ON TENSOR FORCES

Imagine all matter as made of countless miniature spinning tops, each spinning with its axis pointed in a random direction.

Most of the particles that make up matter have the property called spin. But so many spins pointing in different directions normally cancel out each other's effect. In some cases, polarizing a set of particles — that is, forcing them to spin in the same direction — can produce dramatic effects. For example, a bar of steel with most of the atoms polarized becomes a magnet.

Understanding the fundamental nature of the forces between spinning particles is an intriguing challenge to physicists, among them researchers in Brookhaven's Physics Department. And to investigate a force that depends on spin requires a probe that carries spin — polarized spin. Our physicists use just such a probe — the polarized gamma-ray beam from the Laser Electron Gamma Source (LEGS) at Brookhaven's National Synchrotron Light Source (NSLS).

The LEGS facility was built by a team of scientists from Brookhaven's Physics Department, together with collaborators from Italy's Frascati National Laboratories and the University of Rome, the University of South Carolina, the University of Virginia, Virginia Polytechnic Institute and Rensselaer Polytechnic Institute.

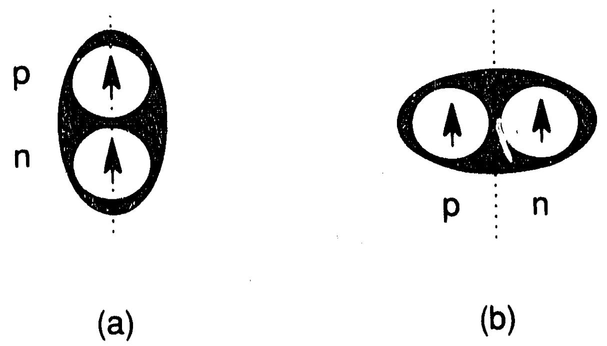


Figure 1. Possible arrangements of a proton (p) and a neutron (n) with parallel spins, relative to the axis of a deuteron (dashed line).

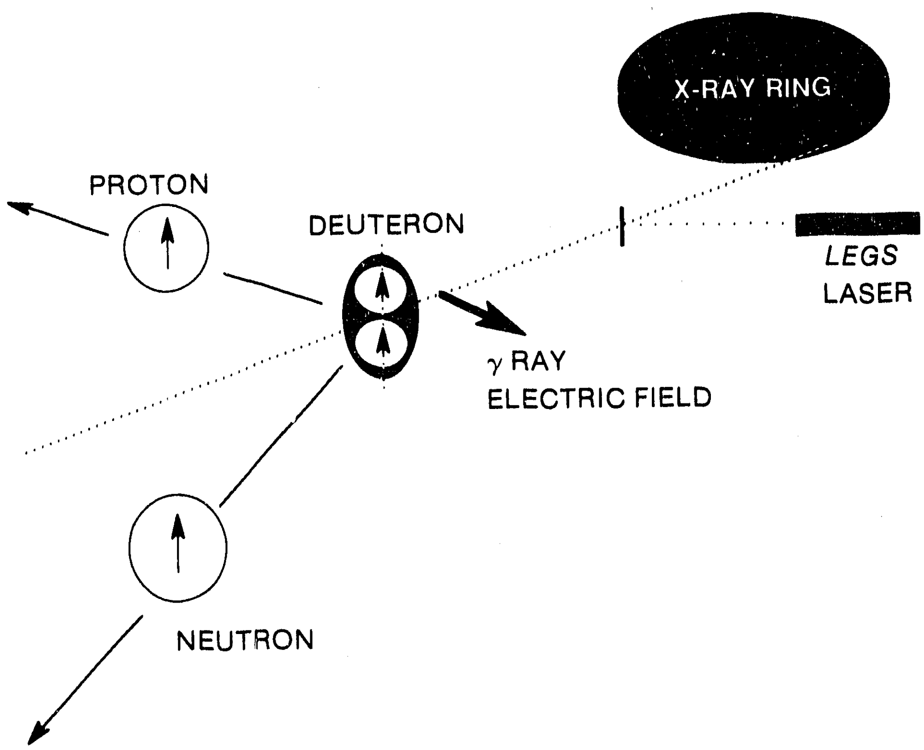


Figure 2. Polarized gamma (γ) rays from the x-ray ring break up the deuteron into a proton and a neutron. The tensor force between them tends to drive them off at right angles to the γ ray's electric field.

At LEGS, a series of mirrors directs ultraviolet light from a laser to collide head-on with electrons circulating in the x-ray storage ring of the NSLS. Because the electrons are so energetic, all the scattered light bounces back and is forced into a very narrow cone pointed along the original direction of the electrons.

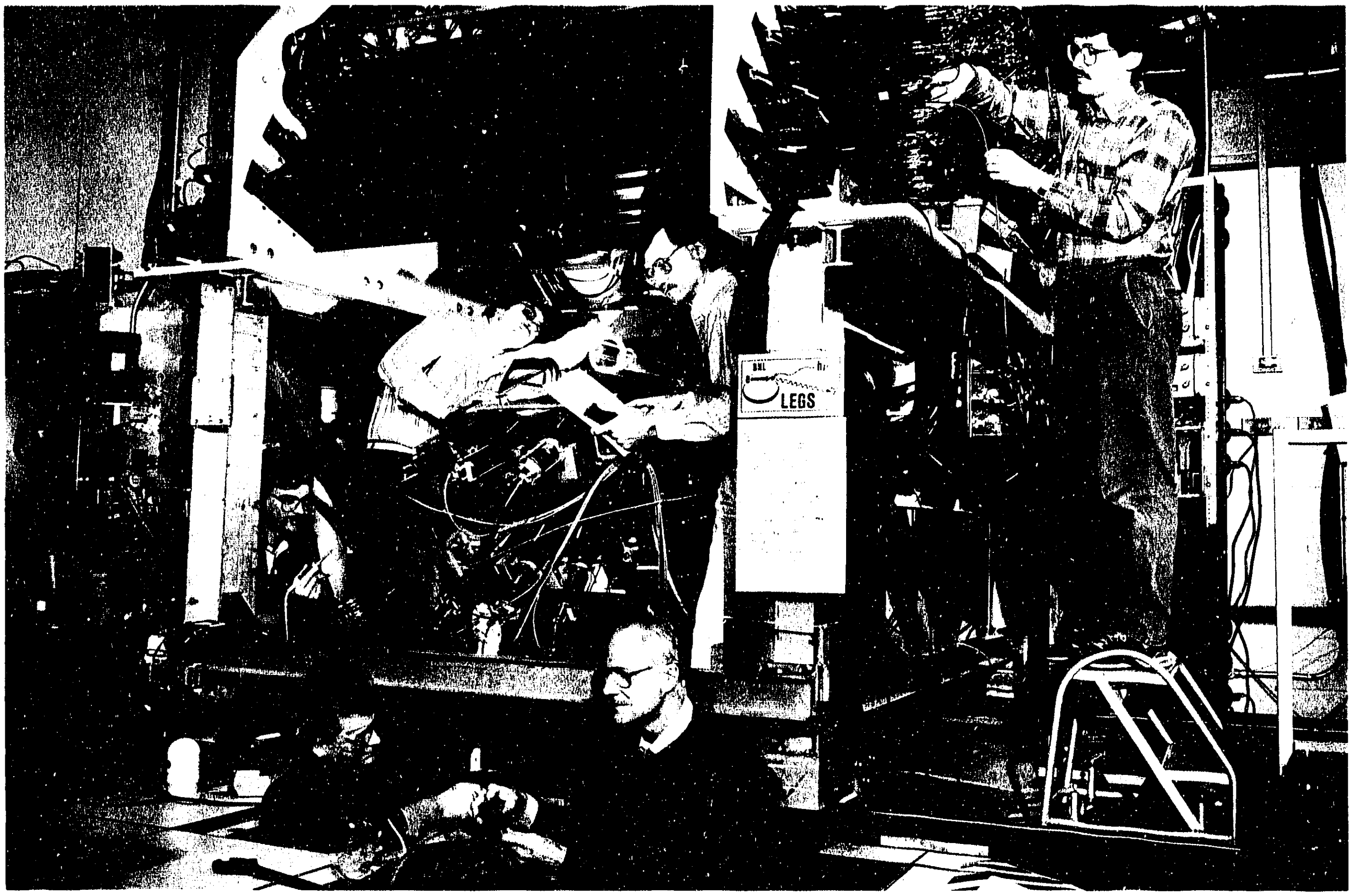
The light's energy is also tremendously boosted. Before the collision, each unit of light, or photon, brings in three electron volts of energy. But after scattering, it leaves with *three hundred million* electron volts. This means that the photons have turned into a beam of high-energy gamma rays. They travel back through the laser light, passing right through the mirrors used to aim the laser at the electrons.

What makes the LEGS beam so useful as a probe of spin-dependent forces is its polarization. Light, regardless of its energy, is made up of electric and magnetic fields traveling like waves. Mostly, these fields can point in any direction that is at right angles to the direction of the wave. But light from a laser can be polarized, that is, oriented so that the photons' electric and magnetic fields all point the same way.

This orientation is preserved when the light bounces off high-energy electrons such as those at the NSLS. As a result, the electric and magnetic fields of the LEGS gamma rays are polarized, making them behave like particles with spins that are all aligned.

The particles of special interest to the LEGS team — protons and neutrons — have only one stable state, the deuteron. In the deuteron are one proton and one neutron, which have their spins parallel.

There are two possible shapes — one football-like, one pancake-like — in which these particles can be arranged to create this parallel alignment (see Figure 1). If both ways were equally likely, the deuteron would flip between these two orientations and, on the average, would appear spherical.



Working on the LEGS detector array are researchers (back, from left) Anthony Kuczewski, Andrew Sandorfi, Craig Thorn, Samuel Hoblit, (front, from left) Frank Lincoln and Ottmar Kistner.

The deuteron, however, always prefers the football-like orientation. This shows that the force between the proton and the neutron depends not only on their spin, but also on their position. Such forces are referred to as "tensor" in character.

When the polarized gamma rays from LEGS break up a deuteron, the proton and the neutron tend to fly off at right angles to the gamma ray's electric field (Figure 2). By measuring the difference between the rates of the deuteron breakup along two directions, one parallel and the other perpendicular to the electric field, the LEGS team gets information about the tensor force in nuclear matter (Figure 3).

The various theoretical predictions on the tensor force, however, do not match the new data from the latest LEGS experiments, which indicate new information about the nuclear force. Scientists at Brookhaven and elsewhere are therefore trying to understand this information and encompass it in modified theories.

Tensor forces are at work not only between protons and neutrons, but also within them. Each proton and neutron is made up of three spinning particles of matter — quarks. But, according to the Standard Model, the generally accepted theory of how matter works, quarks are confined within a "bag" from which they never escape. Therefore, the proton cannot be dissociated into its components to measure the forces between them. Instead, another particle must be created and pulled out from the proton, bringing with it information about the forces.

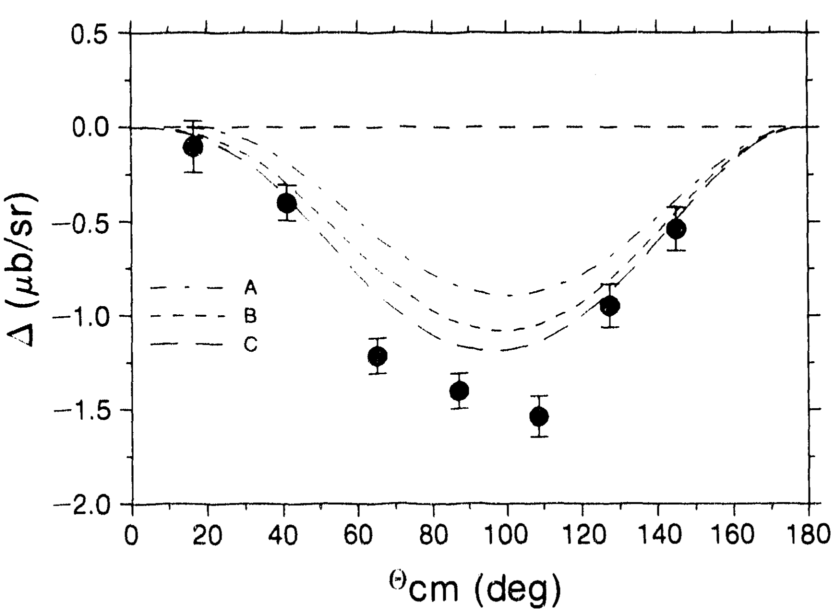
To create such a particle, energy must be added to the proton, and the LEGS gamma rays provide an ideal source.

The lightest strongly interacting particle — therefore requiring the least energy — that can be created and extracted from a proton is called a pion. But a pion is one of the few elementary particles that does not carry spin. So, all the sensitivity to the tensor forces between the quarks must be provided by the polarization of the energy-supplying gamma rays.

Prior to LEGS, such measurements were almost impossible, and very little actual experimental information existed. Now, the recent series of experiments by the LEGS scientists has shown that even the most careful previous estimates of the tensor force between quarks were wrong.

Much work lies ahead to sort out these interesting problems, but the polarized LEGS beam provides a unique edge, cutting a path to a more complete understanding of the world.

Figure 3. Difference between rates of deuteron breakup along two directions, parallel and perpendicular to the LEGS γ rays' 220-million-volt electric field. The A, B, and C curves correspond to three predictions for the tensor force between the proton and neutron. The solid points measured at LEGS have provided the first opportunity to make such detailed comparisons.



Crystal-Gazing Detectors

Anyone who frequents the shrouded tents of fortune-tellers knows that crystals are used as mysterious sources of hidden information.

But for scientists, no dark mystery shrouds crystal gazing. In fact, the hard-to-get information they obtain from crystals is revealed by an unmistakable flash of scintillating light.

This is because some scientists use scintillating crystals for their work. These are crystalline forms of certain materials that, when struck by very high-energy particles, emit flashes of ultraviolet light. And the higher the particle's energy, the more light the scintillator emits. So crystal scintillators can be used as natural calorimeters — detectors that give exact information about a particle's energy.

In Brookhaven's Physics Department, physicists design detectors for different experiments. They study various types of crystal scintillators and use the one that will be the most effective in detecting the particle in question.

For example, barium fluoride crystals are the fastest inorganic scintillators in the world. In addition, they are also one of the most radiation-resistant. This makes barium fluoride ideal for use in high energy and nuclear physics experiments — especially those looking for rare processes using beams of particles with high intensities and high collision rates, or where precise timing is required.

Such beams circulate already in accelerators like the Alternating Gradient Synchrotron (AGS) at Brookhaven, the Tevatron at Fermi National Accelerator Laboratory and the Super Proton Synchrotron at CERN in Europe. They will also be found in the Superconducting Super Collider (SSC) being built in

SCIENTIFIC DEPARTMENTS

James Kierstead (left) and Paul Levy are installing a crystal in the gamma ray irradiation facility.

Texas and the Large Hadron Collider planned for CERN.

One experiment at the AGS, E855, has used barium fluoride detectors to search for production of low-energy light, known as photons. These are believed to be a product of collisions of hadrons, another kind of particle. Since even low-energy photons still travel at the speed of light, the very high speed of barium fluoride's flash — 0.6 billionths of a second — make it an excellent choice for separating the fast-moving photons from slower-moving particles.

Barium fluoride's other unique property, that of being radiation-resistant, will be a great advantage in SSC experiments, where radiation levels will be extremely high, much higher than in the AGS.

Knowing the exact effects of radiation damage on these crystals is vital. So, using two Brookhaven facilities, the gamma ray radiation facility and the high intensity radiation development laboratory, our scientists study what happens to the ultraviolet rays emitted by crystals that have been exposed to high doses of radiation. They are also investigating how these effects are correlated with impurities and defects in the crystal.

Other work is focused on improving techniques for detecting ultraviolet light coming from the crystals. One objective is to lessen or suppress a slower flash that is emitted after the first, almost instantaneous flash signals a collision. The second flash is often still visible when the next event occurs, making it difficult to separate the two signals. Devices being used for these studies include new photocathodes being developed by the Hamamatsu Corporation and electronics developed by Brookhaven's Instrumentation Division.

Another crystal scintillator being examined at Brookhaven is pure cesium iodide, which is less expensive and more readily available than barium fluoride. Although less speedy in producing a first flash, these crystals have a much less intense second flash, which makes them useful in many applications. They also emit light at a longer wavelength than barium fluoride, making it easier to detect.

Yet another advantage is that these crystals are comparatively radiation resistant. So, they are ideally suited to detecting photons emitted by the hot nuclear matter produced in relativistic heavy ion collisions. These collisions will be produced at Brookhaven's Relativistic Heavy Ion Collider (RHIC), now under construction and expected to start operating in 1997. Cesium iodide is also being considered as a photon detector in Experiment 787 at the AGS — a search for very rare decays of the kaon particle.

Brookhaven physicists are also studying lead fluoride. In this medium, light travels more slowly than it does in air. When a particle moves through this crystal faster than ordinary light, it gives off a special, "Cerenkov" light.

Lead fluoride is the most dense of all the crystals being studied. Therefore, when it signals an event, the light spreads out less than it does in other crystals. These highly localized flashes will be particularly useful in experiments where multiple signals come from a single event, such as will occur in the collisions in RHIC.

However well-designed a scintillating crystal detector is, it can only be as good as its crystals. Brookhaven researchers go far to select the very best quality crystals to be found, which in the past have been grown mainly in Europe and Japan, but soon may also come from China or the Soviet Union, where they are cut and polished to the same very high standard.

These high-quality crystals will give good signals — but the detector designers have still more work cut out for them. The ultraviolet light that flashes from the crystals must be recorded and processed. Working in close cooperation with other laboratories and universities, our physicists custom-make the final detectors to suit the needs of each experiment.

And the result? Clear-as-crystal data.

Craig Woody points out the final polish on a cesium iodide crystal held by Sean Stoll.

Department of Nuclear Energy

The power enclosed in the nucleus of an atom can be used safely — through the application of a wide range of scientific and engineering work. The Department of Nuclear Energy (DNE) conducts research on nuclear power safety for the U.S. Department of Energy and the Nuclear Regulatory Commission (NRC). The department also provides vital technical support to the NRC for its licensing and regulatory responsibilities. In addition, DNE conducts studies for the U.S. Department of Defense and the U.S. Department of State. The department analyzes the safety of nuclear power and production reactors, investigates radiological hazards, studies advanced reactor systems, improves methods of safeguarding nuclear materials, and compiles and evaluates data required by nuclear scientists worldwide.

SCIENTIFIC DEPARTMENTS

Arms Control: New Techniques to Verify Treaties

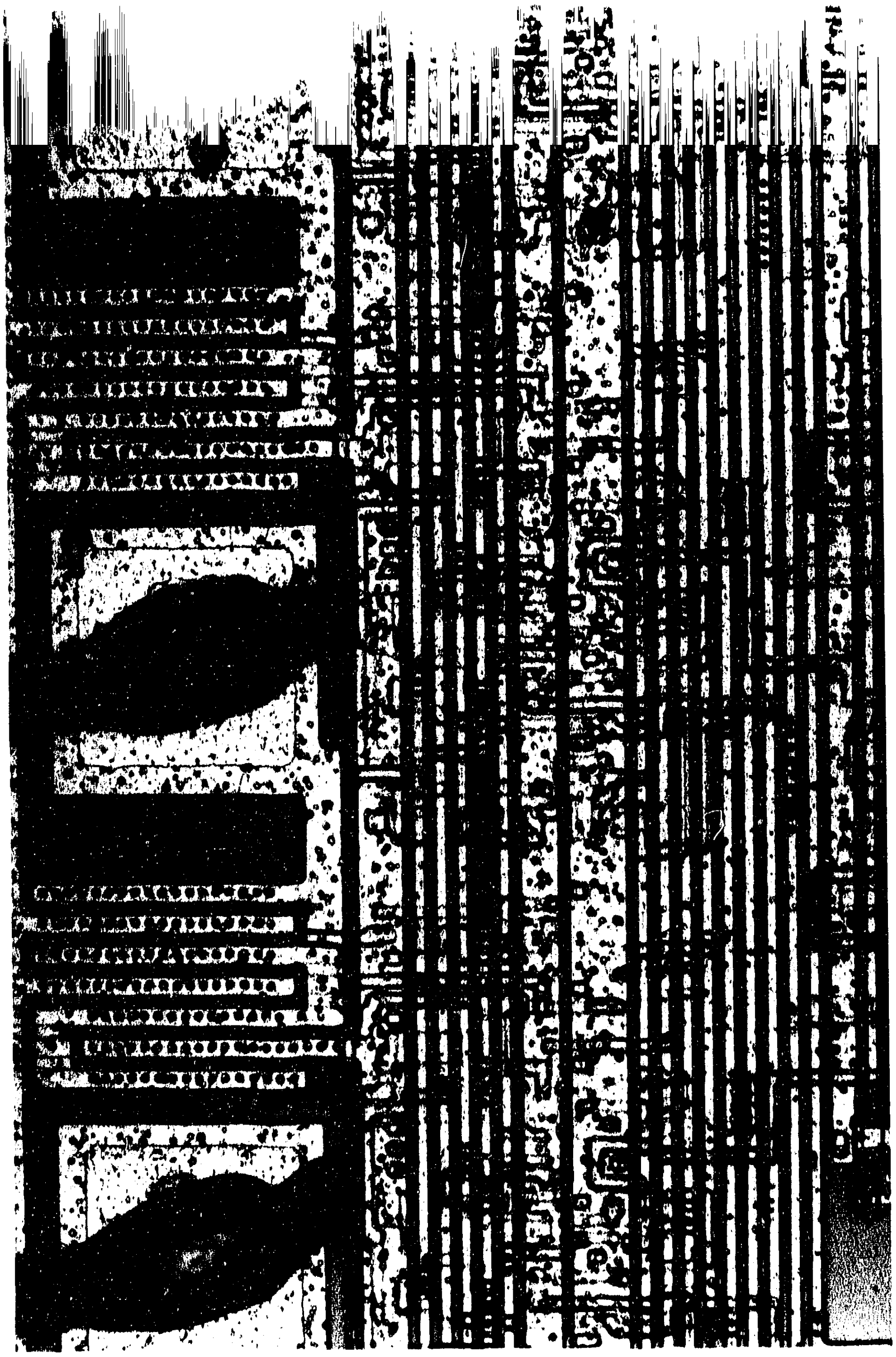
When world leaders negotiate arms control agreements, the stakes are too high to seal treaties only with a handshake. Instead, sophisticated verification techniques and procedures are required to deter a country from violating an agreement, to detect any such violations and to verify compliance.

Since the Department of Nuclear Energy's Technical Support Organization (TSO) was established in 1968, one of its primary tasks has been to develop international safeguards verification techniques. Building on this experience, our TSO team has recently been involved in several timely arms control issues.

Nuclear Weapons

One issue is verification. On November 5, 1990, Congress passed a law requiring the President to prepare a comprehensive technical report on this subject. The report must describe the on-site monitoring techniques, inspection arrangements and national technical means that could be used to verify the dismantlement of nuclear warheads and disposal of their nuclear materials. The report also must address verification of a ban on the production of highly enriched uranium and plutonium for nuclear weapons.

The U.S. Department of Energy selected Brookhaven, along with



◄ In this photomicrograph of a single-chip computer in CIVET, the random pattern of voids in the metallization layer is used as its "fingerprint," thus serving as part of the method to verify the functioning of the electronic components in the CIVET computer. This is needed to assure that the computer has not been covertly modified.

Lawrence Livermore National Laboratory, Pacific Northwest Laboratory and Sandia National Laboratories, to prepare the report for interagency review and subsequent transmittal to Congress.

The Brookhaven team is also working on the technology necessary for verification. Firsthand inspection of nuclear weapons would be the most effective means of verification, but this so-called "instrusive" method would reveal sensitive details about their design to the inspectors. To prevent disclosure of classified information, the TSO team has developed a controlled intrusiveness verification technology, or CIVET.

CIVET uses a video camera or other sensor systems to obtain images of weapons and a special computer to analyze the images. With this technology, information about the weapon that is pertinent to verification can be obtained without divulging details of the weapon's design. No direct images of weapons are displayed on the computer screen, and when the power is turned off, the computer retains no memory of the data.

CHEMICAL WEAPONS

The multinational Conference on Disarmament, in Geneva, has been negotiating the Chemical Weapons Convention (CWC), a treaty banning the manufacture and use of chemical warfare agents. The importance of such a ban struck Americans

Technical Support Organization (TSO) researchers are setting up a laser spectrometer system that can detect and identify chemical warfare agents and related chemicals through the use of a technique known as Raman scattering. The researchers are (from left) David Harder, David Dougherty, David Gordon and Cheng Lin Chen

with new urgency when they watched developments in the Persian Gulf War on television during the winter of 1991. Journalists were reporting the news wearing gas masks.

TSO is providing technical assistance to the U.S. Ambassador to the Conference on Disarmament. Two BNL experts — a physical chemist and a specialist in nuclear safeguards verification systems — accompany the ambassador during treaty negotiations in Geneva. Their focus has been on the CWC.

The CWC would ban the production of chemical warfare agents and provide for on site inspections at chemical and other plants to verify compliance. But some commercial chemical and pesticide plants could easily be modified to produce chemical weapons.

During an inspection at such a plant, three critical questions must be answered: Is the plant manufacturing a chemical agent or its precursors? Is the quantity of chemicals produced by the plant consistent with its needs and declarations? Are any chemicals being diverted from the plant? Our researchers in TSO are developing approaches and technology for detecting misuse of commercial facilities.

Brookhaven is also developing instrumentation for verifying compliance with the CWC. TSO experts are working on an optical method for detecting chemical agents. Using a technique called Raman scattering, the researchers focus laser light on a sample, which shifts the wavelength of the light as it scatters it. The pattern of the wavelengths in the scattered light depends upon the chemicals in the sample and serves as its "fingerprint." Thus, detection and analysis of the scattered light provides a means for identifying these chemicals.

In addition, BNL researchers are working on devices that would be able to determine if liquid waste streams from chemical plants contain chemicals that are used to produce weapons. We have already developed a laminated plastic device, about the size and shape of a credit card, that changes color when inserted into a liquid that contains substances often used in making chemical weapons.

If it does change color, further tests would be required to determine with certainty if chemical weapons were being produced. Therefore, the credit-card device also contains a carbon-based "scavenger" that bonds with chemicals used in weapons production. The scavenger would be analyzed in an off-site laboratory for these chemicals.

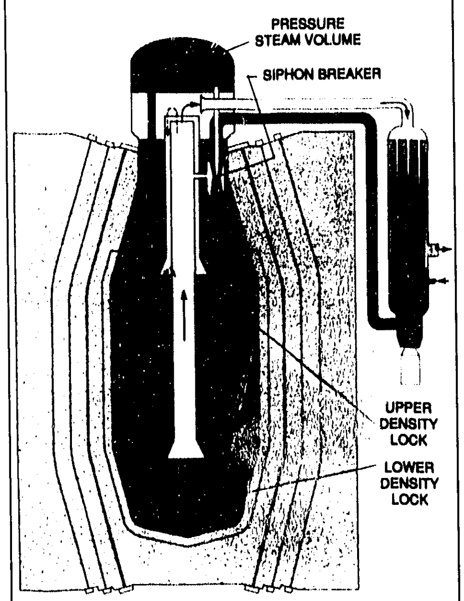
In a related project for the U.S. Army, TSO staff members are participating in practice inspections at American chemical plants to identify and solve problems before they occur in actual inspections. These mock inspections are intended to identify the necessary verification and safety equipment, develop inspection procedures and assess inspection effectiveness, intrusiveness and cost.

New reactors, safer designs

The rapid construction of nuclear power plants ended in the U.S. about a decade ago. In 1979, an accident at the Three Mile Island plant in Pennsylvania brought the domestic, new nuclear power industry to a standstill. Seven years later, a more disastrous mishap at Chernobyl in the Soviet Union increased

PIUS 600

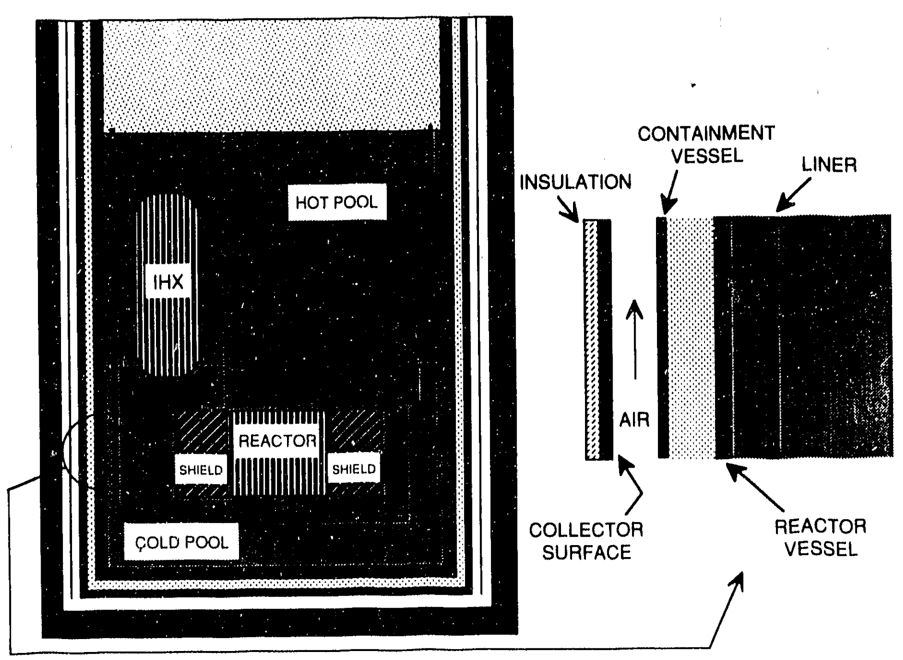
BASIC ARRANGEMENT PRINCIPLE

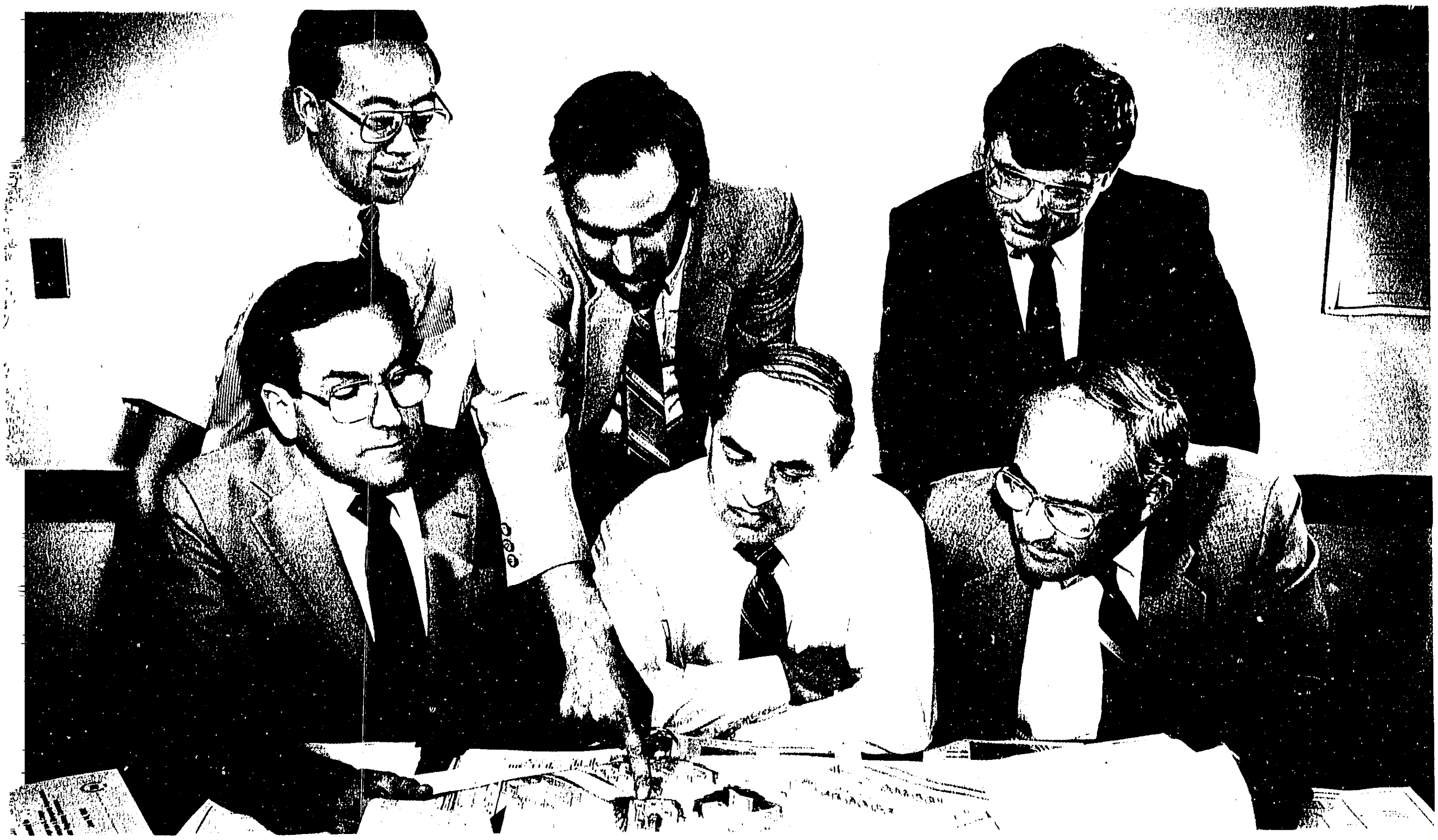


One innovative European design for a new reactor called PIUS has no control rods to stop a chain reaction. Instead, significant change within the reactor's primary coolant loop will cause the heavily borated water surrounding it to pass through the density locks and shut down the reactor.

General Electric's new reactor design, known as PRISM, relies on gravity to remove decay heat. If the intermediate heat exchanger (IHX) fails to remove decay heat, the pool of sodium expands as it is heated and eventually spills over the liner. The hot sodium then travels downward along the inside of the reactor vessel, transferring the heat to the upward-moving air outside of the containment vessel.

PRISM DURING DECAY HEAT REMOVAL EVENT





Specialists from the Department of Nuclear Energy (DNE) examine advanced reactor designs. The DNE team includes (seated, from left) Charles Hofmayer, Tasneem Khan, Robert Youngblood, (standing, from left) Peter Soo, Gregory Van Tuyle and William Luckas Jr.

public fear of nuclear power on a larger scale.

These accidents, coupled with complicated nuclear reactor licensing procedures that caused long delays and skyrocketing costs for utilities, including the high cost of capital, threatened to close the door on the future of nuclear power.

But as global warming and acid rain threaten the environment, and oil resources are being depleted while the demand for electricity grows, nuclear power is gaining popularity again.

To ensure the safety of the next generation of nuclear power plants, the U.S. Nuclear Regulatory Commission (NRC) is evaluating new reactor designs that are expected to have increased safety and economy because they do not rely on many complicated components to make them work. At Brookhaven, a multidisciplinary team of researchers in the Department of Nuclear Energy is performing research and providing technical assistance to the NRC in its investigation of safety and licensing issues for these advanced reactor designs.

The Brookhaven team consists of specialists in reactor physics, thermal hydraulics, probabilistic risk assessment, human factors, materials technology, radiation protection, structural analysis, and other engineering disciplines. To make their evaluation, the researchers use a variety of techniques, including computer analysis based on reactor simulations and experiments using actual reactor components.

The researchers are focusing on six advanced reactor designs devel oped in the last decade: the advanced liquid metal-cooled reactor/power reactor inherently safe module, known as ALMR/PRISM, which was developed by General Electric; the Westinghouse 600-megawatt (MW) advanced pressurized water reactor, AP-600; the newest version of a Canadian reactor, CANDU-3; the modular high-temperature gas-cooled reactor, known as MHTGR, developed by General Atomics with support from others; Process Inherent Ultimate Safe, or PIUS reactor, a European design; and General Electric's simplified boiling water reactor, SBWR.

The advanced reactors are from one-sixth to one-half the size of older reactors. They range in power from 170 to 600 MW, compared to the 1,100 MW generated by the larger, currently operating reactors. As envisioned for the future, groups of two to nine small reactors would be used in place of one large one.

SAFETY FEATURES

The potential hazard in a reactor derives from the tremendous heat in the nuclear fuel resulting from the fission process that creates nuclear energy. Even after the fission process is stopped, if the hot nuclear fuel is not cooled properly, it can melt. To prevent such a scenario, the three most important safety features in a nuclear reactor are its shutdown mechanism, method of heat removal and type of containment, which prevents the release of radioactivity into the environment.

All reactors have shutdown mechanisms that stop the fission process. Most reactors use control rods that contain neutron absorbers to stop the chain reaction. To do so, the rods are inserted into the reactor core.

But one of the new reactors, PIUS, has no control rods. Instead, when the reactor gets too hot, PIUS depends on density locks, which act like valves with no moving parts, to move water with a high concentration of soluble neutron absorbers from outside the reactor core to its inside. These neutron absorbers stop the chain reaction. To help understand whether this passive design is safer than approaches based on control rods, BNL is developing reactor physics models of the PIUS system.

When a shutdown occurs in any reactor, the chain reaction ceases; however, this does not stop heat production in the reactor. Since the fragments of previous fissions are radioactive, they still release energy. This heat production can continue in the reactor for several years, although at a decreasing rate with time.

Current reactors rely on pumps to deliver water to the reactor core for cooling. To run the pumps, backup diesel generators are needed in case the primary power supply is lost. But all the new designs, except CANDU-3, rely only on valves or gravity to help dissipate heat. Valves do not require as much power, and gravity methods work without power, so BNL scientists are investigating whether these might be safer and more reliable cooling methods.

Traditionally, reactors were built with thick concrete and steel containment vessels to prevent radioactivity from escaping into the atmosphere. But one of the new reactor designs — MHTGR — has no containment structure. It uses a fuel made of tiny spheres of ceramic-covered, enriched uranium encased in graphite, which does not fail at temperatures below 2,900°F. Our analyses of this design indicate that it is nearly impossible for the temperatures to exceed 2,550°F. Therefore, the manufacturer's argument that the fuel particle coating serves the containment function has some technical merit.

CERTIFICATION

Another hurdle the nuclear industry has had to overcome is the lengthy and expensive public debates over safety. Some of these discussions have dragged on for many years, causing extended delays in licensing of some nuclear power plants, and even stopping the construction of others.

Over the past year, Brookhaven researchers provided technical assistance to the NRC in the development of a design certification process for the new and novel plants. The new certification process instituted by the NRC will provide a high level of safety assurance. Using this approach, the reactor manufacturer presents the design to the NRC for an extensive safety evaluation, and if it meets NRC safety requirements, it is certified.

In the past, vendors could change the design at any point during licensing. Under these new NRC rules, once a design is certified, the utility may not change it. Public discussion would focus on local issues, such as siting and evacuation plans.

The utility constructs the certified design on a pre-licensed site. To obtain a license to operate the plant, the utility need only prove that it constructed the plant properly, to the certified design, and that it is qualified to operate the plant. This process should greatly reduce licensing uncertainties for utilities and trigger new reactor orders.

Department of Applied Science

Research activities in the Department of Applied Science encompass environmental, health and mathematical programs as well as programs in energy science and technology. Projects range from research on the microstructure of high-temperature superconductors, to measuring the rate of removal of atmospheric pollutants in convective rainstorms, to studying the kinetics of fossil fuel combustion. Highlighted this year are two projects: one, a research voyage planned in the Arabian Sea, designed to provide researchers with a better understanding of the ocean's role in global change; and the other, an investigation of the fundamental nature of corrosion, research that may yield new strategies to prevent it. These programs reflect the diversity of research that characterizes the department.

Global change: Seeking insights in the Arabian Sea

The world's hottest year in recorded history, 1990 capped off a decade in which a warming trend became quite pronounced. Six of the warmest years on record occurred during the 1980s.

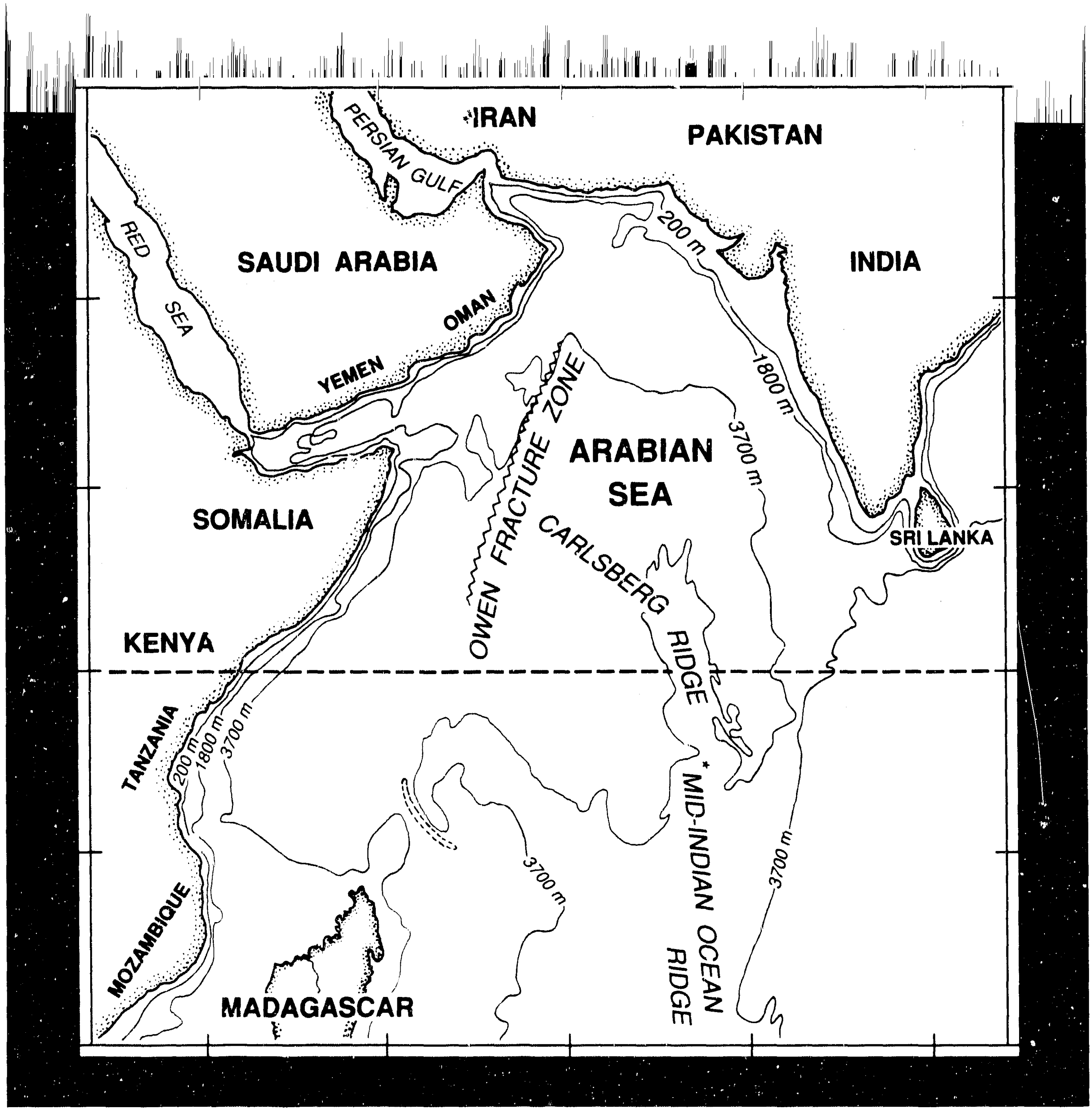
Since the beginning of the century, the earth's atmospheric temperature has risen by 0.5°C. Some scientists theorize that this global warming may be caused by the greenhouse effect — a process in which carbon dioxide (CO_2) and certain other gases trap infrared radiation in the earth's atmosphere.

Over the past 150 years, the concentration of CO_2 in the atmosphere has increased by about 20 percent, and over the next 50 years, it is expected to double. Fossil fuel combustion is the primary cause of increased CO_2 in the atmosphere.

Fortunately, the world's oceans absorb about five billion metric tons of CO_2 from the atmosphere annually, or about 40 percent of humankind's input. In the ocean, microscopic plants known as phytoplankton use CO_2 for photosynthesis. In addition, the ocean takes up the gas through physical diffusion.

New oceanic explorations

Because of their significant capacity to moderate global change, the oceans are a focus of a worldwide group of scientists in a pro-



Carbon cycling in the Arabian Sea is forced by circulation of the water in the basin in response to monsoon winds. Circulation is affected by topography such as narrow continental shelves, the fracture zone and ridges.

gram known as the Joint Global Ocean Flux Study (JGOFS). Oceanographers from Brookhaven's Department of Applied Science are part of this team.

JGOFS was organized in 1985 to determine, on a global scale, which processes control the continuous cycling of carbon and organic matter within the ocean. JGOFS researchers will also measure the related carbon exchanges between the atmosphere and the sea floor.

In a JGOFS research project planned for 1994-95, Brookhaven oceanographers will be among a team of U.S. scientists, along with scientists from France, Germany, India, the Netherlands and Pakistan, aboard research vessels in the Arabian Sea. In those Indian Ocean waters, they will be gathering data that will give them valuable insight into the ocean's role in global change.

Preparing to analyze a seawater sample for total dissolved inorganic carbon on the coulometric titration analyzer at BNL are (from left) Sharon Smith, Douglas Wallace and Kenneth Johnson.

BIG WINDS, BIG CHANGES

The Arabian Sea has the fastest current in the world during the southwest monsoon period. The seasonal carbon production activity in this ocean is driven by monsoon winds — at 45 knots, some of the strongest winds in the world. The strong winds tend to increase carbon production by bringing nitrogen and phosphorous up from the ocean depths, providing more fertilizer for the growth of phytoplankton. In addition, the winds blow in sand and trace metals from land, which also help to fuel an increased production of organic matter in the ocean. Increased plant productivity tends to decrease atmospheric CO_2.

Because the annual monsoons exaggerate these activities in the ocean, causing regular fluctuations between two extremes — water that lacks plant nutrients and water that contains an abundance of these nutrients — data related to oceanic carbon cycling can more readily be obtained in the Arabian Sea than in other, calmer waters.

MEASUREMENT MODES

Precise and standardized measurements of the CO_2 cycle in the Arabian Sea are needed to understand the carbon cycle in all of the world's oceans. DAS oceanographers are preparing instrumentation to make such measurements on the JGOFS cruises.

Among the sophisticated instruments needed is the single-operator coulometric titration analyzer, a device that measures the total dissolved inorganic carbon in sea water with an accuracy of one part in 2,000. The system has been used successfully in several previous deep ocean cruises.

Measurements of the organic carbon in the ocean are also crucial to understanding the ocean's role in global change. Microscopic animals known as zooplankton feed on phytoplankton. As the plants are broken apart during ingestion, dissolved organic carbon is released, and JGOFS scientists plan to measure it.

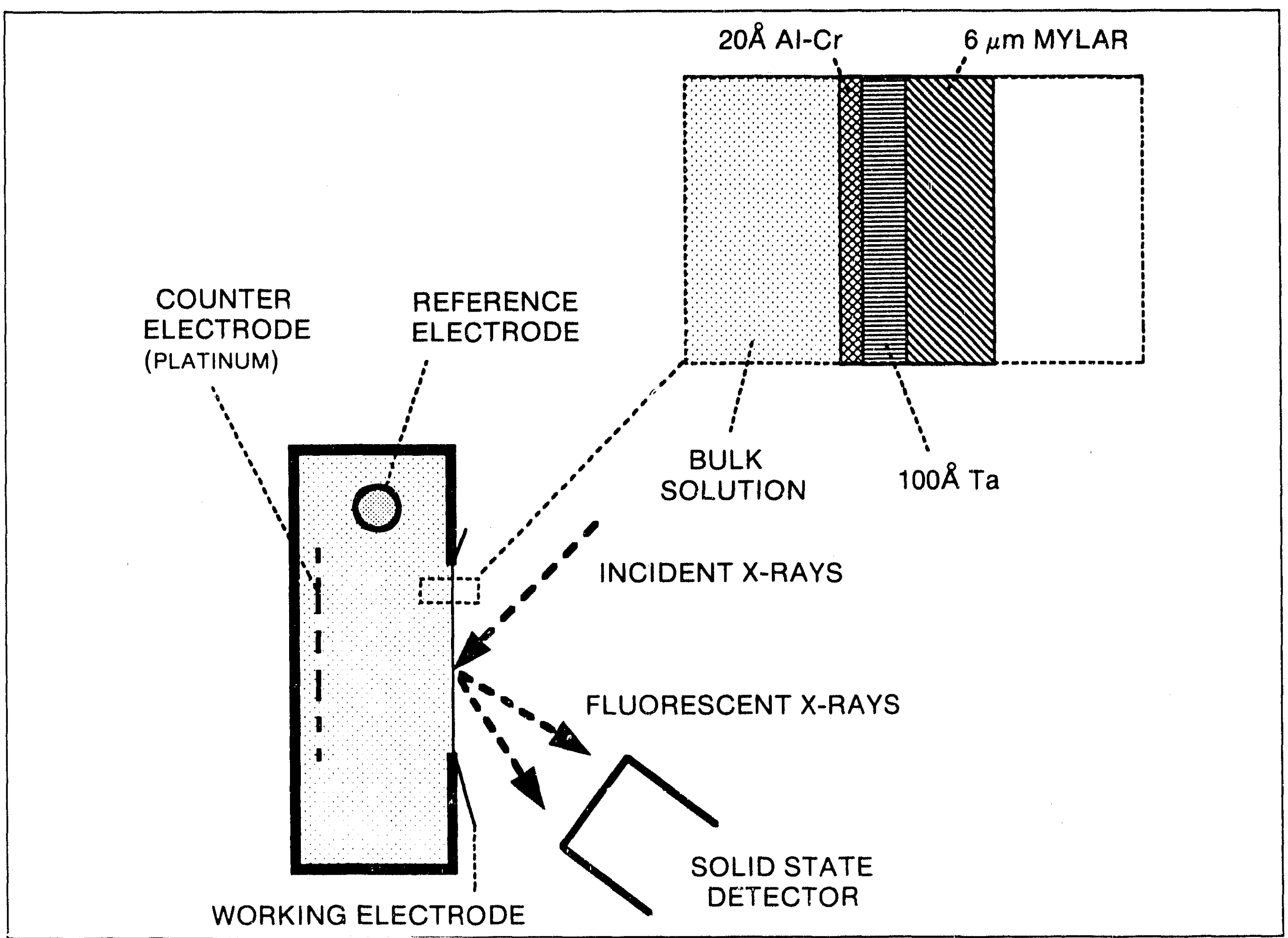
To measure the rate of plant growth in the ocean, the researchers will add small amounts of radioactive CO_2 and natural isotopes of nitrogen to ocean water samples and record how fast they are taken up. The faster they are used, the more plant growth is taking place.

To realize their goals, JGOFS researchers will put pertinent data from their sea voyage into computer models designed to simulate the response of the world's oceans to climate changes. These models need further data to verify their accuracy. In addition, research findings will be included in a JGOFS data base. This information will lead to new insights into the processes and complexities of carbon cycles and global change.

DYNAMIC STUDIES OF CORROSION

Corrosion exacts a huge toll on the U.S. economy. This natural process, sometimes accelerated by

Experimental apparatus used in a BNL-developed surface study technique, X-ray Absorption Near Edge Structure (XANES). XANES is used to measure corrosion-inhibiting oxide layers on metals in wet environments as corrosion is occurring. At the top right is an enlarged drawing of the aluminum-chromium alloy sample (Al-Cr).



Alison Davenport and Hugh Isaacs are setting up their apparatus at beam line X19A at the National Synchrotron Light Source for an experiment to study the thin oxide layers in aluminum chromium and iron chromium alloys that make these metals corrosion resistant.

human activities, costs the nation an estimated 5 percent of the Gross National Product annually. In 1990, that amounted to roughly $2.75 billion.

Much energy is required to extract metals from the natural state in which they are found in the earth — as oxides, sulfides, or other element combinations chemically bound to the metal — and to convert them into their thermodynamically less stable metallic form. All metals except gold, are unstable in air and can corrode. Corrosion is a process in which metals react with the environment and are converted to more chemically stable forms.

Researchers in the Department of Applied Science are investigating the fundamental nature of the corrosion process. This work may result in new stategies to prevent it.

Metals have a protective surface oxide layer. As a result, they generally corrode at an extremely slow rate even though the thickness of the protective layer is usually only a few atoms deep. But when this protective layer is disrupted by exposure to the environment, rapid corrosion occurs. On iron and its related products — steels — this results in the formation of rust, the most familiar kind of corrosion.

PREVENTING CORROSION

Industry copes with corrosion by making stainless steels formed by adding chromium to alloy with the iron. The chromium provides an added amount of protection to the metal's oxide layer, which retards rusting. Treating metal surfaces with soluble chromate corrosion inhibitors can also change the oxide and protect the surfaces from rapid corrosion. But these inhibitors have been found to be carcinogenic, so their use is being limited.

DAS researchers, in collaboration with scientists from IBM and the National Research Council of Canada, are investigating the thin oxide layers in metals. In particular, the collaboration is studying the behavior of chromium in aluminum-chromium and iron-chromium alloys. This basic research may help industry in its search for noncarcinogenic corrosion inhibitors.

A NEW TECHNIQUE

Surface studies of metal generally involve analytical techniques, using a subatomic probe such as electrons, that require the sample to be placed in a high vacuum. These techniques, however, cannot be used to study corrosion processes in wet environments — real world conditions. But with the aid of x-rays produced by the National Synchrotron Light Source (NSLS), our researchers have developed a method that allows them to make measurements of oxide layers in water while corrosion is taking place.

At the NSLS, a surface study technique known as X-ray Absorption Near Edge Structure (XANES) allows scientists to observe easily the changes in the different chemical states of chromium. Using the XANES technique, electrons in the chromium atom absorb x-rays and are stimulated to higher energy levels. When the electrons drop to lower energy levels, x-rays of characteristic energies are emitted. The electron energies are measured with a special solid-state detector.

To make these surface measurements at the NSLS, a special sample holder was developed. A very thin layer of the chromium-containing alloy is deposited on Mylar, a thin plastic film. The Mylar forms the window of an electrochemical cell containing the solution in which the sample metal is tested. When the metal layer is placed in the wet environment, the exposed surface is converted to a protective oxide film. The x-rays pass through the back of the Mylar and the thin metal layer, and are used to detect changes that take place in the protective oxide film that is in contact with the solution.

Due to the high intensity of x-rays at the NSLS, measurements of the chromium's chemical state can be made in a matter of minutes. This makes possible dynamic measurements of changes in the chromium that occur as the corrosion conditions are changed. These measurements have shown that under certain conditions a normally soluble state of chromium can be trapped in oxide films.

ALTERNATIVE ALLOYS

The researchers are also studying the behavior of aluminum-manganese and aluminum-vanadium alloys to determine if manganese and vanadium have characteristics that are similar to chromium. Since aluminum and its alloys, which are used as current conductors, corrode catastrophically in the presence of moisture, the electronics industry is interested in these results. Indeed, stainless aluminum may become a reality thanks to BNL corrosion studies.

NATIONAL SYNCHROTRON LIGHT SOURCE DEPARTMENT

The world's foremost facility for scientific research using x-rays, ultraviolet radiation and infrared radiation is operated by the National Synchrotron Light Source (NSLS) Department. In a single year, about 2,600 researchers from almost 400 institutions come to use the world's largest source of synchrotron light. Industry is well-represented among the users, with about 50 companies carrying out research at the NSLS. Guest researchers often work in collaboration with staff scientists at the Light Source, performing a wide range of innovative experiments in physics, chemistry, biology, materials science and various technologies.

PROBING SURFACES IN DEPTH

The numbers tell the story. More than 2,600 scientists from BNL, other laboratories, universities and private companies did research at the National Synchrotron Light Source (NSLS) in fiscal year 1991, and well over a third of these users did surface studies. Clearly, the capabilities of the NSLS have made new and innovative experiments possible, thus enabling researchers to explore the surface properties of materials with greater detail and accuracy than ever before.

Surface studies are investigations of the arrangements of atoms and of their electrons at the boundaries between solids, liquids, gases or a vacuum.

On the basic research level, surfaces are fascinating because their structure is often so surprisingly different from that of the bulk material. The bulk of a crystalline material is completely periodic in three dimensions with its atoms placed in a repetitive design. Under certain circumstances, such as changes in temperature or the addition of foreign atoms, this pattern is broken at the surface. In basic studies, researchers are trying to gain insight into this phenomenon, which is called reconstruction.

But more practical concerns also make surface studies a prime area of interest. Industry is motivated to study surfaces for three major reasons: to improve the performance of catalysts, to minimize corrosion and to manufacture more efficient semiconductor devices.

An estimated 20 percent of the Gross National Product (GNP) depends on catalysis for processes as diverse as making gasoline and plastics to eliminating pollution from automobile exhaust. Corrosion destroys metals each year with a value equal to five percent of the GNP. The chemical reactions involved in catalysis and corrosion occur at the interfaces between materials — the boundaries between the surfaces. The functioning of semiconductors, which are used in electronic devices, also depends on how one surface interacts with another.

BRIGHTER LIGHT, BETTER STUDIES

The beginning of surface science dates back to the mid-1800s with interest in solid-liquid interfaces. In modern times, surface investigations have surged forward dramatically with the availability of synchrotron light.

Since synchrotron radiation is 10,000 times brighter than radiation from laboratory-based sources, surfaces can be analyzed at the NSLS with extremely high resolution. Surface studies are done on both the vacuum ultraviolet ring, which produces infrared, visible and ultraviolet light, as well as the x-ray ring, which extends the radiation spectrum into the higher-energy x-ray region of the spectrum.

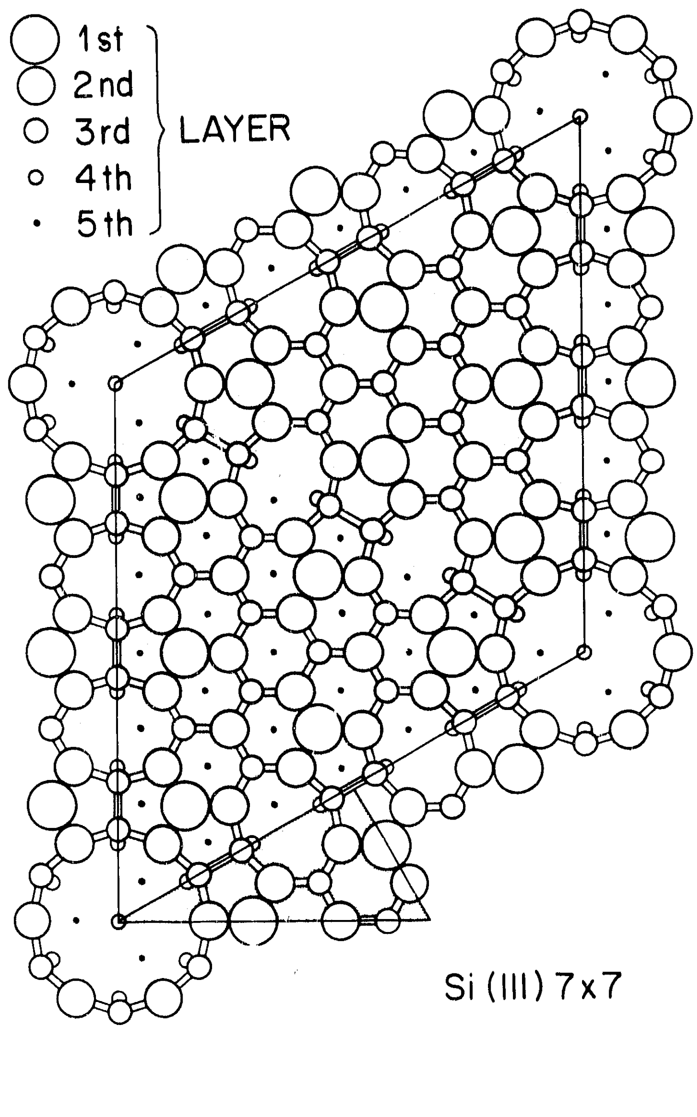
Further, the radiation at the NSLS is tunable, while laboratory sources have fixed wavelengths. Thus, researchers at the Light Source can select the specific spectrum — from infrared to ultraviolet light to x-rays — that best allows them to investigate the surface properties of most interest to them.

Because synchrotron radiation at the NSLS is pulsed, rather than continuous, scientists can look at an electronically or chemically induced change in a surface as a function of time. To further enhance many studies, ultrahigh vacuum chambers have been constructed at nearly all of the surface science beam lines. A vacuum keeps a surface free from contamination over the course of an experiment.

FOCUSING ON SILICON

Silicon is the most widely used semiconductor material, and so its surface is one of the most studied. Since semiconductors are at the heart of computers and many types of electronic devices, industry is aggressively seeking to improve their function. A complete understanding of the silicon surface and its interaction with other surfaces is essential to fulfill this goal.

Resembling an intricate floor tile pattern, here is the structural mosaic of silicon(111) 7 x 7 as viewed from above. The circles represent atoms and the diamond shows the motif that is infinitely repeated across the surface. The lattice spacings on the surface are seven times greater than the bulk.



While BNL's Gwyn Williams (right) reviews recent data, Carol Hirschmugl, Yale University, aligns a copper crystal to study how its surface interacts with carbon monoxide in an infrared spectroscopy experiment at Brookhaven's National Synchrotron Light Source.

A model for the surface structure of a simple silicon crystal face — silicon(111) — had been presented by researchers from the Tokyo Institute of Technology in 1986, ending a 27-year search. Shortly after, AT&T Bell Laboratories scientists working at the NSLS used a technique called grazing incidence x-ray diffraction to determine the detailed positions of all the atoms and their bond lengths on the silicon(111) crystal face. In an intricate network of rearranged bonds, the surface structure repeats itself after every seven atomic spacings in each direction.

Several researchers are investigating ordering on the (001) surface of silicon — the crystal face most often used in making semiconductor devices. Also using x-ray diffraction, researchers are looking at how the surface changes when it is cut at a small angle with respect to the (001) planes of atoms. One recent experiment found that, under certain conditions, the miscut surface of silicon resembles a staircase of regularly spaced steps between atomic planes.

Scientists using the Light Source have been examining how metal adsorbates such as lead, gallium and silver become attached to silicon. The adsorbates, which are atoms bound to the surface of a material, are characterized by their binding sites, the locations at which atoms are attached to silicon. These sites vary from one metal to another. Other metals such as nickel and palladium react with silicon to form silicide compounds that may one day be used to make semiconductor devices.

The silicon-oxide-silicon interface is remarkable in having a very low number of electronic defects, and this is the basis for much of the silicon semiconductor industry. Recent research at the NSLS has shown that a very ordered, epitaxial oxide is formed on this face. This is an important finding for the semiconductor industry because, as devices decrease in size, even the extremely small number of defects at this interface becomes troublesome. The NSLS research suggests solutions to these problems.

Many industrial, governmental and univers.ty researchers are using techniques known as high-resolution photoemission and photoabsorption spectroscopy to learn important information about the bonding between silicon and metal adsorbates. IBM, for example, is studying the etching of silicon by xenon difluoride.

MULTIPLE TECHNIQUES, DIVERSE DATA

Numerous techniques are used to study surfaces, and some of the most prevalent ones are listed in the accompanying chart. Each technique yields different information, so that the various techniques complement each other in providing a complete picture of a material's surface. For example, both surface-extended x-ray absorption and x-ray diffraction are used to study the atomic arrangements at surfaces, while infrared and photoemission spectroscopy provide data on their magnetic, electronic and vibrational properties.

New tools and methods for studying surfaces have been developed at the NSLS for both basic and industrial surface studies. One example is beam line U4IR, the only beam line in the world where infrared radiation is used for surface studies. These infrared studies are particularly useful for understanding the characteristic frequencies of atoms vibrating on surfaces.

An x-ray microscope, called the high-resolution scanning photoelectron microscope, was developed by a research collaboration from BNL, IBM, Lawrence Berkeley Laboratory and the State University of New York at Stony Brook. The device is used to study the elemental and chemical composition of a surface and its electronic structure.

The microscope allows researchers to probe an area on a solid surface as small as 0.3 microns (the width of a human hair is about 50 microns). Currently, the collaboration is using the microscope to study alumina surfaces. These studies are essential for an understanding of heterogeneous catalysts, which typically contain a precious metal, such as gold or platinum, and a support substrate, like alumina.

For most materials, it is impossible to separate the electronic structure of the surface from that of the bulk using conventional photoemission spectroscopy. To do this, a collaboration of scientists from BNL, Brandeis University and Rutgers University has been using a technique called Auger-photoelectron coincidence spectroscopy (APECS). For example, using APECS, they measured the electronic structure of only the surface atoms of tantalum and tantalum-carbide surfaces and found new electronic processes for the surfaces of these materials.

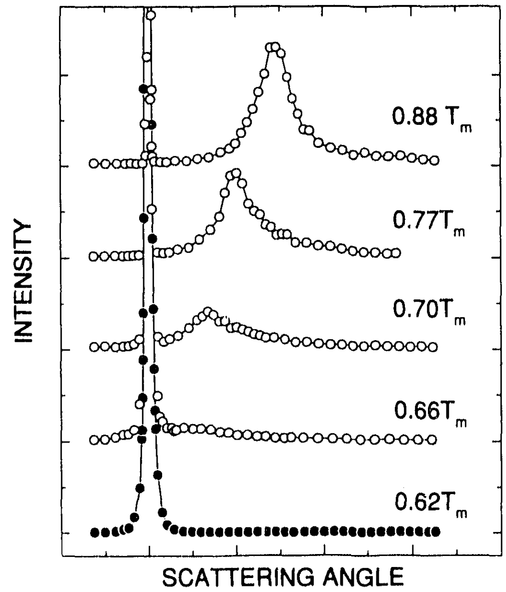
Other promising research, done by researchers from Sandia National Laboratories, involves probing a new kind of material made by growing atomic layers of one metal upon a well-ordered template of another metal. These metallic overlayer structures have electronic, chemical and mechanical properties that are unique hybrids of the properties of the two metals.

Unlike alloy surfaces, these one-atom-thick overlayers do not mix with the underlying support metal. Using photoemission spectroscopy, the Sandia scientists are studying the new electronic properties of these materials. As a result of this research, they may be able to tailor the properties of materials used in the technologies of the future.

All these examples provide a small glimpse into the fast-growing science of surfaces. In the last decade, new technology and varied investigations by physicists, chemists and engineers into the intriguing questions posed by surfaces have caused the field to advance explosively.

Surface Reconstruction

BNL, Massachusetts Institute of Technology and Oak Ridge National Laboratory researchers recently discovered that the surface of platinum(111) reconstructs at high temperatures — specifically, at two-thirds or higher than its bulk melting temperature (0.66Tm). The graph compares the intensity of photons scattered with the angle at which they scatter. The broad peaks on the right correspond to the reconstruction. Note that the peak position changes with temperature, showing that the surface is more compressed at the highest temperature. The black dots show the photons before reconstruction takes place, while the white dots represent photons after surface reconstruction occurs.



Techniques for Surface Studies	Beam Lines
INFRARED SPECTROSCOPY — Used to study vibrational modes (the characteristic frequencies at which atoms or molecules vibrate) of adsorbates on surfaces. Examines the frequencies, line shapes and widths of these modes. The vibrations are detected by changes in the reflectivity of the surface, the spectrum being analyzed by an interferometer.	**U4IR**
PHOTOEMISSION SPECTROSCOPY — For exploring the electronic structure of surfaces. When the sample is struck with photons, or light beams, electrons are ejected from atoms within it. A detector then measures the energy and momentum of the ejected electrons. This information is related to the electron's energy and momentum within the solid.	**U1, U3, U4, U5, U7, U8, U12, U13, U14, U16**
SURFACE EXTENDED X-RAY ABSORPTION FINE STRUCTURE (SEXAFS) — Used to study short-range, up to approximately 5 angstroms (Å), geometric surface structure with an absolute accuracy of 0.02 Å or better. Incoming x-rays are absorbed by atoms adsorbed on the surface of the sample, creating photoelectrons. Some of these photoelectrons scatter back towards the absorbing surface atoms, thereby interfering with the original outgoing photoelectrons. From this interference pattern, called fine structure, researchers can determine very accurate information about the position and number of neighboring atoms.	**U1A, U3B2, U4B, U7A, U7B, U16B, X11, X15B, X23A2**
X-RAY DIFFRACTION — For investigating long-range surface structure over distances ranging from a few hundred to many thousands of angstroms, and determining how temperature changes affect structure. X-ray photons hit the sample, scatter, and produce interference, or diffraction, patterns. An x-ray detector measures the angles and intensities of the diffracted beams, and the data are used to calculate the geometrical arrangements of atoms at the surface.	**X3, X6, X10, X14, X16, X18, X20, X22, X24, X25**
X-RAY STANDING WAVES — For determining the position of atoms in a perfect crystal with a precision of 0.01 Å. In this technique, a perfect single crystal diffracts an x-ray beam from a set of crystal planes. The diffracted beam interferes with a primary x-ray beam to produce a standing wave pattern. By rotating the crystal a few thousandths of a degree, the standing wave field moves relative to the crystal planes. This field excites the atoms on and below the crystal's surface, producing element-specific emission signals. From these signals, the constituent atoms' positions relative to the crystal planes can be determined.	**X3, X15A, X19, X24, X25, X27**

Examples ▼ | Users ▼

Researchers from BNL, in collaboration with AT&T Bell Laboratories and Exxon, are investigating the interactions of carbon monoxide and potassium (K) on copper (Cu) surfaces. Among other findings, they have discovered that adding K to the Cu surface increases the oxidation rate a millionfold. The researchers also studied surfaces of larger molecules, such as ethanol, methanol and formate. For the first time, the vibrational modes involving the entire molecule against the surface were observed. These studies are important in understanding catalysis and corrosion.

AT&T Bell Laboratories; BNL; Exxon; Michigan State U.; Surface Science Research Center, England; U. of Paris; Yale U.

On beam line U5, BNL is part of a large collaboration that is studying the surface magnetism of thin films — films a few atoms thick that are deposited on various substrates. These films may be used in magnetic memory technologies, such as cassette tapes, compact discs and computer storage discs. For example, the researchers are investigating iron-chromium-iron multilayers. The thickness of chromium affects the relative alignment of the magnetic moments (a measure of the strength of an atom's interaction with a magnetic field) in adjacent iron layers.

Argonne National Laboratory; AT&T Bell Laboratories; BNL; Cornell U.; Exxon; IBM; Los Alamos National Laboratory; National Institute of Standards and Technology; Sandia National Laboratories; U. of Oregon; U. of Pennsylvania; U. of Texas

On beam line X15B, AT&T Bell Laboratories researchers are studying alkali metal atoms adsorbed on metal and semiconducting substrates. The positions of these alkali atoms are believed to change with the substrate and with the amount of material deposited. Through understanding the geometry of the alkali atoms, insight is gained into how they are chemically bound to the surface.

AT&T Bell Laboratories; BNL; Case Western U.; Cornell U.; Du Pont; Exxon; Georgia Institute of Technology; Hoechst-Celanese; Illinois Institute of Technology; Lawrence Livermore National Laboratory; Mobil; National Institute of Standards and Technology; Naval Research Laboratory; North Carolina State U.; U. of Notre Dame; Sandia National Laboratories; SUNY at Buffalo; U. of Connecticut; U. of Washington

On beam lines X20 and X22, BNL, Massachusetts Institute of Technology and Oak Ridge National Laboratory are studying the arrangements of atoms over distances up to 10,000 Å for various crystal orientations of copper (Cu), gold (Au) and platinum (Pt). The structure of these surfaces depends on their cut. For example, the top layer of atoms of the simple cubic or (001) faces of Pt and Au forms a triangular array, even though the underlying layers are square. The simple triangular or (111) faces also form triangular arrays, but these arrays are more densely packed than they are inside the crystal. In other studies, the researchers are determining how temperature changes between room temperature and bulk melting temperature affect surface reconstruction. The surfaces of these materials reconstruct and exhibit different phases as the temperature changes.

Argonne National Laboratory; AT&T Bell Laboratories; BNL; Cornell U.; Exxon; Harvard U.; IBM; Massachusetts Institute of Technology; National Institute of Standards and Technology; Northwestern U.; Oak Ridge National Laboratory; Purdue U.; State University of New York (SUNY); U. of Chicago; U. of Illinois; U. of Missouri

On beam line X25, BNL researchers are investigating the surface structure of strontium titanate ($SrTiO_3$), the most popular substrate used for growing high-temperature (T_c) superconductors. By probing a $SrTiO_3$ crystal with a finely collimated x-ray beam, a sufficiently perfect spot can be located to perform a standing wave measurement. This research shows that the technique may be used on crystals with some imperfections. Knowing the surface characteristics of $SrTiO_3$ can aid in understanding how high T_c films grow.

Argonne National Laboratory; AT&T Bell Laboratories; BNL; National Institute of Standards and Technology; SUNY

Chemistry Department

The broad range of research in the Chemistry Department includes programs in nuclear and radiation chemistry, radiopharmaceuticals, homogeneous and heterogeneous catalysis, state-to-state chemistry, and thermal and photo-induced charge-transfer processes. All share a single goal: the fundamental understanding of the properties of nuclei, atoms and molecules. In this work, the special facilities, apparatus and techniques available at Brookhaven enable chemists to discover detailed structural and spectroscopic information on solids, liquids and gases, and the dynamics of physical and chemical change.

Lights... Camera... Action...

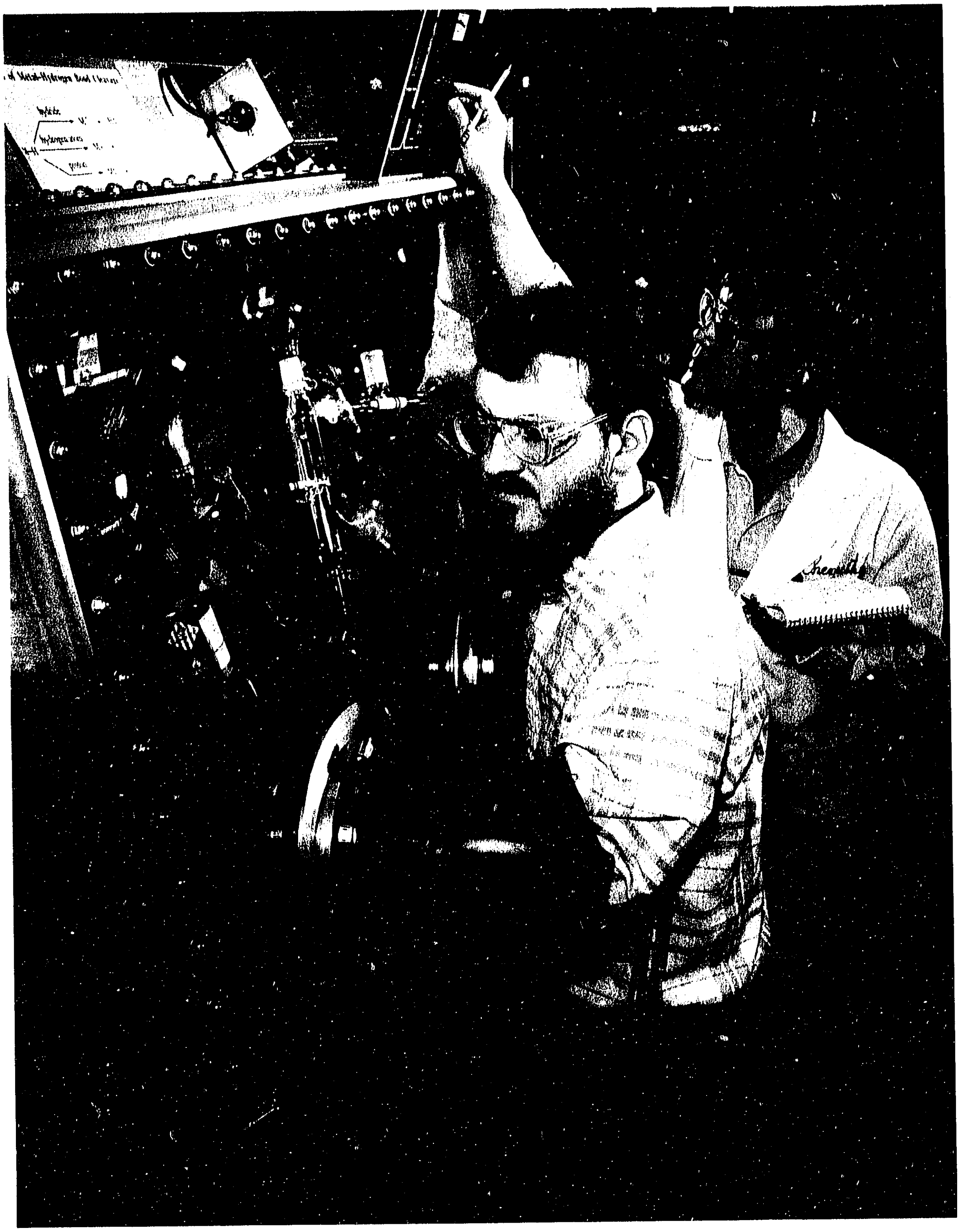
Recording the breakup of a relationship with lights and camera makes most people think of Hollywood — but the breakups being recorded by a group of chemists in Brookhaven's Chemistry Department are somewhat specialized.

The chemists are studying metal hydrides, which act as catalysts in one or more steps of many chemical reactions.

These hydrides are compounds made of hydrogen bonded to a transition metal (such as iron, chromium or manganese). Other molecules, such as carbon monoxide, are also bonded to the metals, but they remain unchanged during these reactions.

The hydrogen-metal bond in the hydrides can be cleaved more or less quickly. The amount of time this breakup takes, more than anything else, speeds up or slows down the hydrides' action in hydrogenation — delivering hydrogen to the substrate, which is the organic or organometallic compound being changed.

The Brookhaven chemists have recorded and examined the way the bonds break at a detailed, molecular level. From these data, information has been gathered on the hydrides' kinetics, or speed of reaction, which can depend on circumstances such as temperature or the particular compounds being catalyzed.



As Morris Bullock prepares a metal hydride sample, Jeong-Sup Song checks the purity of the glove box atmosphere.

Since homogeneous catalysts similar to those being studied at Brookhaven are used in organic synthesis, and on a huge scale in industrial processes involving oil or chemicals, to understand exactly how they work is a great advantage. For example, a simple change in composition of the catalyst or the conditions of the reaction, resulting in a quicker break of the metal-hydrogen bond, could save thousands of dollars a day.

IN THE LAB

For the experiments, our chemists made metal hydrides in the laboratory. They chose the slower catalysts because the slower the catalytic action, the easier it is to record and analyze.

The metal-hydrogen bond in the hydrides has two electrons. When the bond is cleaved, the electrons can take three different pathways (see diagram A). In path one, the hydride transfer reaction, the hydrogen takes both electrons and leaves the metal positively charged.

In path two, the hydrogen atom transfer, the metal keeps one electron and the hydrogen keeps the other, making it a hydrogen atom.

In path three, the metal retains both of the electrons, and the hydrogen, positively charged, leaves as a proton.

The reactions of metal hydrides are so diverse that some of them can take any one of these three pathways, depending on the substrate in the reaction.

One reaction studied at Brookhaven required two hydrogen atom transfers before it was complete. The questions were: How different were the two transfers? How much time and energy did each need? Did the metal hydride that performed best in one step act as efficiently in the other?

The chemists chose a method that had never before been

employed for this purpose, and they succeeded in getting useful results.

A substrate was used that includes a molecule whose parts form a closed ring (diagram B, substance 1). When the metal-hydrogen bond broke (action I), a hydrogen atom joined the substrate to form a compound containing a carbon-centered radical (ultra-active chemical) — the closed ring still intact (substance 2).

To complete the hydrogenation, the carbon-centered radical needed another hydrogen from another metal-hydrogen bond breakup. In action II, this happened: A hydrogen atom was donated, and the compound was altered as expected.

But another result was possible. If the second hydrogen took too long to get to the carbon radical, the closed ring opened up (action III). It then accepted a hydrogen atom from the metal hydride to make a different product (action IV).

By measuring the amounts of the two different products formed in the experiment, the researchers calculated the time needed for each step. They found that the original breaking of the metal-hydrogen bond was the slowest part, determining the rate of the whole reaction. Also, by systematically changing the metal and the temperature, our researchers found out how well different hydrides performed in this process.

A SECOND "FIRST"

In another "first" our chemists used the same hydrides to change the composition of certain olefins. These organic compounds, like the compounds treated in the previous method, have a carbon-carbon double bond.

With the same hydrides acting on the same type of compound, one might expect no surprises. But the chemists first added a very strong acid, which could also donate hydrogen — in a proton transfer.

This reaction was so rapid and powerful that the entire product could have self-destructed. But the metal hydride reacted immediately, breaking its metal-hydrogen bond as a hydride (diagram A, path 1). This second hydrogen was donated to the substrate to obtain the desired hydrogenated product.

The whole conversion was incredibly swift — a process that takes many hours by other methods took about five minutes. The procedure, which was patented by our chemists, was effective on certain substrates that respond only slowly to other methods, and it may be very useful to industry.

Thus, these reactions, both involving overall hydrogenation of a carbon-carbon double bond to give a hydrogenated product, demonstrate the versatility of the metal-hydrogen bond breakup. In the first reaction, the metal hydride provides the hydrogen as two hydrogen atoms. In the second, the acid donates a proton and the same metal hydride donates a hydride — a distinctly different mode of delivery.

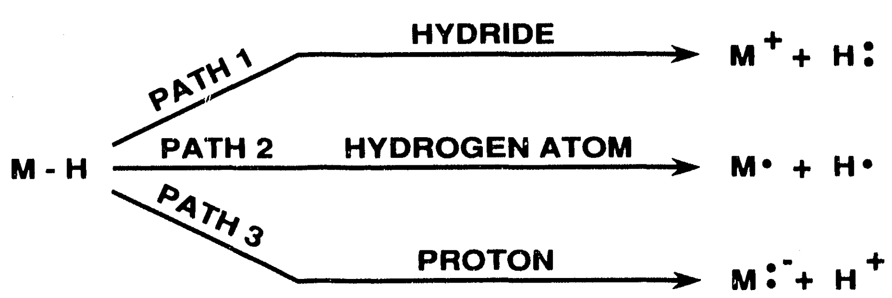
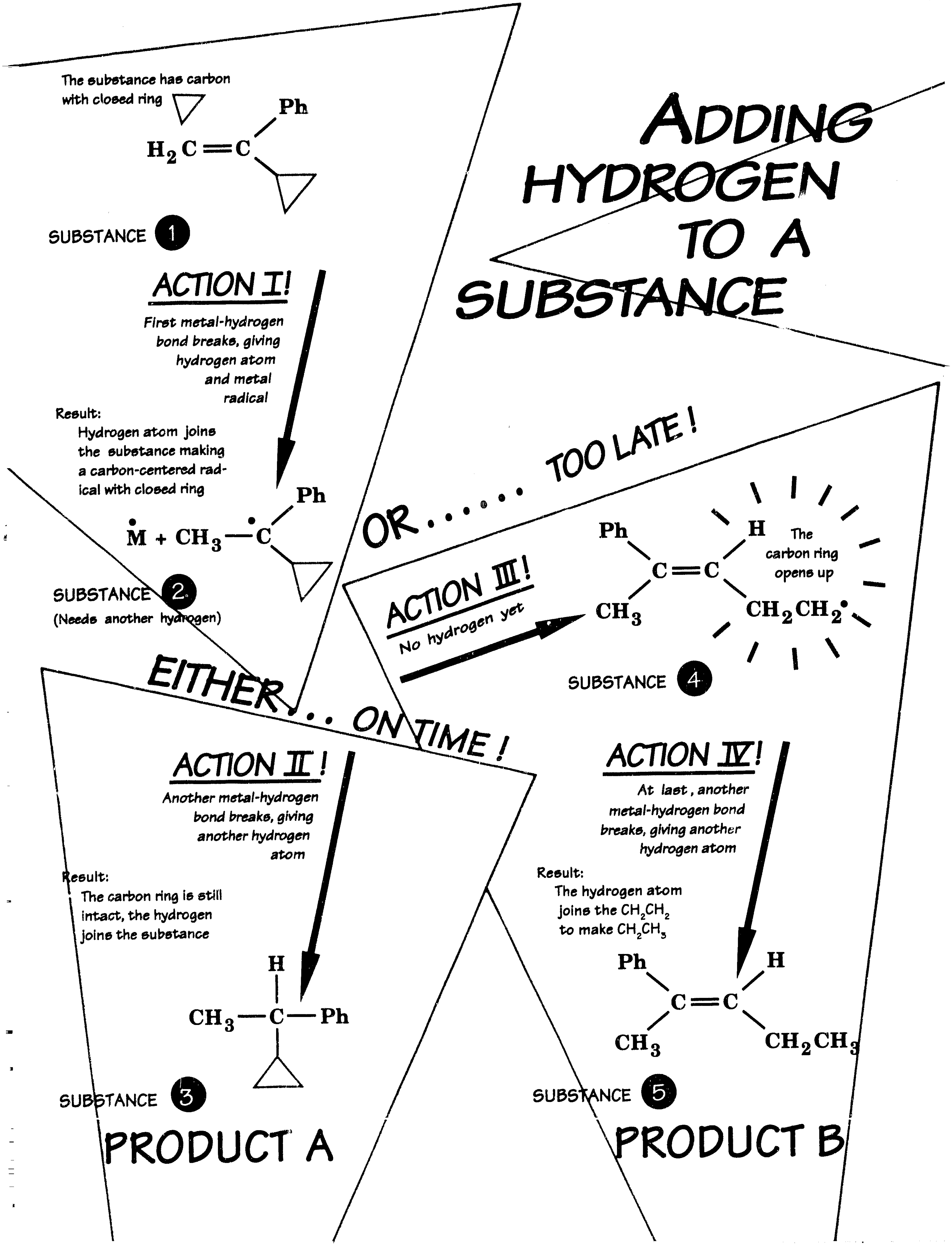
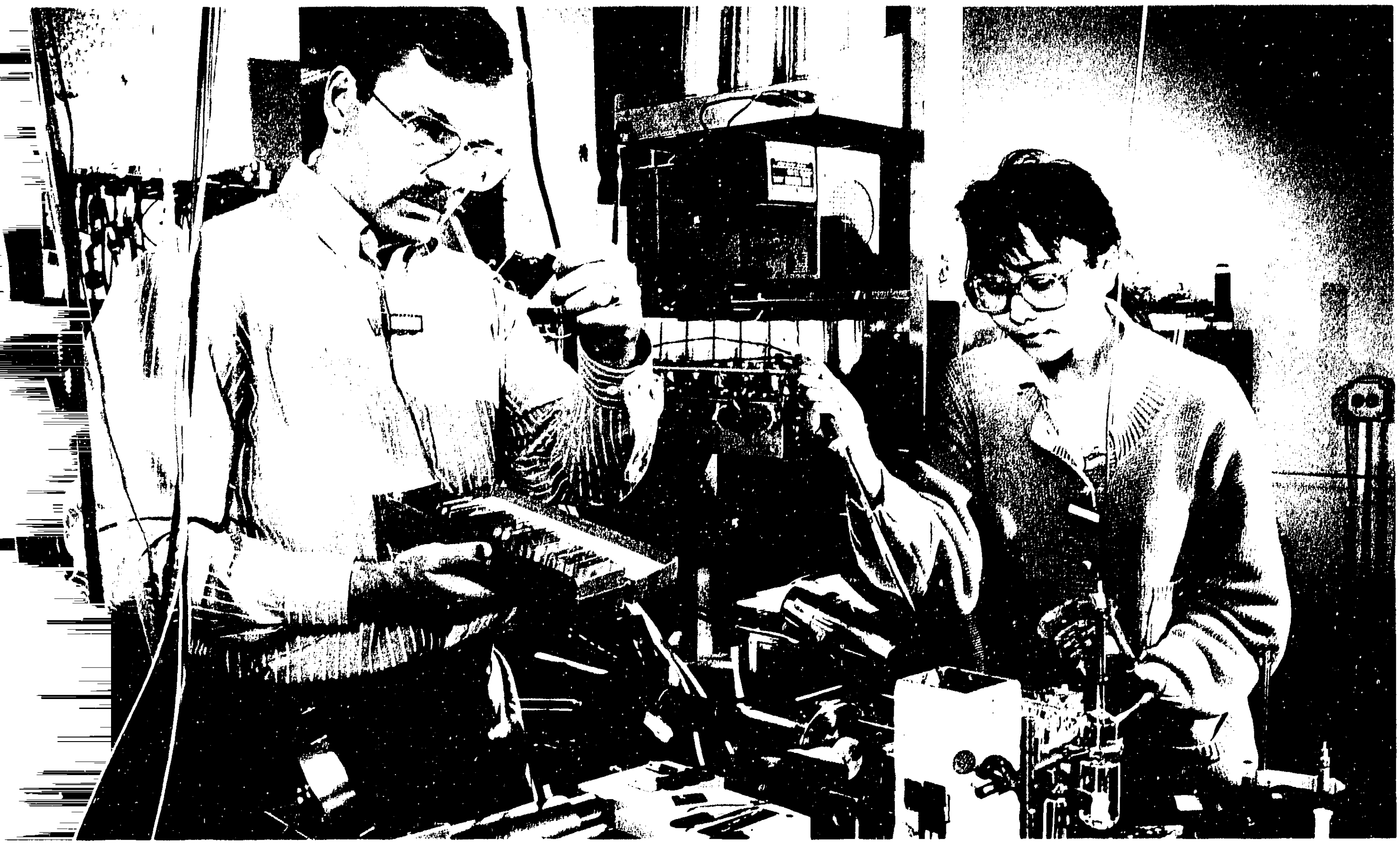


Diagram A: Three modes of metal-hydrogen bond cleavage.

Diagram B: The main steps in the action when hydrogenating a substance.

ADDING HYDROGEN TO A SUBSTANCE





James Wishart and Chang Su work on pulse radiolysis experiments at the Tandem Van de Graaff Facility.

The Long Goodbye - Electron Transfers over Distance

When two friends move apart to distant places, the first flurry of letters and phone calls between them usually abates quickly. Then they keep up with occasional birthday and season's greetings.

Of course, electron transfers are not the same as letters or phone calls between friends.

Yet, as two electroactive metal centers are moved farther apart in a molecule, the rate of electron transfers taking place between them quickly abates. Then, at a certain point, even though the distance increases, the rate levels off to a very gradual slope. In fact, the electrons continue to move between the two centers at slow, but appreciable, rates over comparatively long distances.

Researchers working in Brookhaven's Chemistry Department, in collaboration with chemists at Rutgers University, are among the first to have made this observation. They have been studying the mechanisms of long-range electron transfers in biological systems, which are important, for example, in respiration, photosynthesis and forms of energy storage.

The results of their experiments are particularly interesting because they contradict previous predictions that electron transfer rates would continue to fall off rapidly as the distance between the donor and acceptor centers increased.

To study how distance affects electron transfer rates, the Brookhaven chemists measured these rates between metal centers separated by different lengths of polypeptides, which are chains of amino acids, a subunit of protein. In addition to being found naturally in protein, specific peptide sequences can be made synthetically.

Of all the naturally occurring amino acids, one called proline has a unique structure that provides rigidity. Proline exists in two forms, known as cis and trans. These forms can interconvert, but very slowly. The trans-proline form is dominant in aqueous solution, making up at least 98 percent of the polyproline chains used in these experiments.

From data observed in x-ray diffraction and nuclear magnetic resonance experiments, the chemists knew that each trans-proline unit in the chains measures 3.1 angstroms long. Because they are so rigid, so very slow to change into the cis form, so prevalent, and, above all, so regular in length, the chains of trans-prolines act as very accurate rulers.

Therefore, just by counting the proline units between two centers, the researchers could get an exact measurement of how far the transferring electrons were traveling.

For the experiment, the chemists made complexes containing two metal centers — one ruthenium and one cobalt — bridged by rigid proline chains of varying lengths. The strong yellow color of the ruthenium complex deepens as soon as it receives an electron, so it can easily be used to calculate how quickly the electrons are transferring. Cobalt was chosen because it is a very good, irreversible electron acceptor; thus, all the transferred electrons ultimately end up with the cobalt.

To initiate the reactions, the experimenters used electrons accelerated to energies of two million electron volts by a Van de Graaff accelerator, to rip through a sample cell containing an aqueous solution of the complex to be studied.

The tremendous energy of the electrons, absorbed by the aqueous solution, tore some of the water molecules into fragments. Among the fragments were aqueous electrons, which readily attach themselves to acceptors such as the cobalt and ruthenium complexes.

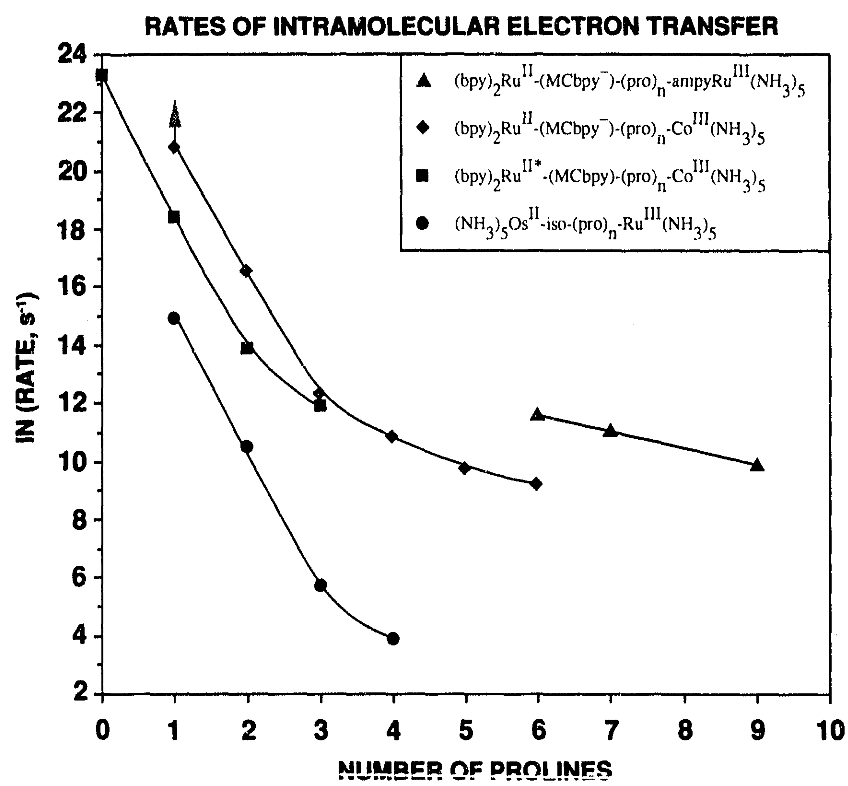
The extra electrons joined the two metal centers at random, about half going to the more stable cobalt center and the other half to the ruthenium center. The researchers then measured how long it took the electrons to move differing distances between the ruthenium and the cobalt by increasing the number of proline units bridging the centers, effectively increasing the separation distance by 3.1 angstroms per proline.

Results showed that the electron transfer rate fell off rapidly as the number of prolines increased from one to three, then decreased more gradually for larger numbers of prolines (see figure).

The chemists then replaced the cobalt center with another type of ruthenium complex and extended their long-distance record to nine prolines, or 38 angstroms between metal centers. This is the same length as the diameter of the protein cytochrome c, which plays a vital role in the electron transfers occurring in the natural process of respiration.

Thus, by learning more about how electrons are transferred across synthetic protein fragments, the Brookhaven chemists hope to understand more about electron transfer processes in nature, in which energy is released to power living organisms.

Graph of the electron transfer rate between molecules, with different numbers of prolines for four different compounds.



MEDICAL DEPARTMENT

The unique physical and chemical science resources and facilities at Brookhaven are used by Medical Department scientists to develop new medical applications of nuclear technology, as well as to understand effects of energy-related agents on human health. Research includes improving radiotherapy and nuclear medicine procedures; developing new radiopharmaceuticals and methods for noninvasive measurement of trace elements in humans; and mechanisms of disease caused by energy-related agents. Two promising research projects are described here: a form of cancer treatment that has been successful in controlling certain tumors in laboratory animals, and a nuclear imaging technology that has been used to investigate the effects of smoking cigarettes, crack and marijuana on the lungs, brain and heart.

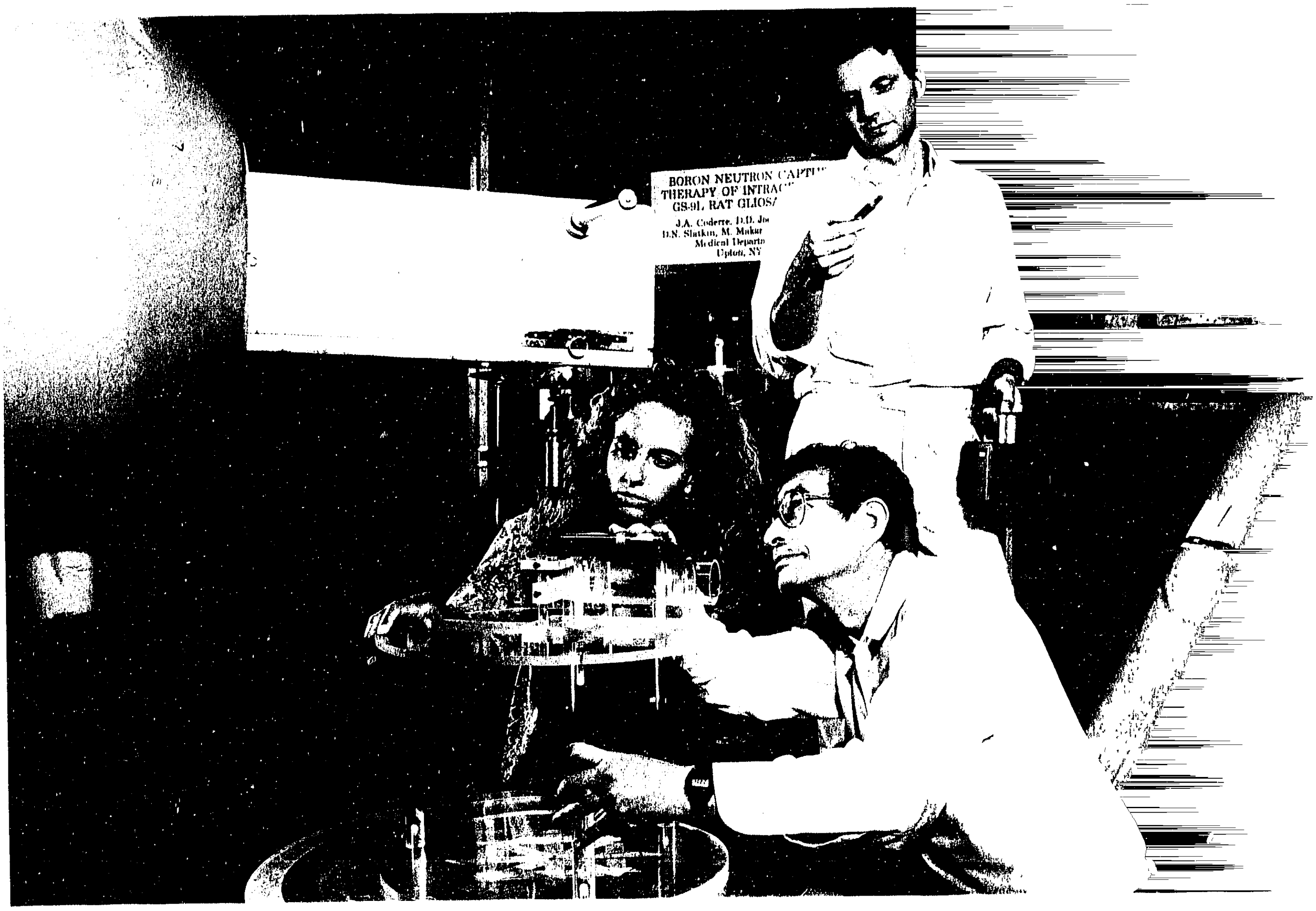
MANY FORMS OF CANCER, ONE PROMISING TREATMENT

Conventional chemotherapy or radiotherapy cannot stop the growth of some kinds of human cancer, such as certain malignant tumors of the skin, brain and eye. But in studies at BNL's Medical Department, a promising two-component treatment has proven effective in controlling these types of tumors in animals.

Called boron neutron capture therapy (BNCT), the treatment involves administering to the patient or the animal a compound containing boron-10, which concentrates at the tumor site. The tumor is then irradiated with a low-energy neutron beam. The boron-10 absorbs the neutrons, and, in the process, undergoes an instantaneous nuclear fission. The fission products — alpha and lithium particles — injure or kill the tumor cells, thereby slowing or stopping tumor growth.

SKIN CANCER

According to the American Cancer Society, the incidence of malignant skin melanoma has recently been increasing by four percent per year. About 27,600 people in the U.S. were diagnosed with this most serious form of skin cancer in 1990. While this melanoma is curable through surgery in its early stages,



it still kills about 6,000 Americans each year.

Some BNCT animal studies at Brookhaven in the 1950s succeeded in curing over 90 percent of mice with brain tumor tissue transplanted into thigh muscle. Over the last five years, experiments have focused on other forms of cancer as well as brain cancer.

Recently, using a boron compound called p-boronophenylalanine (BPA), up to 80 percent of the mice with transplanted skin melanomas were cured. In contrast, the death rate for the untreated control groups was 100 percent in each study.

BRAIN CANCER

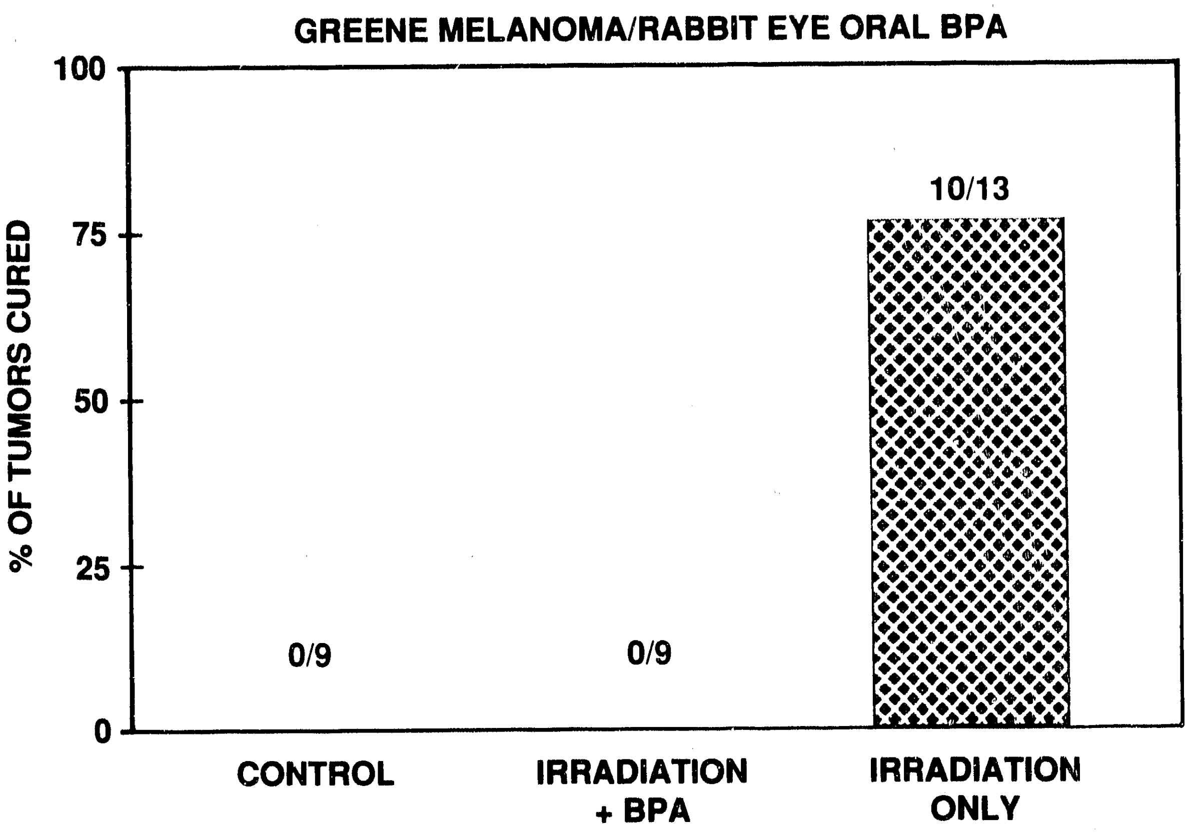
Every year, about 2,000 new cases of a form of brain cancer known as glioblastoma multiforme are reported in the U.S. About 10,000 people in the nation are afflicted with it, and less than one percent survive more than five years.

To test BNCT as a viable treatment for this cancer, our medical researchers injected the brains of healthy rats with cells that cause glioblastoma multiforme.

The rats were divided into three groups, two of which received different treatments. The median survival in the control group (which received no treatment) was 22 days. The group irradiated without receiving a boron compound had a median survival of 25 days. But more than 50 percent of the rats that received BNCT showed regression and eventual disappearance of brain cancer. These rats survived a year or longer. (The average life span of a rat is about three years.)

Different boron compounds were used in two separate BNCT studies

Britta Mast (left, foreground), a student intern from Southampton College, and BNL researcher Daniel Slatkin position the experimental animal shield in the Brookhaven Medical Research Reactor in preparation for a boron neutron capture therapy experiment. BNL's Jeffrey Coderre (standing) is examining the ionization chamber to verify the x-ray dose rate.



▲ The graph shows that boron neutron capture therapy was effective in curing ten of 13 tumors implanted in the front chamber of rabbits' eyes. Not cured were a control group of nine rabbits that received no treatment, as well as another group of nine rabbits that were only irradiated.

on the rats: BPA and sulfhydryl borane dimer (BSSB). While both boron compounds produced survival rates of a year or longer in a significant fraction of the treated rats, BPA was about 100 times more effective than BSSB when the cell survival in the brain tumor was tested in cell cultures.

The researchers hypothesize that BPA is distributed uniformly throughout the tumor and, when irradiated, kills tumor cells directly, while BSSB is concentrated in the tumor's blood, causing damage to blood vessels and, ultimately, possibly cutting off the nutrient supply to the tumor. If this theory proves to be correct, our researchers may revise BNCT so that a combined dosage of the two boron compounds would be administered to the patient for a more effective therapy.

EYE CANCER

Each year, about 1,800 Americans are diagnosed as having ocular melanoma, a malignant cancer in the pigmented membrane of the eye known as the choroid. The disease is fatal in 85 percent of cases.

In collaboration with North Shore University Hospital-Cornell University Medical College, BNL's Medical Department researchers implanted a melanoma in the front chamber of the eye in three groups of rabbits.

The tumors in the control group grew rapidly and the rabbits were euthanized after two weeks. When the tumors were irradiated without boron, the rabbits' life span increased to four weeks. When treated with BNCT, 10 of 13 rabbits were cured, but with one side effect: All of these survivors developed cataracts in the treated eye within three to six months after receiving BNCT. Nevertheless, cataracts can be treated surgically and would be an acceptable side effect.

INITIAL HUMAN STUDIES

Because the BNCT animal studies have proceeded so well, the U.S. Food and Drug Administration has approved initial distribution studies of BPA for patients with melanomas of the skin or eye, or for brain tumors. These studies are conducted to determine where the drug accumulates in the body. Since initial BNL animal distribution studies of BPA in mice with breast cancer also looked promising, additional distribution studies for breast cancer patients are planned by our researchers.

In preliminary tissue distribution studies of all these cancers, performed on animals, BNL researchers found that BPA accumulates in the tumor with about eight times greater concentration than in the blood. Also, the animals showed no serious toxicity from either BPA or the dimer form of boron.

So far, 14 volunteer surgical patients — seven with ocular melanomas, four with skin melanomas and three with glioblastomas — have been selected for the distribution study, which will determine the safety of BPA when taken orally by humans. Eventually, the researchers will perform the study on 60 additional patients.

Each volunteer was orally administered a low dose of BPA, which was gradually increased as the study proceeded. The researchers then measured the boron concentrations in the blood, urine and tumors of the patients. Also, routine blood chemistry was performed.

As in the animal studies, the tumor-to-blood boron concentration ratio was approximately 8:1. The blood chemistry remained normal in all the patients. Forty-eight hours after BPA intake, 61 percent of the compound had been recovered in the urine, which means the body effectively absorbed at least that percentage of the drug during that time. Thus, all the tests so far indicate that BPA is safe and effective for humans.

DRUG ABUSE: IMAGES OF DAMAGE

Smoking is hazardous to health, whether the substance inhaled is tobacco or crack. Now, BNL's medical researchers have found that when cigarette smokers use crack, the negative effects of both substances on the lungs are enhanced. Additional studies show that smoking crack can produce abnormalities in the brain and heart.

The research involves the nuclear medicine imaging technology called Single Photon Emission Computed Tomography (SPECT). Using this noninvasive imaging technique, a subject's internal organs can be examined without surgery.

In brief, radiopharmaceuticals are administered to the subject. Next, the subject is positioned in the SPECT system and a detector rotates around the person, collecting up to 180 images of the administered radioactivity. A computer then processes the images to produce pictures that depict the distribution of the radiopharmaceutical in three dimensions in the internal organs to be examined. Thus, we can determine how a particular substance affects body organs.

LUNG DAMAGE

The lungs contain a membrane that prevents potentially harmful particles from clearing the lungs and entering the bloodstream. Because healthy lungs are the least permeable, they retain inhaled particles the longest.

Toward Better Images

The photons that are emitted by the radionuclides used in Single Photon Emission Computed Tomography (SPECT) highlight the organ under study and form the basis of the three-dimensional SPECT image. Medical Department researchers are working on new methods to maximize the precision of these SPECT images.

One problem is that photons are scattered within tissues and organs before they escape the body, resulting in loss of precision and lack of definition in the image. This photon scattering is known as the Compton effect.

Our researchers are trying to understand better the scattering process in the human body by designing a computer code to simulate the entire SPECT process. The results of this study will be used to correct SPECT images for losses in spatial and quantitative accuracy of the radioactivity distribution. To date, we have been the first to develop an experimentally validated simulation code to characterize the distribution of scattered photons in human bones, muscles and lungs.

If our calculations prove to be correct and adequate corrections are made, the result would be better resolution and more accurate mapping of radiopharmaceuticals in organs and tissues. This should lead to more sensitive imaging procedures and expand the use of SPECT in the detection and diagnosis of disease.

Marija Ivanovic and David Weber review tomographic images from a SPECT study

[illegible] permeability of 23 [illegible] some of [illegible] cigarette smokers and [illegible] was compared to a [illegible] free control group. To [illegible] atomized radioactive [illegible] Tc-99m DTPA ([illegible] 99m-labeled diethylenetriaminepentaacetic acid) was administered to all the subjects. [illegible] clearance rates were measured [illegible] for 25 [illegible]

[illegible] control subjects [illegible] administered [illegible] aerosol [illegible] average [illegible]

[illegible] indicated that chronic [illegible] compromised [illegible]

But seven crack users who were also chronic smokers fared even worse. Their lungs cleared the labeled aerosol in about one quarter the time of the control group. A similar clearance rate was recorded for the nine crack users who smoked both cigarettes and marijuana.

With 83 percent of the crack users studied showing normal findings on conventional pulmonary function tests, these results indicate that the highly sensitive Tc-99m DTPA procedure is an extremely important test of early lung damage in drug abuse.

BRAIN DAMAGE

[illegible]

regional cerebral blood flow in the brains of 21 crack abusers and an equal number of control subjects were examined.

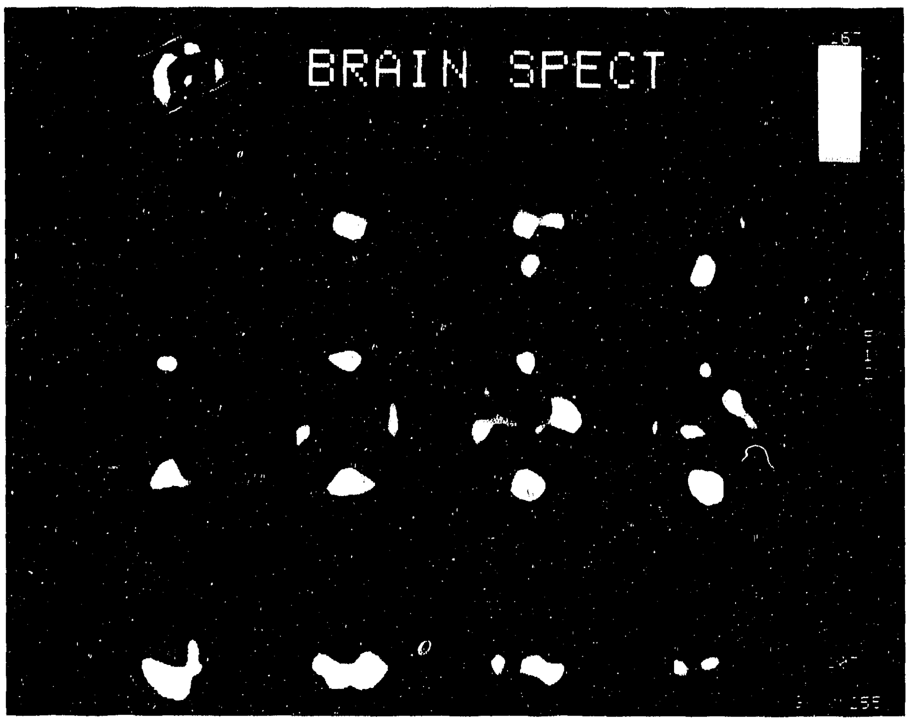
Our researchers found that 90 percent of the crack users showed defects in either the frontal or posterior lateral cortex of the brain, or disruption in the normal activity distribution pattern of the brain's gray-white matter. This was in marked contrast to minor alterations seen in regional cerebral blood flow in the control subjects.

The results indicate that the use of crack can cause blood flow abnormalities in the brain. Further investigation is under way to clarify the significance of these early findings.

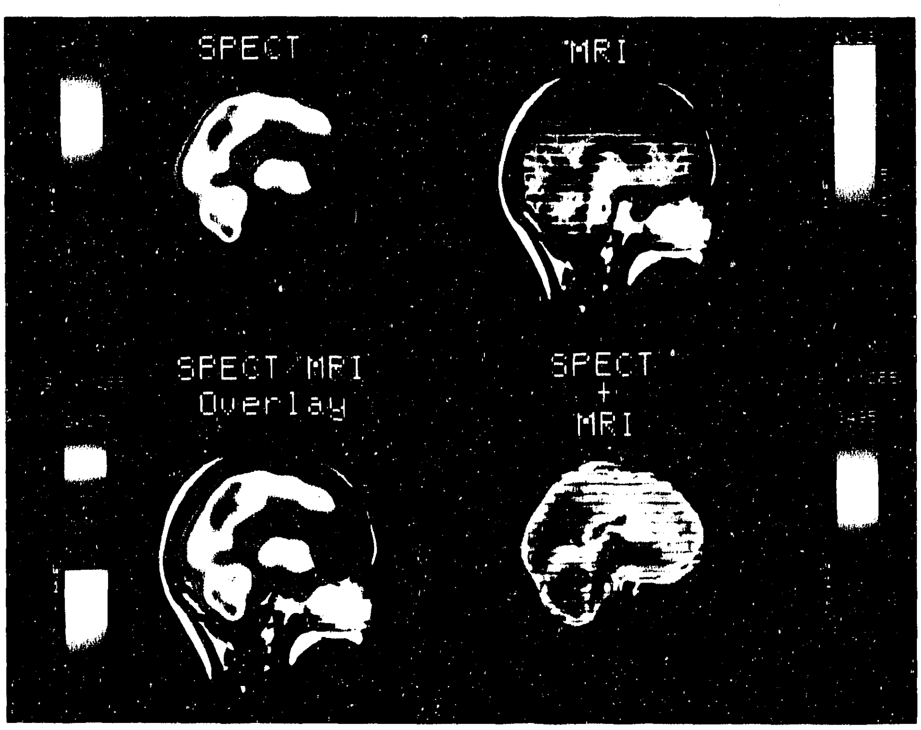
HEART DAMAGE

SPECT studies of cocaine abusers' hearts show that the drug seriously impairs cardiac perfusion, or blood flow. Using a thallium (Tl-201) chloride radiopharmaceutical, well-defined cardiac perfusion defects were found in 9 of 20 subjects who were chronic crack users. This compared with normal cardiac blood flow observed in seven control subjects.

These blood flow abnormalities indicate detrimental changes in the walls of the heart, which may seriously affect function. Our next step is to determine if these abnormalities are permanent or reversible.



Tomographic images show typical distribution properties of I-123 IMP. The images are used to investigate regional cerebral blood flow in the human brain. The three rows of images are consecutive slices, approximately one centimeter thick, beginning at the top of the skull and extending to the base of the brain. The lightest areas indicate maximum blood flow.



Pictured are examples of a midbrain tomographic slice done by SPECT and by magnetic resonance imaging (MRI). MRI provides images of structures in the brain, while SPECT shows regional blood flow. Overlaying the images allows precise identification of the relative blood flow in the brain's various structures.

Biology Department

Research in the Biology Department encompasses studies on molecular structure and genetics, DNA damage and repair, and cell biology of plant and animal systems. The department maintains the Scanning Transmission Electron Microscope facility and also operates experimental stations for molecular structural studies at the National Synchrotron Light Source and the High Flux Beam Reactor. The broad range of studies covered by our researchers is illustrated in the following articles. The first describes engineering a gene for one of the proteins found in the bacterium that causes Lyme disease, an advance that may lead to a vaccine that could eliminate the disease. The second describes an investigation of DNA-PK, the only enzyme of its type known to be directly regulated by DNA. Scientists theorize that this unusual enzyme may recognize damaged DNA in a cell and broadcast the message that activates other enzymes that repair the damage.

New Promise for a Lyme Vaccine

Lyme disease, a tick-borne infection that can lead to potentially serious complications, was first recognized in 1975 in Old Lyme, Connecticut. Since then, its incidence has dramatically increased, and it has been documented in 46 states. In 1990, New York reported by far the largest number of cases — a total of 3,244.

The disease is caused by a spirochete, a spiral-shaped bacterium, known as *Borrelia burgdorferi*, which is transmitted to humans by the bite of a deer tick. Researchers in BNL's Biology Department, in collaboration with the University of Texas Health Science Center, have engineered the gene for one of the proteins of *Borrelia*. This protein, called OspA, may be a key to developing a more sensitive test for the disease and a possible vaccine to prevent it.

OspA, a major protein on the Lyme spirochete's outer surface, is an antigen. It can stimulate the production of antibodies in humans, which may help to destroy the invading Lyme spirochete. But this immune response may take several months to develop in humans.

Studies of mice have shown that their immune system recognizes OspA immediately, and this may be one of the reasons mice are not susceptible to Lyme disease. Scientists theorize, therefore, that if there were a way to hasten the immune response to OspA in humans, they might not get the disease.

Toward this end, the Brookhaven/Texas team has used recombinant DNA methods to produce large amounts of the OspA protein. The researchers designed and cloned a version of the OspA gene that produces a shortened protein. The shorter protein is easier to work with than the complete OspA protein because it is soluble in its *E.coli* host and easily purified.

Early detection and treatment of Lyme disease prevents complications, such as arthritic, cardiac or neurological problems. The truncated version of the OspA protein may be an important ingredient in developing new diagnostic tests for Lyme disease that are more sensitive than the current blood test, which is not definitive until a few weeks after initial symptoms appear. OspA also looks promising as an active ingredient in a Lyme disease vaccine because large amounts of it can now easily be made in a highly purified, soluble form.

OTHER COLLABORATIONS

The Brookhaven/Texas collaboration has provided other laboratories with the truncated OspA protein for further studies. To test the effectiveness of OspA as a potential vaccine, BNL researchers, working with the Centers for Disease Control, are injecting it into hamsters. The hamsters can get Lyme disease symptoms, which are then challenged with spirochetes.

In another joint project, this one with researchers at the State University of New York at Stony Brook, BNL biologists are characterizing a large number of DNA clones from the spirochete, many of which are for previously unidentified surface proteins. From this research, the biologists may identify the genes for other proteins that may be on the surface of *Borrelia* cells.

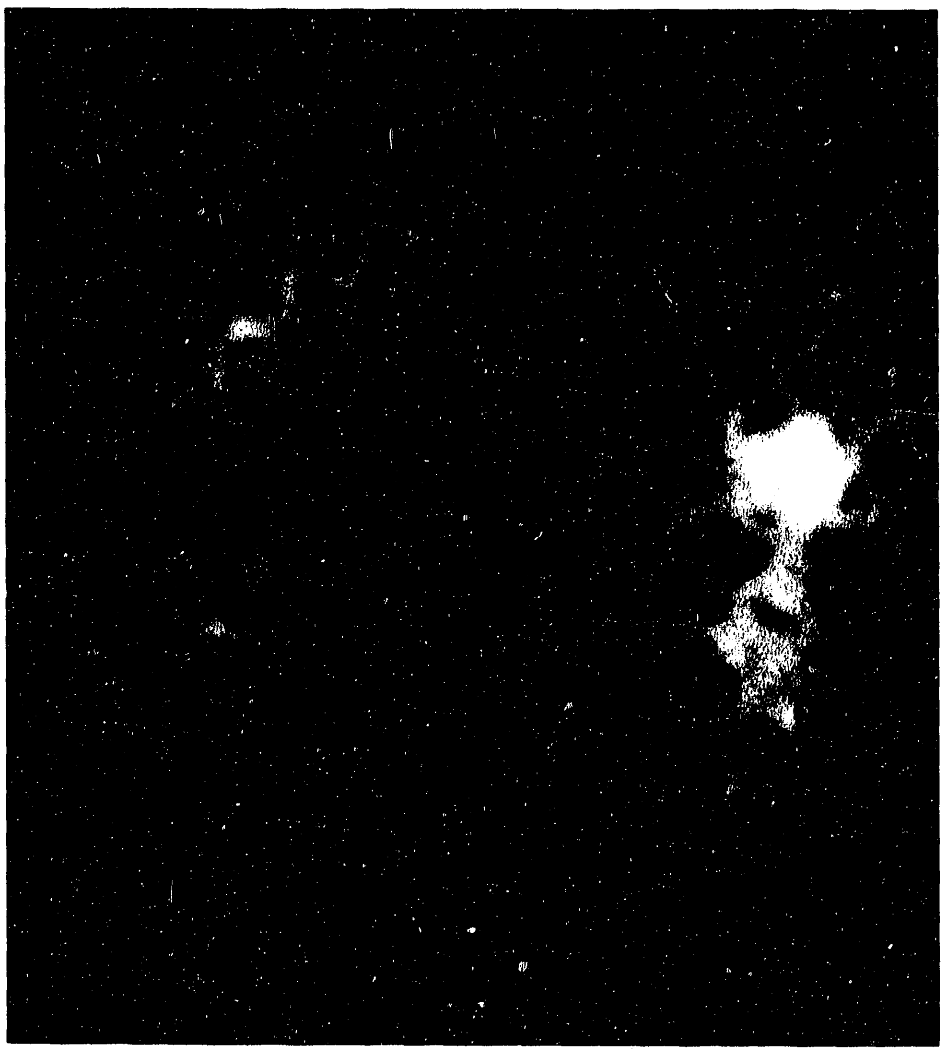
The BNL biologists are performing structural studies of OspA using spectroscopy and hope eventually to use x-ray crystallography at Brookhaven's National Synchrotron Light Source. Knowing the structure may lead to identifying the OspA antigen sites. This would be a major breakthrough in developing a Lyme disease vaccine.

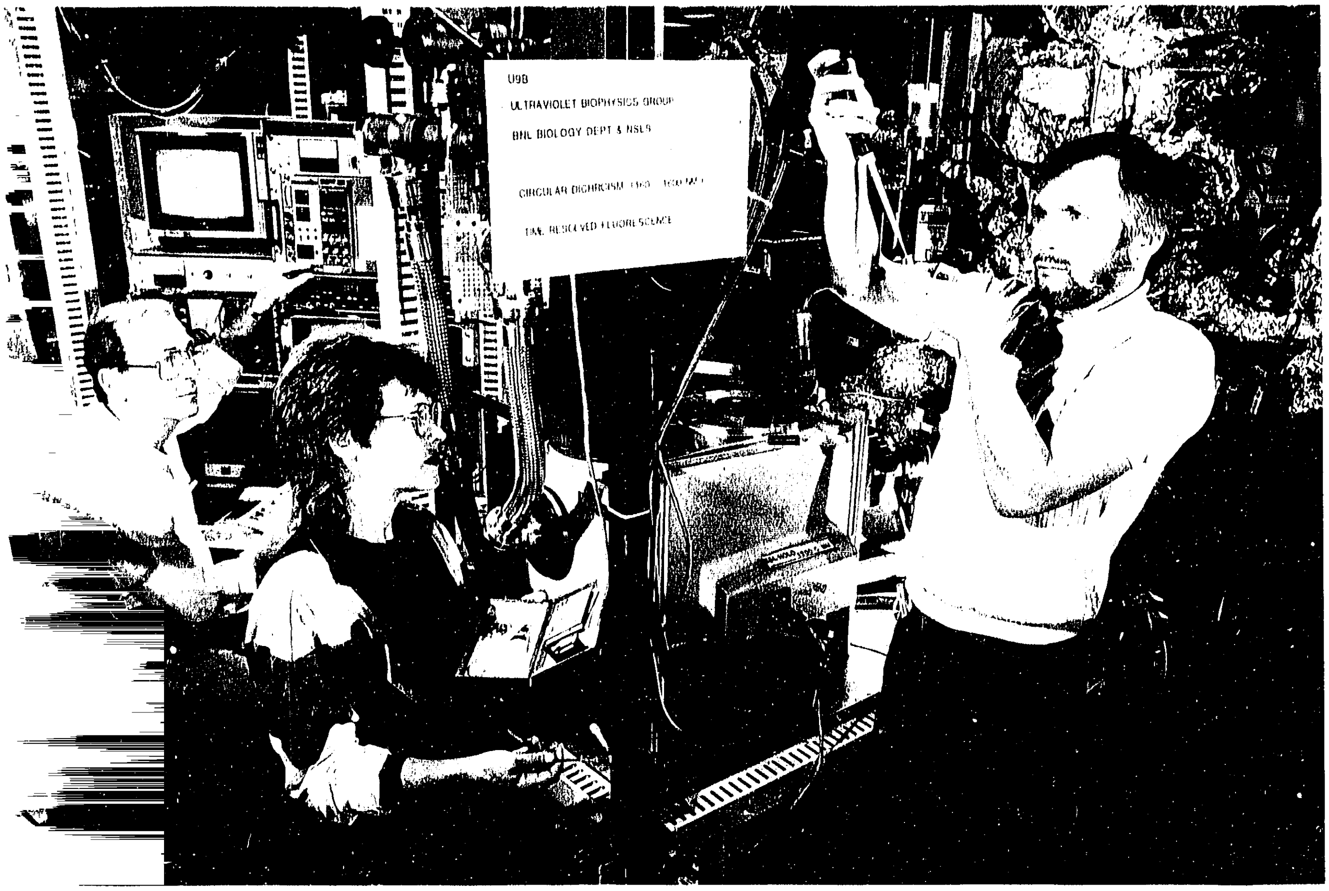
A vaccine may contain numerous antigens, but usually only one or two of these engender a protective antibody. To formulate an effective vaccine, researchers must find the antigens that stimulate these protective antibodies.

Another important aspect of structural studies is the identification of significant amino acids — the building blocks of the OspA protein. If critical amino acids are changed or deleted in an engineered protein, a more effective antigen may be the result.

In the future, BNL researchers plan to sequence the entire DNA genome of the Lyme spirochete, which has a single large chromosome of about one million base pairs, plus a few ancillary DNA molecules of under 50,000 base pairs. Through sequencing, researchers can gain valuable information about the organization, control and expression of genes.

A microscopic view of the spirochete *Borrelia burgdorferi*, the helically shaped bacteria that causes Lyme disease. It is transmitted to humans through the bite of a deer tick.





Studying the structure of the recombinant OspA protein at BNL's National Synchrotron Light Source are (from left) John Dunn, Louisa Lee France and Jan Kieleczawa.

DNA-PK: THE GREAT COORDINATOR

A single, microscopic cell, acting separately or in unison with other cells, performs the myriad functions needed to sustain life. The biochemical reactions that take place within a human cell are so complex that special enzymes have evolved that regulate and coordinate many of the different reactions.

Recent research in BNL's Biology Department has identified one of these coordinating enzymes that seems to monitor the state of the DNA in the cell. This enzyme is a DNA-activated protein kinase known as DNA-PK.

Protein kinases are enzymes that add a phosphate group to other proteins. Adding phosphate produces small changes in a protein's structure, which can profoundly increase or decrease its biochemical activity. Other enzymes, called phosphatases, remove the phosphate group. Addition and removal of phosphate groups is a mechanism by which cells rapidly control biochemical activities.

Protein kinases themselves respond to certain physical and biochemical signals, and their main job is to allow cells to adapt quickly to changes in their biochemical state or environment.

Of about 100 protein kinases identified so far, DNA-PK is the only one whose activity is directly regulated by DNA, the material in chromosomes that carries genetic information. Our researchers theorize that DNA-PK provides a cell with a way to adjust the activities of enzymes or other proteins that interact with its DNA.

BIG AND POWERFUL

To understand how DNA-PK works, Brookhaven biologists first purified it from the many other proteins found in human cells. We found that DNA-PK contains about 3,000 amino acids, making it the largest known protein kinase and one of the largest proteins that has been purified from human cells.

Next came the identification of several proteins to which DNA-PK can add a phosphate. Most of the proteins identified so far have some known role in interacting with DNA to repair damage, control gene expression or regulate cell division. Examples include a protein, hsp90, that helps protect cells from damage caused by exposure to chemicals or heat; the SV40 tumor antigen, a viral oncogene; a tumor suppressor gene, called p53, that has been implicated in many human tumors; and the oncogene protein, Fos, a DNA-binding protein that controls expression of many cellular genes required for growth.

To learn more about how DNA-PK produces its effects, we are investigating where the phosphate groups are attached to these proteins. A few years ago, this was prohibitively expensive because cells contain only a few molecules of each of these proteins. But now, genetic engineering techniques permit many such proteins to be produced in sufficient quantity for easy biochemical analysis.

So far, we have found that DNA-PK attaches phosphates to two threonines in hsp90 and to four serines in the SV40 tumor antigen. (Threonine and serine are two of the 20 types of amino acids found in proteins.)

In each case, glutamine, a third type of amino acid, was found next to the amino acid to which the phosphate was attached. The adjacent glutamine may be an important feature that helps the kinase distinguish these threonines and serines from the many others in the protein. Knowing which features are recognized by DNA-PK will be helpful in identifying sites at which it may attach phosphates to other proteins.

To determine what effect attachment of phosphates by DNA-PK has on the functions of these proteins, BNL biologists are working with researchers at the State University of New York at Stony Brook, Cold Spring Harbor Laboratory and the National Institutes of Health.

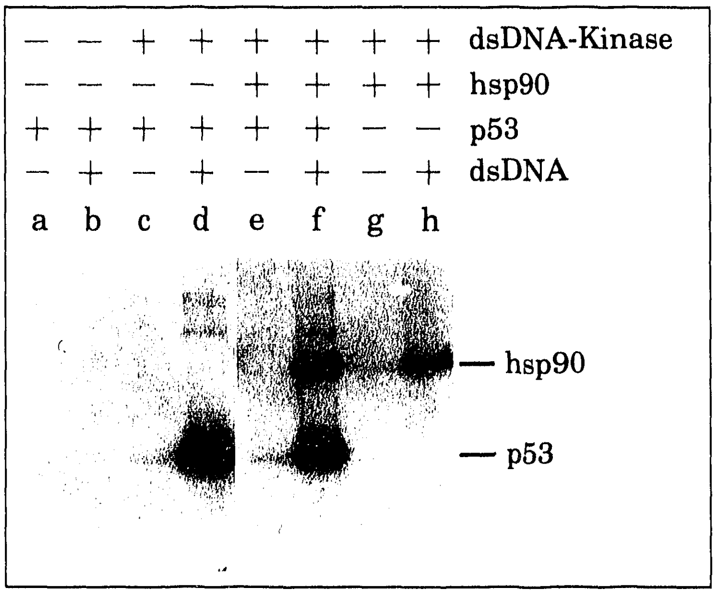
DETECTING DAMAGE

An important part of understanding the role of DNA-PK is determining when and how it is activated by DNA in a cell. A clue came from recent experiments that used DNA from human adenoviruses to activate the kinase.

Adenoviruses, which cause cold-like symptoms in people, contain a linear DNA molecule with a protein attached at each end. Unlike DNA from a cell, adenovirus DNA can be easily extracted and manipulated in the laboratory without being broken.

Our researchers found that adenovirus DNA is a poor activator of DNA-PK, compared to cellular DNA, until it is broken; but when cut only a few times, adenovirus DNA becomes just as effective an activator as the broken cell DNA. This result suggests that one function of DNA-PK may be to recognize damaged DNA in a cell.

Easily damaged, DNA is especially sensitive to radiation and chemicals. For a cell to survive, its DNA molecules must be kept intact and unchanged. Activation of DNA-PK by damaged DNA may broadcast an alarm that activates enzymes that repair DNA. At the same time, DNA-PK may inhibit other enzymes, thus preventing cell growth and further damage until repairs are complete. This coordination of repair and growth activities is vital for cell survival, and a task for which a DNA-activated protein kinase is well-suited.



Purified DNA-PK attaches phosphates to hsp90, a human stress response protein, and p53, a cell growth control protein. Radioactive phosphate transferred to each protein was detected after separating the proteins according to their size by gel electrophoresis.

To investigate the properties of the protein kinase DNA-PK, (front to back) Susan Lees-Miller and Carl Anderson load the amino acid analyzer while Nicholas Alanzo and Sydell Lamb check the protein sequencer in the Biology Department's protein chemistry laboratory.

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

The Reactor Division operates one of the world's leading research reactors, the High Flux Beam Reactor (HFBR), as well as the Brookhaven Medical Research Reactor. The HFBR's intense beams of neutrons support experiments in nuclear and solid state physics, metallurgy, nuclear and structural chemistry, and biology. The tradition of outstanding research carried out at the HFBR by Brookhaven staff as well as an international community of scientists includes award-winning investigations into such topics as the structure and behavior of metals and ceramics, and high-temperature superconductor systems.

A NEW BEGINNING FOR THE HFBR

After a two-year shutdown to assess the safety of Brookhaven's High Flux Beam Reactor (HFBR), the world-class research reactor resumed operations in May 1991.

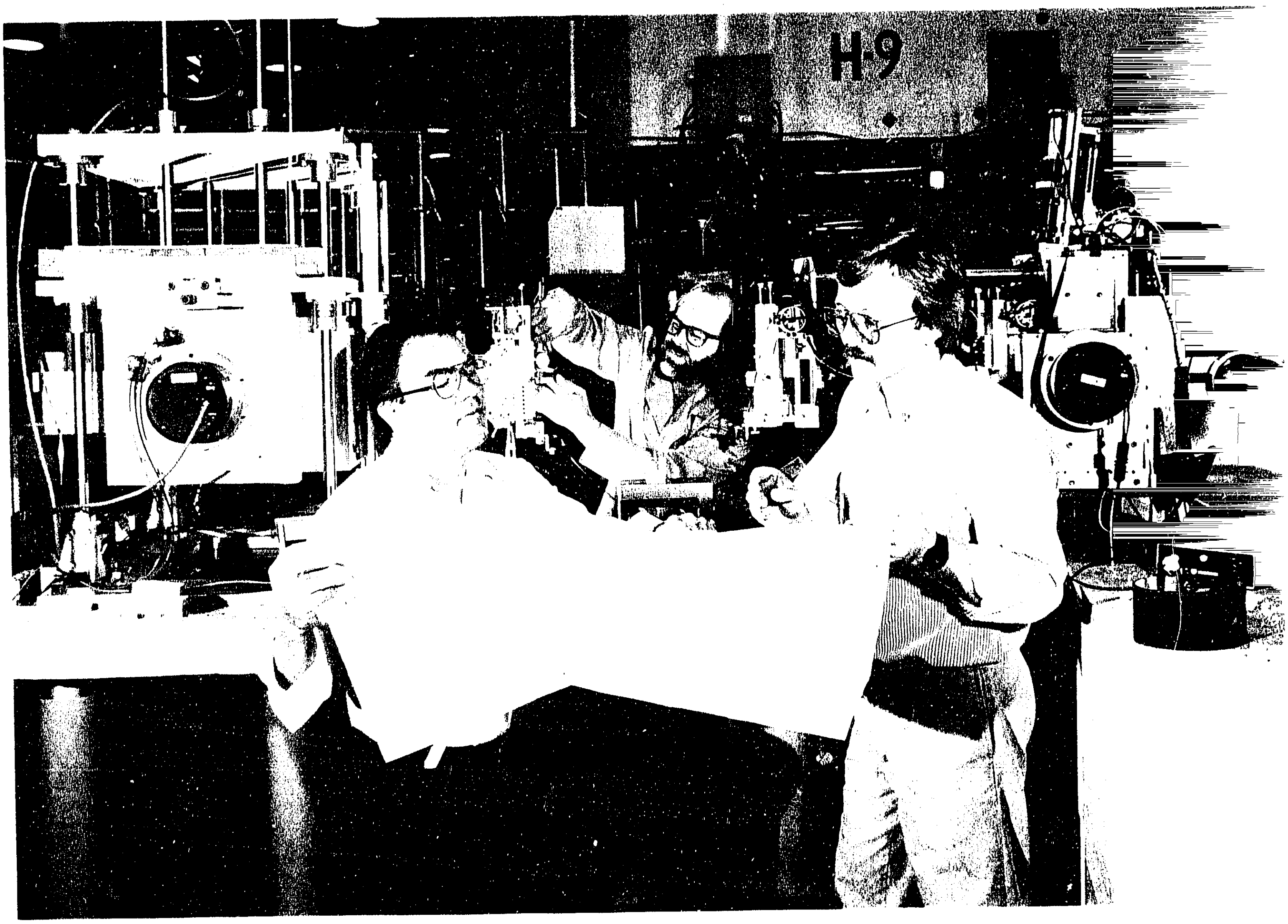
Researchers have now begun work on a backlog of neutron-based experiments that require the reactor's capabilities. Over the next year, as many as 250 scientists will use the reactor for research in solid-state and nuclear physics, chemistry and structural biology.

SAFETY REVIEWS

The HFBR began operations in 1965, and it achieved full operating power of 40 megawatts (MW) early in 1966. In 1982, the power level was increased to 60 MW, which produced a 50 percent increase in neutrons for experiments.

In 1988, the National Academy of Sciences' National Research Council issued a report on safety issues at five of the U.S. Department of Energy's (DOE) test and research reactors. Regarding the HFBR, the report's authors noted that a significant change in safety philosophy had occurred when reactor power was increased from 40 to 60 MW, since about one percent of the fuel could be damaged during a worst-case loss of coolant accident (LOCA) at 60 MW, while no fuel damage was postulated at the 40-MW operation.

• Following the report's recommendations, BNL launched an investiga-



At the High Flux Beam Reactor, (from left) Frank Langdon, Richard Rothe Jr. and Michael Taylor check the instrument parameters of the new neutron reflectometer.

tion into potential radiation exposures to reactor operators during postulated LOCAs. Our analysis indicated that, if a LOCA occurred at 60 MW, and the reactor fuel were damaged, it could result in unacceptably high levels of radiation exposure to reactor operators.

At the time of the investigation, the reactor had been shut down for routine maintenance. Subsequently, DOE notified the Laboratory to delay its restart until these safety issues could be resolved.

Consequently, comprehensive reviews were conducted by a number of teams, including DOE's Advisory Committee for Nuclear Facility Safety; Ames Laboratory Committee; Office of Energy Research Review, performed by Burns and Roe Utility Management Consultants for DOE; Office of Nuclear Safety, DOE; and Office of Nuclear Energy Independent Oversight, DOE.

After thorough investigations into safety, reactor management and training, the consensus to restart operations at the HFBR was unanimous.

A FRESH START

Currently, the HFBR has been cleared for operation at a power of up to 35.4 MW, but the Laboratory opted to begin operations at a conservative 30 MW. Additional analyses and thermal hydraulic tests are being done to support a return to 60 MW in the future.

Several modifications have been made as a result of the two-year

John Tranquada (foreground) checks data in an experiment on superconducting copper-oxide compounds at the High Flux Beam Reactor while Peter Gehring makes an adjustment to a neutron spectrometer.

safety review. For example, some valve controls were relocated, more readouts were installed to measure the reactor vessel's water level, and the pump shutdown function was automated — all to shorten the amount of time it would take for an operator to respond to a LOCA. In addition, since two certified reactor operators are now required in the HFBR control room when the reactor is operating, more staff has been hired, and the operator training program has been extended and enhanced.

A VARIETY OF RESEARCH

The HFBR is the only reactor in the U.S. designed specifically for neutron beam research and the only one equipped with a liquid hydrogen moderator for the production of low-energy "cold" neutrons. Scientists in many fields have used these neutrons to probe matter on the nuclear, atomic and molecular levels. Also, the HFBR's polarized neutrons are used to study the magnetic properties of materials.

Research at the HFBR frequently complements studies performed at BNL's National Synchrotron Light Source, where scientists use x-rays to probe materials. Neutron diffraction provides researchers with structural and chemical information about the material under study that is not available through x-ray probes. For example, the placement of hydrogen atoms in a material cannot be satisfactorily determined by x-ray diffraction, but only through neutron diffraction.

Current studies include investigating the structure of human viruses and cyclosporin and other anti-rejection drugs; probing the nature of high-temperature superconducting materials (see sidebar); and examining catalysts, such as zeolites, which are important to the petroleum industry. In addition, experiments now under way to understand the interactions between oil and water may lead to practical applications, such as improved oil recovery methods and new, more effective ways to clean up oil spills.

NEW INSTRUMENTATION

Two new instruments — a neutron reflectometer and a high-resolution powder diffractometer — will broaden the scope of research at the HFBR.

The neutron reflectometer, which began operating this year, is used to investigate the structural properties of surfaces. This device measures the fraction of neutrons reflected at small angles from the surface of a material. The pattern of reflected neutrons provides researchers with structural and chemical information about the material under study.

For example, one practical use of the new reflectometer might be in formulating new blends of plastics for easy recycling. Certain plastics cannot be recycled because they are chemically incompatible. But with the aid of the new instrument, researchers can determine the exact chemical differences between them, which could lead to the design of new plastics with properties that mix easily for recycling.

The high-resolution powder diffractometer, now under construction, will enable researchers to study the structure of polycrystalline materials in more detail than ever before possible in the U.S. The only comparable instrument is located at the Institute Laue-Langevin in Grenoble, France. Many large U.S. companies and institutions, such as Du Pont, Georgia Institute of Technology, IBM, the National Institute of Standards and Technology and the State University of New York at Stony Brook, have joined in a Participating Research Team to perform research with this unique tool.

Powder diffraction studies have proven to be of particular importance in determining the crystal structures of high-temperature superconductors. Besides providing a better understanding of existing crystalline materials, other newly discovered materials with potentially useful electrical, magnetic or chemical properties can be quickly identified using this state-of-the-art instrument.

Probing the Secrets of Superconductivity

The first high-temperature superconductor — a compound of barium, lanthanum and copper-oxide known as Zurich-oxide — was discovered at an IBM laboratory in Zurich in 1986. That discovery has inspired an intense, worldwide search for new and better superconductors, largely motivated by the promise of important technological applications for these materials. But copper-oxide superconductors are also fascinating to physicists because the occurrence of superconductivity is so surprising in these materials — normally poor electrical conductors that can easily be transformed into insulators.

Superconductivity is a phenomenon in which certain metals and alloys lose their electrical resistance, thus becoming perfect conductors below a certain transition temperature (T_c). The pre-1986 record transition temperature of 23 kelvins (−418°C) has now been increased to 125 kelvins (−234°C) in a copper-oxide compound that also contains thallium, barium and calcium. The new T_c record is well above the temperature of liquid nitrogen, a commonly used coolant, which could mean considerable savings in refrigeration costs for commercial applications of these materials.

Many theorists have suggested that unusual magnetic properties play an important role in high T_c superconductivity, and BNL researchers are now exploring that possibility at the High Flux Beam Reactor (HFBR).

Whether certain copper-oxide compounds are superconducting depends on slight differences in their chemical composition. Magnetic moments also appear to be an important aspect of superconductivity in these compounds. The magnetic moment of an atom is a measure of the strength of its interaction with a magnetic field. The moment of any magnet also has a direction associated with the orientation of its poles.

In their insulating state, copper atoms have magnetic moments that align themselves in an antiparallel fashion known as antiferromagnetism. When the composition of a sample is changed to produce superconductivity, the static ordering of the magnetic moments disappears. Nevertheless, neighboring magnetic moments, though fluctuating, try to remain antiparallel.

Neutrons are an ideal probe for studying both the static and dynamic magnetism in these systems. Because a neutron possesses a magnetic moment, it can scatter from the magnetic moments of atoms in a crystal. Also, the exchange of energy between a neutron and magnetic fluctuations provides information about the dynamics of magnetism.

In collaboration with researchers from Massachusetts Institute of Technology and from Nagoya and Tohoku Universities in Japan, BNL physicists have been performing neutron-scattering experiments at the HFBR to characterize the magnetism in several copper-oxide superconductor systems. The continuing success of these studies, which are crucial to understanding the relationship between magnetism and superconductivity in these materials, is due in large part to the ability of the university collaborators to grow large single crystals of lanthanum strontium copper-oxide and yttrium barium copper-oxide.

Safety and Environmental Protection Division

The Safety and Environmental Protection Division provides technical support and appraisal in the areas of environment, safety and health. As described in the following article, this includes monitoring the BNL workplace for possible chemical, physical and radiological hazards, as well as surveying the environment. The division also manages the Radiological Assistance Program, which can respond to any type of radiation incident in the Northeast. In addition, it is responsible for developing and maintaining instruments for radiation monitoring and industrial hygiene surveys. Further, the division provides support for on-site construction safety and conducts safety reviews of new and modified facilities.

Guarding the Environment

Clean air. Pure water. These natural commodities are free, abundant and taken for granted by many people. To keep it that way, Brookhaven keeps careful watch over the effects of our operations on the environment through an extensive monitoring program.

BNL's monitoring program began when the Laboratory first opened in 1947. Since then, environmental standards set by government agencies have become much stricter, and in response, the Laboratory has lowered its emissions to air and water and improved its monitoring techniques and capabilities. The results of BNL's monitoring were reported periodically during the first 20 years of operation and annually since 1971.

Today, the Laboratory's environmental monitoring program is carried out by a staff of 20 in the Safety and Environmental Protection Division. Our aim is to ensure that all BNL operations are conducted safely, in compliance with applicable regulations and with minimum risk to the environment. The program extensively monitors the air and water on site and assesses the impact of BNL operations on the local groundwater and the Peconic River. Also, soil, vegetation and wild

Anette Meier and Richard Lagattolla measure temperature, acidity, alkalinity and conductivity in the groundwater at one of the Safety and Environmental Protection Division's monitoring wells. Later they will collect samples for laboratory analysis.

game on site are monitored periodically.

EFFLUENT MONITORING

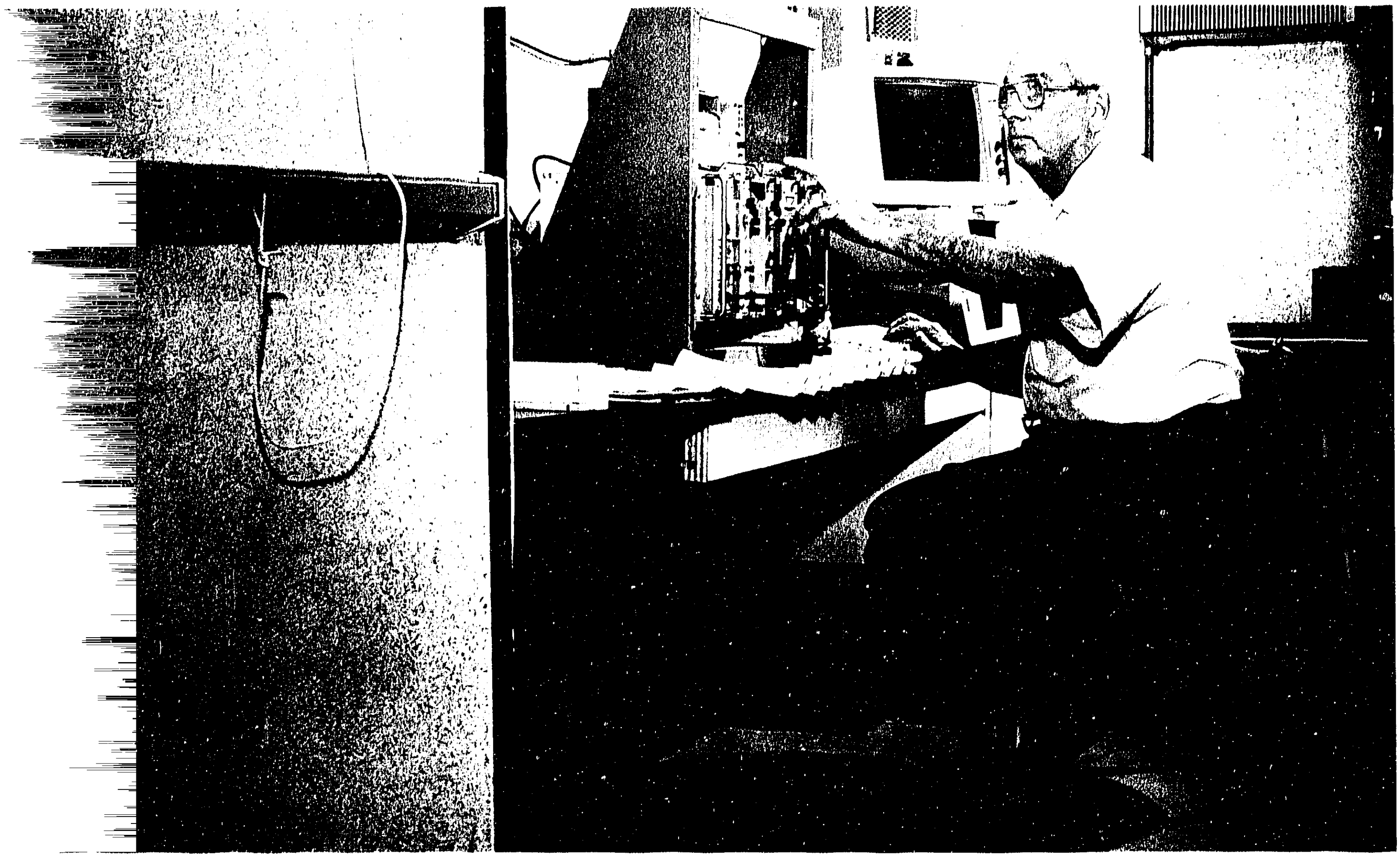
Effluents are emissions released into the air or water that are the byproducts of industrial, scientific or residential activities.

At BNL, effluents are monitored before they are released into the environment, or just at the point of release, using state-of-the-art technology.

Effluent air monitoring is conducted at seven facilities. At the Central Steam Facility, the source of steam for the Laboratory's heating and air-conditioning requirements, sulfur and nitrogen emissions are monitored to ensure that emission rates meet the New York State air permit release criteria.

At Brookhaven's Inhalation Toxicology Facility, health effects of industrial and environmental pollutants are tested. To be sure the effluents released from the facility are safe, they are continuously monitored and the effluent is filtered using carbon and high-efficiency particulate filtration systems.

Monitoring for radioactive airborne emissions is conducted at five locations on site: the High Flux Beam Reactor, the Brookhaven Linac Isotope Producer, the Tandem Van de Graaff Facility, the Chemistry Building and the Hot Laboratory. The monitoring systems are typically composed of particulate filters, charcoal filters and silica



Joseph Stelmers calibrates a sewer radiation monitor. The device is used to check the Laboratory's sanitary waste stream for radionuclides.

gel (dessicant) cartridges that permit the detection of radioactive emissions in the picocurie-per-cubic-meter range — several times more sensitive than required.

Liquid effluent from the Laboratory's Sewage Treatment Plant, located some one-and-a-half miles away from central BNL facilities, is monitored around the clock for radioactivity. Acidity levels and the conductivity of the liquid effluent — indicators of chemical pollutants — are also monitored constantly.

The plant's monitors are connected to a computerized alarm system that alerts appropriate personnel if any pollutants are present at unacceptable concentrations. This station provides an hour's warning — enough time for personnel to divert the liquid effluent to a lined holding pond before it reaches the Peconic River.

Acidity, conductivity and radioactivity are also continuously monitored at the center of the Laboratory site. These monitors are also attached to the computerized alarm system.

Besides on-line monitoring, flow-proportional sampling at the Sewage Treatment Plant is used to obtain measurements for radioactivity and substances such as lead, silver, mercury, copper, nitrates, sulfates, phosphates, iron, copper and sodium. Periodic sampling is used to look for organic contaminants and to determine coliform concentrations.

ENVIRONMENTAL MONITORING

In contrast to effluent monitoring, environmental monitoring takes place away from the point of release of any potential pollutants. The Laboratory has many locations both on site and off site where environmental monitoring is performed.

Air monitoring for radioactivity is performed at 16 site perimeter locations on a weekly to monthly basis. At the site boundary, the predicted radiation dose from air emissions is typically less than 0.1 millirem per person per year — 100 times lower than the maximum allowable dose specified by the Environmental Protection Agency for airborne effluents.

Off-site communities are monitored for exposure to airborne radiation four times per year at 60 locations throughout Suffolk County. The monitoring sites are located in concentric circles around the Laboratory at radii of approximately 2 miles, 5 miles and 10 miles. The average annual dose from naturally occurring radiation in this area is 60 millirem, and our measurements show no measured contribution from Laboratory operations.

Since the Laboratory is located directly over Long Island's sole source aquifer, we are constantly vigilant of the cleanliness and quality of local goundwater.

Two extensive programs are in place to monitor groundwater on a quarterly basis: on site, at about 125 wells, and off site, in cooperation with the Suffolk County Department of Health, at 16 to 20 homes, all within a half-mile of BNL's boundary. This monitoring is done to gauge water quality and concentrations of radioactivity, metals and volatile organics.

The water in the Peconic River is also monitored quarterly at six locations for the same potential pollutants. BNL's compliance with effluent standards for discharge to the Peconic River has been greater than 99 percent. The one percent exception has typically been due to high acidity, equivalent to the acidity of natural precipitation here on Long Island.

In another program performed in cooperation with the New York State Department of Environmental Conservation, fish in the Peconic River are analyzed for traces of radioactivity. Radiation measurements in the fish have consistently been found to be well within governmental guidelines for human consumption.

In conjunction with the Suffolk County Department of Health, surface soils and vegetation at local farms are monitored for radioactivity.

The advancement of science is the Laboratory's mission, but preserving a clean environment is its mandate. Our extensive monitoring program attests to BNL's concern for keeping the environment safe for our staff, our neighbors, and Long Island's future.

INSTRUMENTATION DIVISION

Inventing and developing new tools and methods to make high-precision measurements for various types of scientific research 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. The division concentrates on providing unique solutions to specific problems in experiments at Brookhaven's major research facilities. The division's expertise also provides the Laboratory with special services in vacuum-deposition technology, optics metrology, electron microscopy and printed circuit board fabrication.

BROOKHAVEN'S SILICON JUNCTION

For some years, California has had its Silicon Valley, where breakthrough computer technology is largely founded on the amazingly "user-friendly" properties of silicon.

And at Brookhaven, we have what might be called Silicon Junction, where a group of scientists in the Instrumentation Division use these same properties and techniques to build silicon junction detectors — state-of-the-art detectors tailored individually to particular experiments in high energy particle physics research and other specialized applications.

In this research, many current experiments involve either fixed targets or colliding beams of particles. To be successful, such experiments depend on very precise identification of the particles and their pathways. Detectors are devices that collect this information, allowing scientists to sort out the new and exciting events the particles signal as they emerge from the target region.

Silicon junction detectors have been used for many years — the term "junction" referring to the boundary, or junction between two types of silicon in the wafers required to produce the electric field in the device.

Silicon has particularly good chemistry for making devices because a clean, tenacious oxide can be grown on its crystal surface, forming a robust coating on which features can be inscribed micropho-

Wei Chen (front) is gowning up to join Rolf Beuttenmuller for work in the clean room, where dust particles are kept to about 100 particles per cubic foot of air.

tographically. The oxide gives the protection of an impervious edge to the smallest features engraved on it.

As experimenters require more and more precise measurements on a very small scale, the technology of microcircuits has been applied to silicon junction detectors. They now have a secure place in the field of "position-sensitive" detectors — sensitive to the position and time of a particle passing through them. Structures that are sensitive to an incident particle can be built in the detector at the micron size — a micron being only one-fiftieth the size of a human hair. So tiny silicon detectors can be placed at the heart of an experiment, very close to the collision, without crowding other parts of the apparatus.

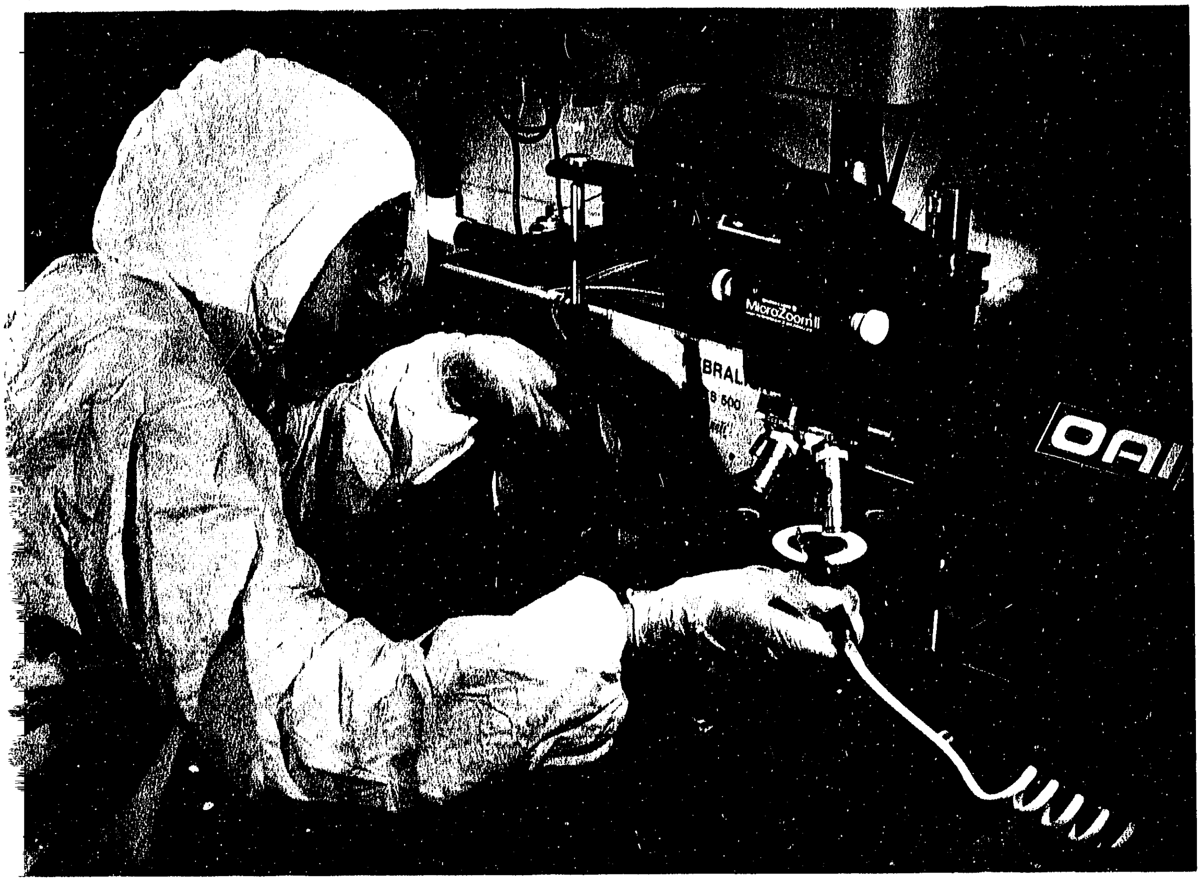
STRIPS AND PADS

Because their expertise results in adaptability and quick turnaround time, our scientists are in demand to make a variety of silicon detectors. For example, they make strip detectors and pad detectors, each destined for a specific role in an experiment.

A strip detector is formed of a wafer of silicon covered with many narrow, charge-collecting electrodes in the shape of strips. Each strip or junction contact is an active sensor and may be only 20 microns wide by about 7.6 centimeters — the diameter of the silicon wafer on which it is made.

As a high-energy particle passes through the detector, the strip electrode collects the resulting electric charge in the wafer directly underneath it. A "track" of a particle is defined by straight-line patterns in the hits on a series of strip detectors placed around the target area. Because the strips are so finely spaced, an extremely accurate positioning of the particle is assured.

Another type of multijunction silicon detector made at Brookhaven is a "pad" detector. Formed on a single wafer of silicon, the detector has up to 512 larger areas — some up



Wei Chen is engrossed in photolithography, a critical step in the micron detector process.

RESEARCH DIVISIONS

to one square centimeter — arranged over the wafer face. Position sensing is only part of the function of pad detectors; they are often used to measure the number of particles produced in the event in addition to their distribution.

These kinds of data can be rapidly analyzed to determine — within a millionth of a second — if the event is of real interest and should be saved for further analysis. If it is not, all those data can be discarded, saving precious computer space and time.

THE BROOKHAVEN DRIFT DETECTOR

The most complicated silicon device yet produced by the Brookhaven instrumentation scientists is called the silicon drift chamber. Invented by a Brookhaven scientist in collaboration with a researcher from the Polytechnical University of Milan, Italy, this detector provides very high spatial resolution.

In a complete departure from tradition, this particular detector uses a new geometric arrangement of electrodes that allows the electric charges caused by particles passing through the wafer to be collected laterally.

To make this drift detector, an electrode structure was built on both sides of a wafer of silicon, establishing a uniform electric field with a collecting anode at the center or on the edge of the detector area. When a particle hits the wafer, the field pulls the particle's electric charges to the collecting anode at a constant velocity. The time taken for the charge to "drift" to the center from the instant of impact shows the particle's position when it hit the wafer.

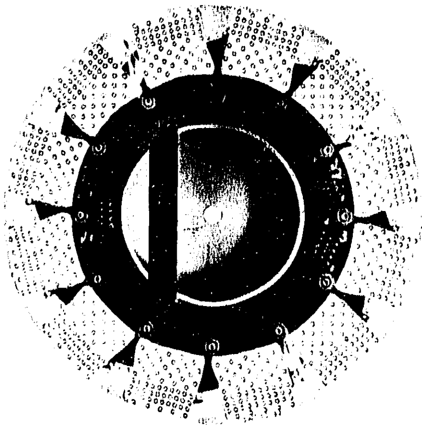
Another advantage of this configuration of electrodes is that it has very low background electrical noise and therefore is sensitive even to very small signals.

A circular device based on this Brookhaven invention was processed in the Instrumentation Division, mounted in the Physics Department, and it is now taking data in the NA45 experiment at CERN, the European particle physics research laboratory. Several applications of it are planned for BNL's Relativistic Heavy Ion Collider, now under construction, and, in addition, it has a bright future as an x-ray detector at the National Synchrotron Light Source.

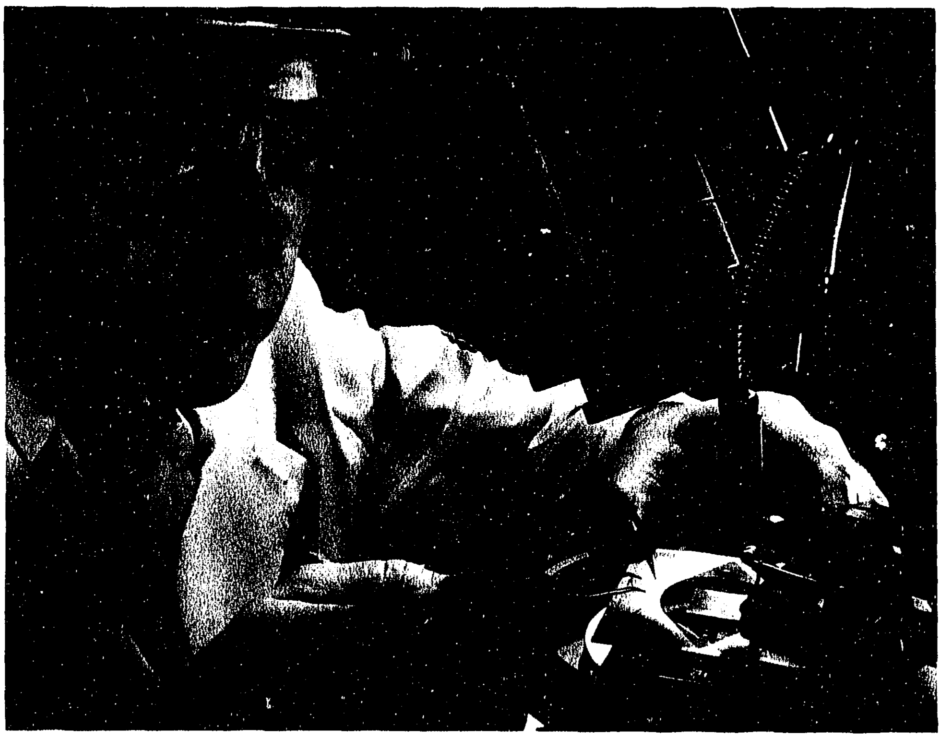
DETECTING ON ANOTHER TRACK

In addition to making silicon detectors, Instrumentation Division scientists study radiation effects on typical detectors and detector electronics. For example, at the future largest proton colliding-beam accelerator — the Superconducting Super Collider (SSC) in Texas — very high numbers of particles are expected to be produced. The SSC experiments will use silicon tracking detectors close to the colliding region — but a serious radiation damage problem is anticipated.

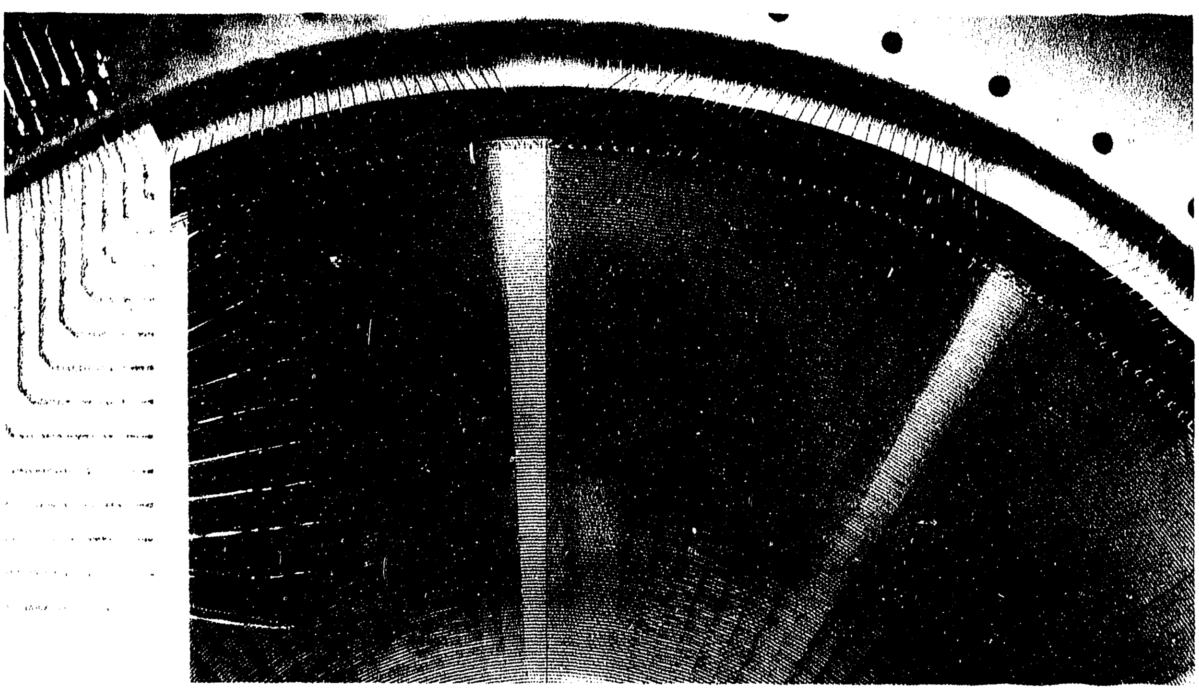
Brookhaven's instrumentation scientists are testing various devices in conditions that simulate the expected SSC conditions. Once they have traced potential effects in some detail, they will investigate ways to prevent or lessen these effects.



The Brookhaven-made silicon drift chamber invented by Pavel Rehak, BNL, and Emilio Gatti, Polytechnical University of Milan. In the center is a 7.6 centimeter-in-diameter silicon wafer.



Using wire about one-third as thick as a human hair, Rolf Beuttenmuller wire-bonds a wafer that will connect a detector to its external electronics.



A magnification of small features and interconnections of the silicon drift chamber, showing the wire bonds.

Computing and Communications Division

Vital to Brookhaven's scientific programs, computing and communications technologies are the responsibility of the Computing and Communications Division. The division plans and develops future data-processing facilities and tools; operates the Laboratory's major central computers and communications networks, including the telephone system; assists in all areas of programming; provides computer systems maintenance services; and supports scientific and engineering computer workstations for different applications, such as computer-aided design and manufacturing systems. In a recent program, the division is investigating and acquiring devices to alleviate communication problems for the hearing-impaired at Brookhaven.

Hearing by Eye

In summer 1991, a telecommunications device for the deaf was installed by the Computing and Communications Division (CCD) with the Brookhaven telephone operators.

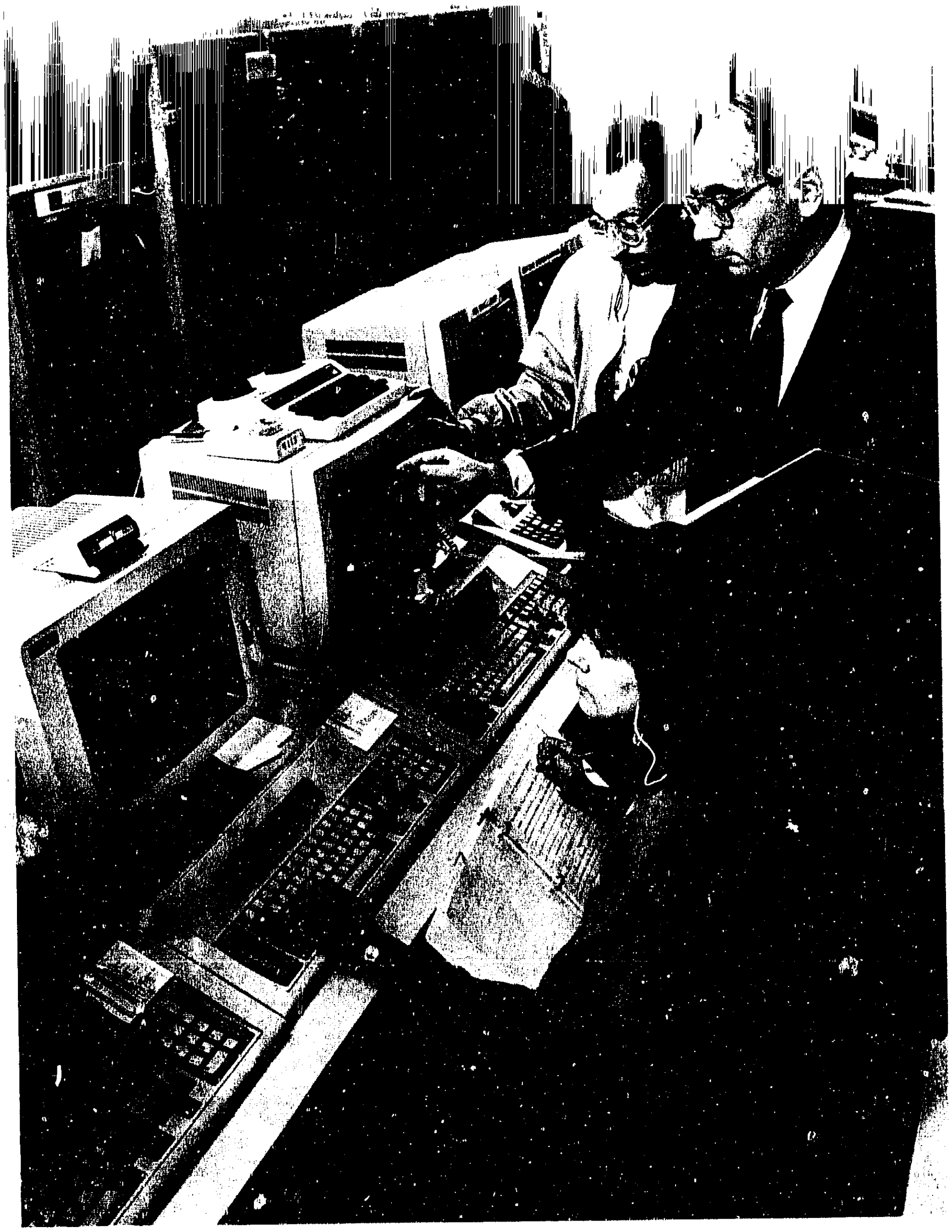
This teletypewriter-like device allows any hearing-impaired person who has access to the device, whether on or off the Laboratory site, to communicate with a Brookhaven operator.

The facility is expected to be used primarily to provide information to callers, who then could be instructed to dial other lines equipped with the telecommunications device. The device will be listed in the next issue of the Suffolk County edition of the New York Telephone Directory.

Not only this device, but others that can help alleviate problems for the hearing-impaired are being investigated and acquired at Brookhaven by CCD.

As another example, most fire alarms give warning by sound. But devices are now in use at Brookhaven that vibrate at the ring of a fire alarm, thus using touch, not sound, to alert the hearing-impaired person carrying the device.

CCD's interest in identifying and using technology and tools for the deaf was initially the result of hiring four hearing-impaired staff members. The success of these employees both in operating and programming computers encouraged the division to overcome as



At the Central Scientific Computing Facility with Arnold Peskin (right) are Christine Kaufmann and Enrique Garcia, two of the hearing-impaired staff members of the Computing and Communications Division.

many of their special problems as possible.

To this end, a Gallaudet University professor was invited to spend the summer at Brookhaven, to collaborate with CCD staff in meetings and informal discussions. Gallaudet is one of the foremost institutions in education of the deaf and offers degree programs for hearing-impaired students. On the agenda were topics such as identifying new ways to use technology, computer programs to assist communication, and a resource database that might include a list of deaf aids recently tested and a list of hearing-impaired persons in different fields.

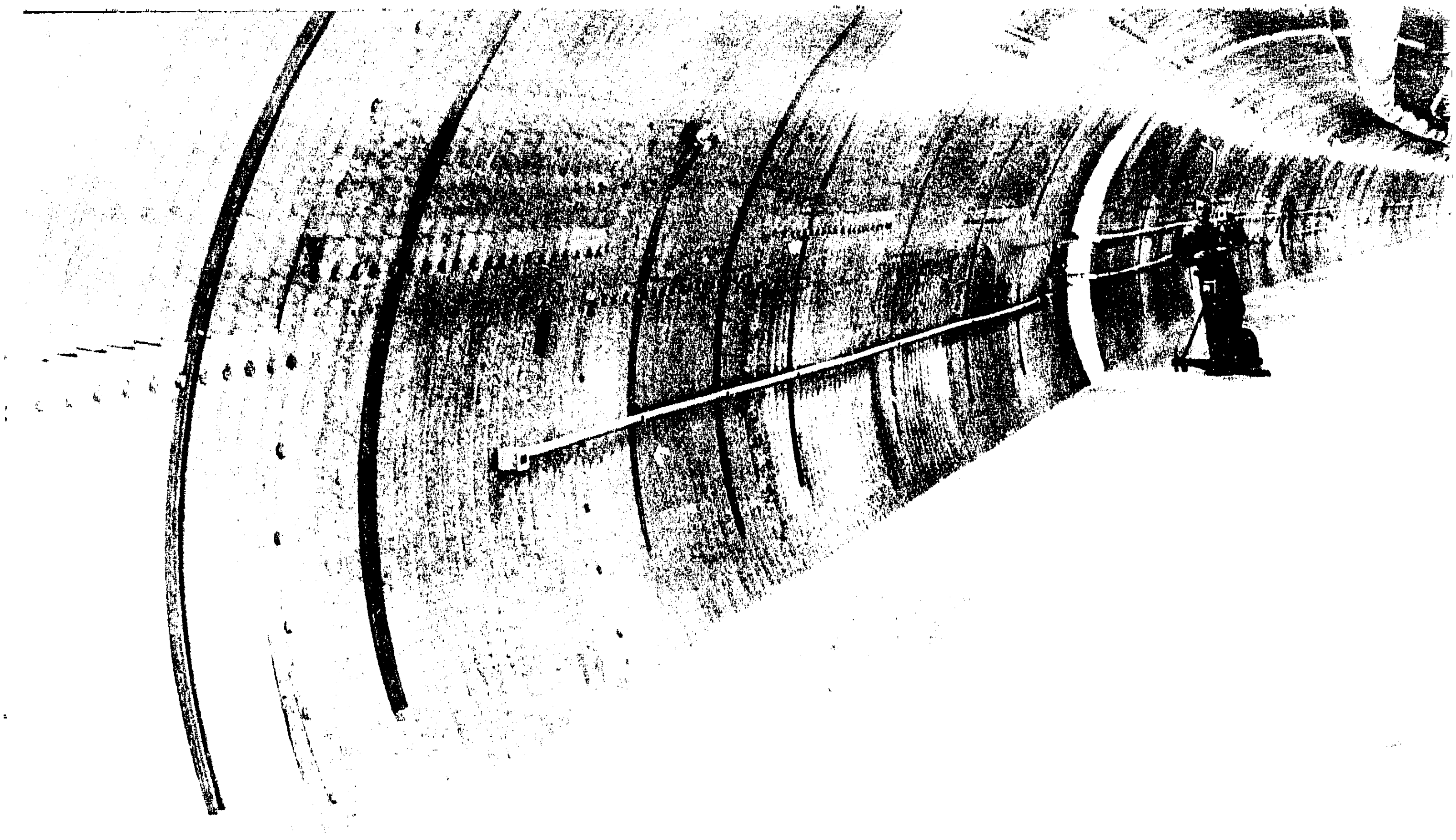
Hearing-impaired people may be at a disadvantage in other, more subtle situations. For instance, picking up the style of informal, written communications that would normally contain colloquial speech is harder for a deaf person and may result in misunderstanding. Attending a workshop for professional advancement may be much less valuable without an interpreter skilled in both sign language and computer technology.

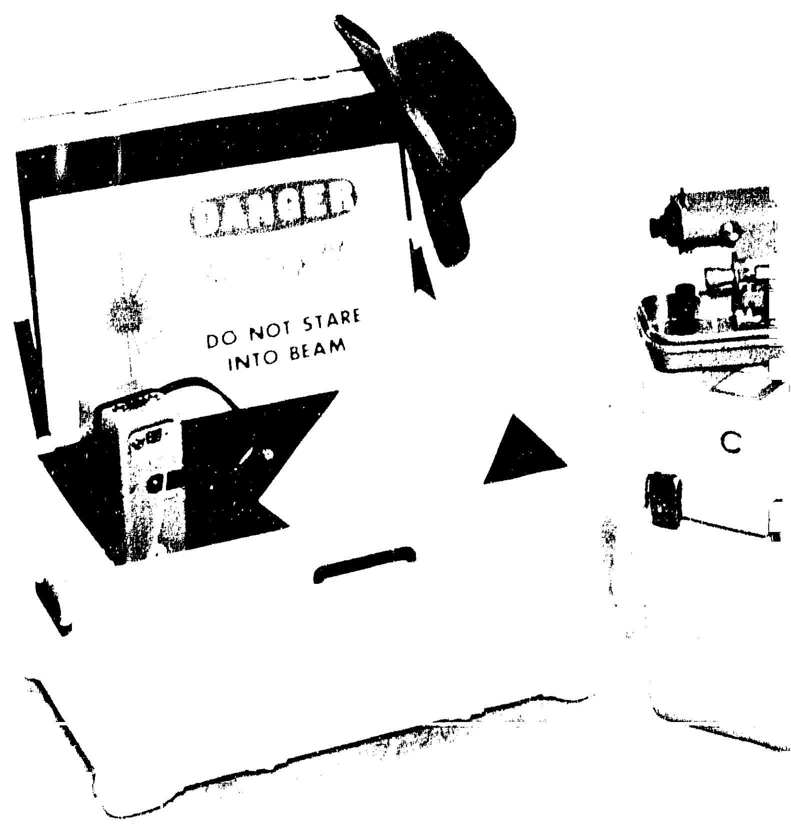
In CCD these considerations have been directed towards finding ways in which computers and technology can lessen the difficulties of the deaf. But perhaps the deaf can help advance computer technology.

A challenge being investigated at CCD is to look at the ways deaf people use visual means to communicate, to see if they are relevant in improving computer performance. For example, can analyzing the symbols of sign language give new ideas to computer program writers looking for a new, quick way to communicate from a screen?

Another possibility might be that the spatial, three-dimensional aspect of sign language could have implications for parallel processing, a system in which several computers are used simultaneously to solve parts of the same mathematical problem.

The adventure and originality implicit in these ideas bode well for the future. In the meantime, CCD's commitment to exploring practical improvements for professional computer staff who are hearing-impaired is very much in the present.




DO NOT STARE
INTO BEAM

LABORATORY PROFILE

The following pages summarize activities that have taken place at the Laboratory during fiscal year 1991. 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

At the National Synchrotron Light Source, AT&T physicist David Adler shows a model of a "buckyball," a new form of carbon not yet seen in nature, to some of the executives and educators who came to BNL on July 8, as part of the U.S. Department of Energy program to foster science and math education in the U.S.

This small survey of the many conferences, meetings, workshops and symposia held at Brookhaven during the course of 1991 reflects the broad range of subjects that are studied and discussed daily at our multidisciplinary laboratory.

A major step towards full-scale, industrial production of superconducting magnets for BNL's Relativistic Heavy Ion Collider (RHIC) took place November 13-15, when 83 representatives of 33 companies gathered at Brookhaven for the **RHIC Magnet Industrialization Program.**

To predict the consequences of the buildup of carbon dioxide in the earth's atmosphere, researchers from around the world have written a variety of computer models simulating processes that control the earth's climate. At the **Fourth Annual Climate Model Intercomparison Workshop,** held December 3-4, an international group of participants compared model variations resulting from differing methods of modeling ice and snow.

The semiannual business meeting of the northeast region of the **Federal Laboratory Consortium** was held at BNL January 9-10. A national network of technology transfer representatives from about

600 federal laboratories, the consortium was established in 1974 to facilitate the transfer of federally owned technology to state and local governments and to industry.

Research at BNL's High Flux Beam Reactor (HFBR) conducted under the sponsorship of the U.S.-Japan Cooperative Program on Neutron Scattering was discussed in a workshop on **Neutron Studies of Martensitic Phenomena,** held March 14-16. The 10-year-old program revolves around a neutron triple-axis spectrometer that began operating at the HFBR in 1985, resulting so far in over 120 publications.

Over 100 users of BNL's Alternating Gradient Synchrotron (AGS) were in attendance March 20-21 for the **AGS Users' Group Annual Meeting,** which focused on the current and future AGS physics program, as well as the status of two accelerators to which the AGS is closely linked — the Booster and RHIC.

A **Workshop on Lead: Metabolism and Bone Deposition** was held April 10-12, to review the current understanding of how lead is absorbed by bone cells and where in bone tissue lead is deposited, with the aim of applying this knowledge to the design of safe, effective and economical instruments for measuring lead concentration in humans and developing improved treatments for removing lead from the body.

High school science and mathematics instructors — 120 strong — came to the Laboratory on March 28 to participate in a **Teacher In-Service Day** provided by the Tour Program of the Public Affairs Office.

Some 2,600 researchers performed experiments at the National Synchrotron Light Source (NSLS) last year. Some 380 of them attended both the **1991 Annual NSLS Users' Meeting** on May 22, and the five workshops held the day before on specific topics.

In addition to being the home laboratory of the coinventors of magnetically levitated (Maglev) transportation, BNL is a player in the National Maglev Initiative. As part of this involvement, the Laboratory cosponsored a two-day **Workshop on Technology Issues of Superconducting Maglev Transportation Systems,** May 23-24.

Oceanographers have focused increasingly on how elements such as carbon, nitrogen, sulfur, oxygen, phosphorous and silicon are cycled in the ocean, and how the cycles affect each other and the earth's atmosphere and climate. To discuss progress in understanding the "Primary Productivity and Biogeochemical Cycles in the Sea," 200 oceanographers from all over the world gathered at **BNL Symposia in Biology No. 37,** held June 2-6.

The United States and the Soviet Union updated each other on their respective neutron-scattering facilities and exchanged ideas for future collaborations during the **U.S.-U.S.S.R. Workshop on Neutron Scattering,** held June 18-20. Informal agreements were discussed in which the Soviets offered their ideas in exchange for shared beam time at U.S. neutron-scattering facilities.

On the Lecture Circuit

Hundreds of lectures and seminars are sponsored annually by the Laboratory's various departments. Additionally, under the aegis of several special programs, a number of other speakers come to Brookhaven throughout the year

- ***AUI Distinguished Lectures*** — Addressing topics of general interest in this lecture series were oil-industry scientific advisor Morrel Cohen, energy conservation and efficiency specialist Arthur Rosenfeld, Soviet space science expert Roald Sagdeev, science historian and author Spencer Weart, and earthquake authority Lynn Sykes.
- ***Brookhaven Lectures*** — BNL's multidisciplinary approach to research was underscored by the ten lecturers in this series, who shared details of developments in their various fields of science with the rest of the Laboratory community.

The speakers were: John Haggerty, Physics Department, rare kaon decay; Richard Hahn, Chemistry Department, solar neutrinos; Bernard Manowitz, Department of Applied Science, global climate change; Leonard Mausner, Medical Department, reducing bone pain in cancer patients using radioactive tin; Trevor Pratt, Department of Nuclear Energy, containing severe accidents in nuclear power plants; Graham Smith, Instrumentation Division, gas proportional detectors; Myron Strongin, Physics, surface properties; Robert Sweet, Biology Department, protein structure; William Thomlinson, National Synchrotron Light Source Department, coronary angiography; and David Weber, Medical Department, single photon emission computed tomography.

- ***Brookhaven Women in Science Seminars*** — In this series, lecturers were: physics professor Faye Ajzenberg-Selove, medical director Teri Pearlstein, National Weather Service Eastern Region Director Susan Zevin, and plant molecular biologist Nina Fedoroff.
- ***Haworth Lectures*** — Haworth Distinguished Scientists give several lectures during the time spent in residence at BNL under appointments established in memory of BNL's second director Leland J. Haworth. Lecturers this year included science and technology analyst Harvey Brooks, Nobel laureate and theoretical physicist T.D. Lee, and plasma physics and accelerator physics expert Andrew Sessler.
- ***Van Slyke Lectures*** — Pediatrician and cancer researcher Alfred Knudson Jr. spoke this year under this program, established in honor of the late BNL biological chemist Donald Van Slyke.

Maurice Goldhaber accepts the Wolf Prize in Physics for 1991 from Chaim Herzog, President of Israel, in May at the Knesset in Jerusalem. To Herzog's left are Israel's Minister of Education Zevulun Hammer and Prime Minister Yitzhak Shamir.

The **Brookhaven Bulletin** won an Award of Achievement in the 1991 Publications and Art Competition of the New York Chapter of the Society for Technical Communications.

Dean Chapman, Stephen Cramer, Chi-Chang Kao and Gwyn Williams (National Synchrotron Light Source) and **David Weber** (Medical) received plaques signed by U.S. Department of Energy (DOE) Secretary James Watkins in October 1990, for supporting the 1990 High School Honors Research Program by heading teams that guided students through research experiments. Several plaques were also presented to various BNL groups to acknowledge their contributions.

Jeffrey Coderre (Medical) was honored with an Award for Excellence in Research by the Sidney Melanoma Foundation in December 1990, in recognition of early success in his young career as a biochemist in the field of experimental radiotherapy.

The **Combustion Equipment Technology Program** within the Department of Applied Science was recognized with a 1991 Research & Development Award of the National Energy Resources Organization in May 1991, for its research that significantly impacts the production or conservation of energy.

Mark Culp (Plant Engineering) won an Outstanding Individual

Effort Award from the DOE In-House Energy Management Program for saving BNL an estimated $4,650,000 in electricity charges. Presented in October 1990, the award recognizes Culp's "ongoing and superior accomplishments in energy management as Chairman of the Demand Coordination Committee at the Brookhaven National Laboratory."

Gordon Danby (Alternating Gradient Synchrotron) and **James Powell** (Nuclear Energy) were twice recognized for their co-invention of the concept of Maglev — magnetically levitated transportation. In March, they each received a 1991 Tech Island Award from the Long Island Forum for Technology, "for advancing the well being of humankind through the devotion of professional expertise in science, engineering and technology, and bringing lasting recognition to Long Island as a center of innovation and technical excellence." In May, the High Speed Rail Association presented them with the 1991 Sparky Awards, as the individuals who had contributed the most during the year towards furthering high-speed rail transportation for the U.S., specifically through their invention of superconducting electrodynamical suspension and propulsion, and pioneering of Maglev.

Joanna Fowler (Chemistry) was honored by Brookhaven Town in March 1991, at a National Women's History Month celebration recognizing local women who have made significant contributions to their fields. Fowler was cited for her scientific achievements, including the development of radiotracers for positron emission tomography, or PET.

Gerhart Friedlander (Chemistry) was elected a Fellow of the American Association for the Advancement of Science (AAAS) in February 1991, "for work in nuclear reactions and properties of radioactive nuclides." Then, in May 1991, at the commencement exercises for Clark University, he received an honorary Doctor of Science degree for his long and influential career in nuclear chemistry.

Maurice Goldhaber (Director's Office) shared the $100,000 Wolf Foundation Prize in Physics for 1991, for his "separate seminal contributions concerning the nature of the weak interactions, one of the four fundamental forces of nature."

David Haines (Biology) and **Jack Perez** (Plant Engineering) were saluted by DOE in August, when they received the Secretary's Desert Shield/Desert Storm Service Tribute, "for service in support of Operation Desert Shield/Desert Storm."

Steven Hulbert and **Erik Johnson** (National Synchrotron Light Source), and collaborators **Harald Ade** and **Janos Kirz**, State University of New York at Stony Brook; **Erik Anderson**, Lawrence Berkeley Laboratory; and **Dieter Kern**, IBM's T.J. Watson Research Center, shared an R&D 100 Award in September 1991, for developing a unique high-resolution x-ray microscope located at the National Synchrotron Light Source.

Lawrence Kukacka (Applied Science) and **Jack Fontana** (Applied Science, retired) won a 1991 Federal Laboratory Consortium Award for Excellence in Technology Transfer, for developing a type of polymer concrete that can be used to insulate dikes around liquid natural gas tanks.

Brenda Laster (Medical) was named to the Employer Hall of Fame of Gallaudet University's Experimental Programs Off Campus. As a result of suggesting that hearing-impaired students be included in BNL's Summer Student Program, she was cited in January 1991 for "outstanding supervision [that] has made a difference to our program and to Gallaudet students."

Laurence Littenberg (Physics) was elected a Fellow of the American Physics Society in December 1990, "for his outstanding contributions to high energy physics, especially to the study of rare K decays."

Anant Moorthy and **Duff Henze** (Nuclear Energy) and **Carl Schopfer** (Safety & Environmental Protection) captured an R&D 100 Award in September 1991, for developing the world's most sensitive method for measuring plutonium in urine samples — the fission track method.

James Niederer (Computing and Communications) received a Certificate of Appreciation from DOE Secretary James Watkins in April, "for extraordinary efforts on behalf of the Community Summer Science Program."

Venkatraman Ramakrishnan (Biology) was granted a 1991 Guggenheim Fellowship by the John Simon Guggenheim Memorial Foundation, based on his achievements to date and his future promise within his professional field of biophysics.

E. Parke Rohrer (Director's Office) was honored in March 1991 with DOE's Distinguished Associate Award, "in recognition of his outstanding contributions to the Superconducting Super Collider (SSC) magnet R&D program."

Melvin Schwartz (Director's Office) was awarded the degree of Doctor of Science, honoris causa, by Columbia University at the May 1991 commencement exercises. The Nobel laureate was cited as a "Son of Columbia, visionary pioneer, bold entrepreneur . . ."

Scott Willenbrock (Physics) was awarded an SSC National Fellowship in April. The fellowships are awarded annually as "a mark of true distinction" to outstanding young scientists throughout the U.S.

Alfred Wolf (Chemistry) was presented with the Georg Charles de Hevesy Nuclear Medicine Pioneer Award by the Society of Nuclear Medicine, in June 1991, for his pioneering efforts in the development and use of radioactive tracers.

ADMINISTRATION

PERSONNEL STATISTICS

In 1991, employment at the Laboratory remained generally steady (see chart).

EMPLOYMENT STATISTICS

	1991	1990	1989
*Scientific Staff	588	619	619
Scientific Professional	568	557	526
Nonscientific	2204	2203	2196
Total	3360	3379	3341
PERCENT OF TOTAL EMPLOYEES			
Minorities	17.9	17.0	15.0
Women	24.5	23.8	23.3

*Includes research associates and visiting staff.

Some 3,738 guest researchers, ranging from students to scientists with research appointments, took advantage of Brookhaven's world-class research facilities in 1991. These guest researchers came from

LABORATORY PROFILE

422 U.S. and 236 foreign institutions.

PURCHASING POWER

Of Brookhaven's total purchases of over $102 million in fiscal year 1991, 45.8 percent was made with small and disadvantaged companies.

One of the biggest purchases handled by DCP this year was the $6.5-million contract with Oxford Superconducting Technology to buy 548,000 meters of superconducting cable for the magnets for BNL's Relativistic Heavy Ion Collider (RHIC).

NEW CRANE FOR PE

When the site maintenance group in the Plant Engineering Division was called upon in October to replace a roofing vent cover at the RHIC site, the job was done by the group's new 28,000-pound-capacity truck crane. The new crane is truck-mounted, making it easier to move and set up for jobs that need only a small lift. BNL's other mobile cranes are much larger and require lengthy set-up procedures.

BE A RECYCLIST!

A contest held to kick off the comprehensive recycling program that got under way in November resulted in a new slogan for the BNL effort: Be a Recyclist! By the end of the fiscal year, BNL recyclists were separating each month about three tons of plastic, cans and bottles, and 16 tons of paper and cardboard.

CHILD DEVELOPMENT CENTER

In September 1991, ten months after ground was broken last November, 65 children of BNL employees were enrolled in the new Child Development Center (CDC) — the first newly constructed day-care facility to begin operating at a U.S. Department of Energy (DOE) site. Located in the Laboratory's apartment area, the CDC has a maximum capacity of 96 children, ages eight weeks to five years.

EDUCATIONAL PROGRAMS

The formal ground-breaking ceremony for the Science Education Center was held in December, and, as 1991 ended, the staff of the Office of Educational Programs (OEP) was getting ready to take occupancy of its new 4,700-square-foot building on Brookhaven Avenue.

OEP administers about 25 programs for students from elementary school through graduate school and for faculty. In 1991, some 1,800 people came to BNL under OEP programs. And in a new program this year, volunteer scientists and engineers, many of them BNL retirees, began serving as scientists-in-residence at local schools.

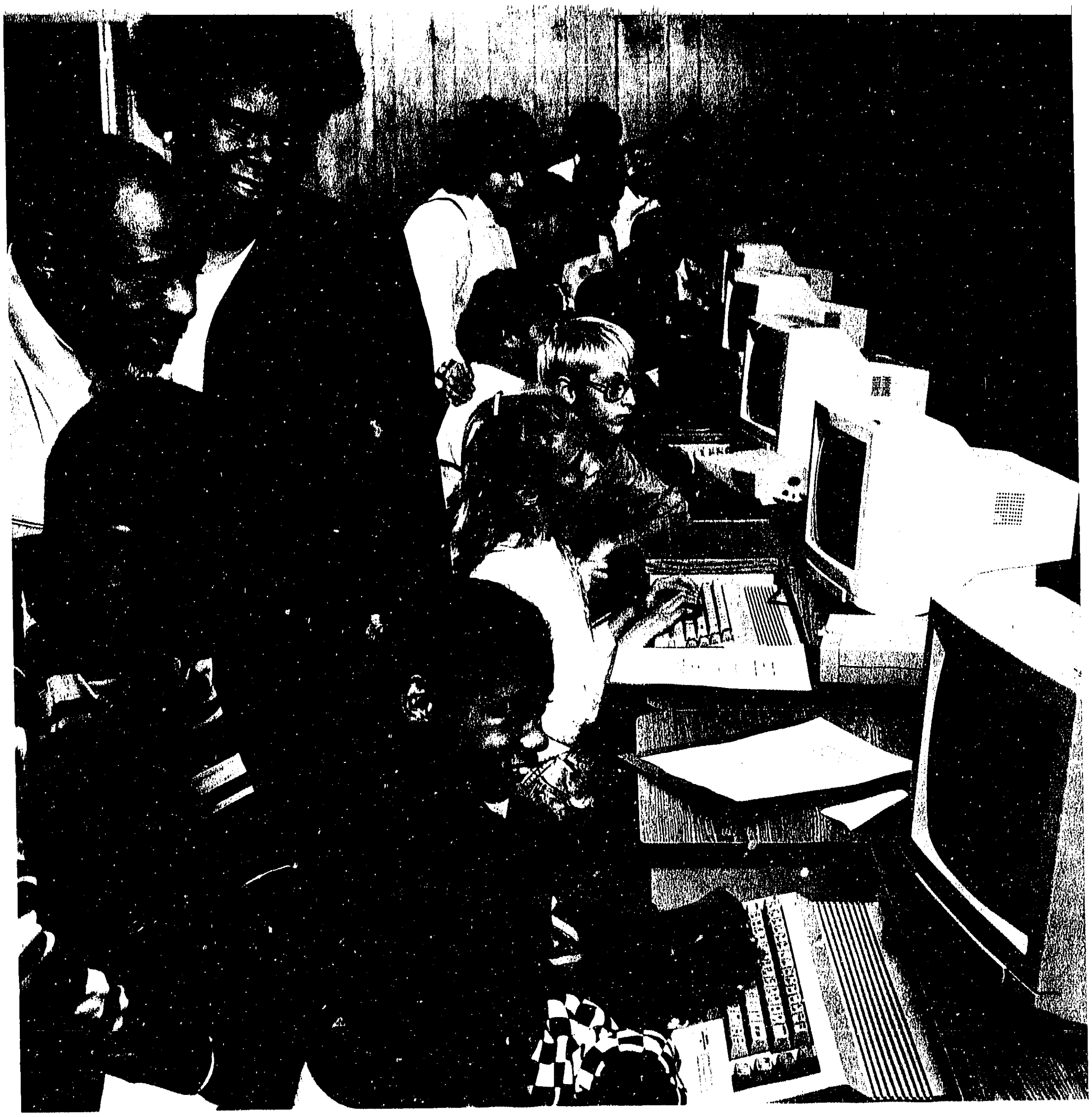
OEP provided coaches and handled travel arrangements for a team of Long Island high school students that placed second in the first National Science Bowl, held in Washington, D.C., in April. BNL was one of the sponsors of the five-member team, which competed against 17 other regional teams from all over the country.

EMPLOYEE HEALTH

At Healthline Lectures run by the Health Promotion Program (HPP) and Outreach Workshops organized by the Employee Assistance Program (EAP), the Occupational Medicine Clinic kept employees informed throughout the year on topics related to healthy living, psychological issues and social problems.

In an offshoot of the Outreach Workshops, in October 1990, the EAP began organizing half-day seminars to teach employees how to cope better with stress.

In January, the HPP introduced the health-risk appraisal. Available confidentially to all employees, the appraisal is a statistical assessment of an individual's health status and risk of illness, injury or death resulting from the person's present lifestyle. That same month, the clinic announced that, since the on-site mammography screening program introduced in 1989 had to be discontinued due to technical problems, the HPP would increase its emphasis on breast cancer education.



Frances Ligon (top) of BNL's Office of Equal Opportunity and Mohammad Raheen, a local parent, help students from the South Country School District who are participating in a BNL-sponsored computer course. The six-week session gives fifth and sixth graders and their parents the opportunity to learn computer basics on Commodore computers donated by Associated Universities, Inc.

BERA NEWS

The BNL Toastmasters became the newest club on the Brookhaven Employees Recreation Association's (BERA) roster of 45 organizations when it received a charter from Toastmasters International, the world's largest organization devoted to communication excellence.

The Afro-American Culture Club celebrated its tenth anniversary with BERA in April. The 185-member club was established in 1981 to function as a conduit through which positive cultural exchanges can be experienced with the majority of the Laboratory community.

MILITARY LEAVE

Shortly after the Persian Gulf crisis began in August 1990, the Laboratory announced several changes to its policy concerning military duty. Last February, after President George Bush announced that the period of service for military reservists called to active duty would be lengthened to one year, the Trustees of Associated Universities, Inc., approved a further revision of BNL policy, extending military leave to one year during this crisis.

WISE CAREER DAY

About 60 high school students, accompanied by an equal number of parents, teachers, counselors and friends, attended the Women in Science and Engineering (WISE) Career Day in April. Meeting them were over 50 BNL men and women who volunteered their time to give the young attendees a full day of positive exposure to the possibilities available to women in scientific and technical fields.

NEW WING FOR CCD

Excavation for the construction of a new 9,000-square-foot addition to the Computing and Communications Division (CCD), Bldg. 515, began in January. The new wing will contain offices, electronics laboratories, CAD/CAM terminal rooms and a conference room.

INFORMATION SECURITY

Since March, processing of ID badges, vehicle registrations and security clearances have all taken place in the lobby of the Brookhaven Center — in the new Information Security Office. Though now out of the confines of Police Headquarters, the office is still very much a part of the Safeguards & Security Division (S&SD).

COMPUTER SECURITY

Organized by S&SD, with support from CCD, a Computer Security Incident Workshop was held in January. This workshop for BNL employees centered on the problems of detecting and recovering from different types of computer-security incidents.

HAZARD COMMUNICATION

In sessions held on 63 days during the first half of fiscal year 1991, over 2,700 Laboratory employees attended two-hour training classes on either Hazard Communication or Laboratory Chemical Hygiene. The result of an intensive effort of the Safety and Environmental Protection (S&EP) Division to ensure BNL compliance with occupational safety and health regulations, the training also fulfilled a commitment made during last year's appraisal by a DOE Tiger Team.

LABORATORY PROFILE

SUPERFUND

Brookhaven established the Office of Environmental Restoration in February to oversee the Laboratory's Superfund activities.

BNL is on the National Priorities List of the U.S. Environmental Protection Agency (EPA). This is a roster of hazardous waste sites that are considered high priority for cleanup under the federal Superfund Program.

The Laboratory is located on Long Island, which draws its drinking water from a sole-source aquifer underlying all of the Island. BNL's inclusion on the Superfund list is primarily due to past disposal practices, which complied with earlier standards, but resulted in groundwater contamination on the BNL site. This contamination is a potential threat to the Island's sole-source aquifer.

The principal areas of concern are the two landfills, a plume of chemical contamination in the groundwater, the hazardous waste management area, the sewage treatment plant and a 1977 oil spill.

In fiscal year 1991, the following documents were completed: the Community Relations Plan; a site baseline report, summarizing existing data on the areas of concern; a response strategy, which takes areas of concern, groups them into operable units and ranks those units; a sampling and analysis plan of action for Operable Unit 4, which consists of the 1977 oil spill, the sump for Building 650, two recharge basins and two contaminated wells; and sampling and analysis plans for industrial cesspools and the soils surrounding underground and above-ground storage tanks.

During the coming year, work will include the remedial investigation and feasibility study for Operable Unit 4, field studies at other areas of concern, and a pilot study for removing the chemical plume by means of spray aeration.

Throughout the cleanup process, the work will be reviewed by EPA, the U.S. Department of Energy (DOE) and New York State. As the federal agency that has jurisdiction over the BNL site, DOE is responsible for all cleanup costs.

RECOGNITION AWARDS

Four new avenues for recognition were opened for BNL employees with the implementation of the new Recognition Awards Program in May. Administered by the Personnel Division, the program gives monetary rewards to employees who make outstanding contributions to the Laboratory, either on a long- or short-term basis.

In the first year, up to five employees could receive a $5,000 Distinguished Research and Development Award, another five could receive a $2,000 Brookhaven Award, as many as 70 could earn $500 Spotlight Awards and there is no limit to how many weekly employees could be rewarded with a $200 U.S. Savings Bond for perfect attendance.

JOBLINE

In January, a new automated job-opening information telephone line — JOBLINE — became available to users of touch-tone phones. JOBLINE may be accessed by calling Ext. 7744 (282-7744 off site) or through the two computers located in the lobby of Bldg. 185, the Personnel Division.

ALARA JOINS SUGGESTION PROGRAM

Two of BNL's improvement programs joined forces in August when the Employee Suggestion Program expanded to accept suggestions regarding the Laboratory's radiation protection program known as ALARA, the acronym for As Low As Reasonably Achievable.

TOURING BNL

A record 21,066 visitors enjoyed BNL's Exhibit Center/Science Museum in the year ending August 31 — more than in any other year during the 14-year history of the Tour Program run by the Public Affairs Office. Over seven summer Sundays, 6,890 visitors were guided through the museum. The other 14,176 were students ranging from kindergarten through high school, who came for tours and school programs.

TECHNOLOGY TRANSFER

During 1991, the program directed by the Office of Technology Transfer continued to reflect the status of this mission within the Laboratory.

Throughout the fiscal year, 17 patents were issued on inventions made by BNL employees and 36 licenses were granted by AUI on BNL-developed inventions. Moreover, 83 American companies conducted research at BNL's designated user facilities, 15 companies had active proprietary users agreements in place covering proprietary research at BNL user facilities, and 16 companies funded research programs at the Laboratory.

MONITORING STATION

A vehicle radiation monitoring station opened on Princeton Avenue in July, operated by S&EP. Containing a detector that is extremely sensitive to certain common radionuclides, the station provides an important final check to ensure that no significant amount of radioactive material is accidentally included in a vehicle load. For example,truckloads of items going to or from the on-site scrap-metal yard run by BNL's Supply & Materiel Division must be accompanied by paperwork indicating that the shipment has been verified as clean by a trip through the monitoring station.

SERVICE IMPROVEMENTS

The Staff Services Division installed a new 22-foot-long dishwasher in the Cafeteria in January. It replaced a 20-year-old, 21-foot model, which owed its longevity in part to faithful service by the Central Shops Division. Then, in November, new tile flooring was installed in the serving area, to replace worn-out carpeting.

In response to suggestions made by employees who participated in a focus group on the Brookhaven Center Club, a new expanded menu was introduced to diners in January. Also this year, a large-screen television and electronic games were introduced in the Tap Room.

In 1991, Staff Services also began a major program to renovate the interiors of all 70, one-to-four-bedroom apartments in the on-site housing area. The project calls for replacing electrical wiring, putting in new furniture, renovating the bathrooms, kitchens and interior decorations, and rebuilding all porches and small stoops.

LABORATORY OPERATIONS SUPPORT

The new Laboratory Operations Support Office completed its first full year of existence in 1991. Established in September 1990, the office's mission is to assist BNL's departments and divisions in implementing U.S. Department of Energy requirements pertaining to operation and maintenance management.

Administrative Actions

Michael J. Bebon
Appointed Deputy to the Associate Director for Management and Physical Plant, in June 1991.

Romney B. Duffey
Joined BNL as Chairman of the Department of Nuclear Energy, in September 1991.

Edward G. Gallagher
Became Manager of the Management Information Systems Division in March 1991.

Mary-Faith Healey
Assumed the management of the Division of Contracts and Procurement in February 1991.

Darrel D. Joel
Began serving as Chairman of the Medical Department in April 1991.

J. Bruce Medaris
Named Manager of the Plant Engineering Division in June 1991.

Mark Sakitt
Joined the Directorate in October 1990, in the new position of Assistant Director for Planning and Policy.

Melvin Schwartz
Returned to Brookhaven as the Laboratory's Associate Director for High Energy and Nuclear Physics in January 1991.

Carol A. Whitley
Named Assistant Secretary of Associated Universities, Inc., in February 1991.

F. William Studier
Began an appointment as Chairman of the Biology Department, in October 1990.

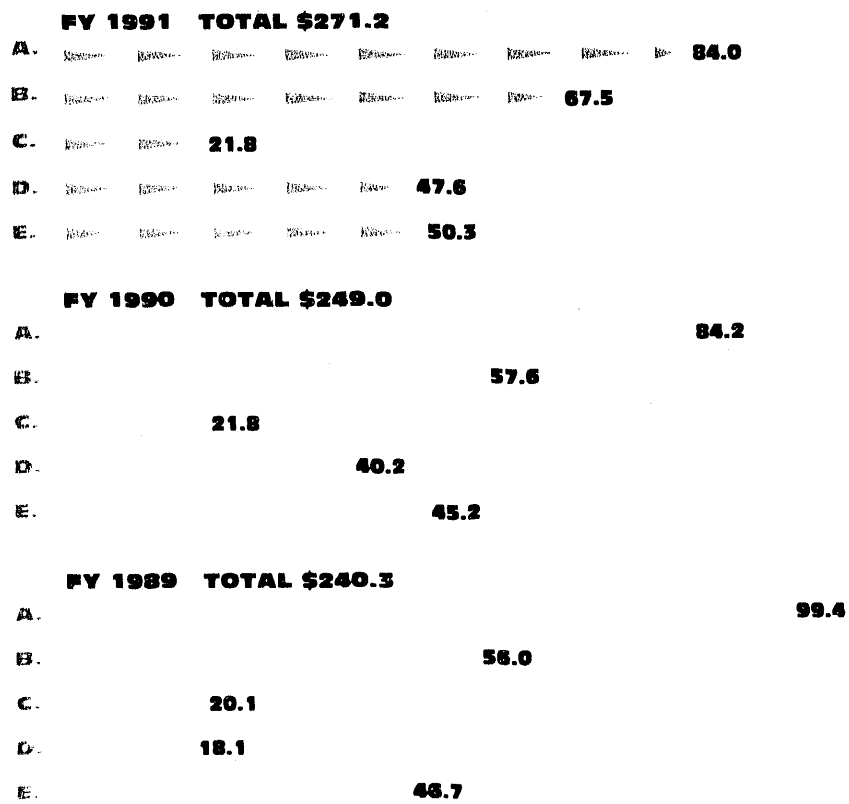
FINANCIAL REPORT

In fiscal year 1991 (FY91), Brookhaven's total budget was $331.3 million, an increase of 9.6 percent over FY90. BNL's budget is divided into three areas:

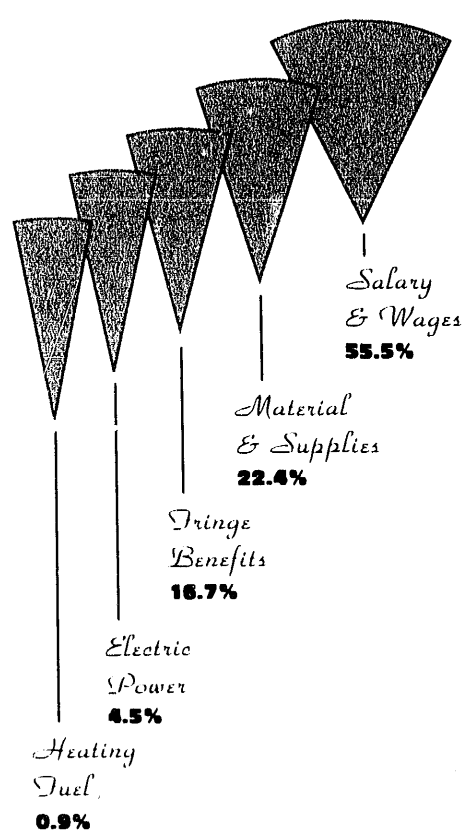
- Operating funds support the Laboratory's various research programs. These funds pay the costs of salaries and wages, fringe benefits, materials and supplies, and energy associated with the research programs. In FY91, operating funds added up to $271.2 million. Additional funding of $20.3 million was received from the Superconducting Super Collider Laboratory for research and development work and is included in the "Other DOE Programs" category in the chart below.
- Capital equipment funding, which amounted to $22.9 million in FY91, provides for instrumentation, scientific apparatus, computers and office equipment.
- Construction funds are used for building projects. These monies increased by about 22 percent in FY91, to $37.2 million, largely due to funding of $13.5 million for the Relativistic Heavy Ion Collider project. Environmental restoration and waste management (non-defense) projects received $5.4 million for hazardous waste management, waste-site closure and waste minimization. The Laboratory also received $3.2 million for a boiler replacement and $1.4 million for Central Shops alteration and addition.

As in previous years, the principal source of BNL's funding was the U.S. Department of Energy (DOE), which accounted for about 81 percent of the operating budget and for all of the capital equipment and construction funds.

BNL OPERATING FUNDS
(millions of dollars)



BNL COST ELEMENTS



A. High Energy & Nuclear Physics B. Basic Energy Sciences
C. Environmental R&D D. Other DOE Programs E. Other Programs

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Quality Assurance

RICHARD J. SPELLMAN
Central Shops

Organization effective as of
September 30, 1991.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1992—612-210

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The Collider Center houses the operations staff and the communications and control systems for the Relativistic Heavy Ion Collider (RHIC). At right is the complex of refrigeration machinery to provide the liquid helium that will keep RHIC's superconducting magnets at cryogenic temperature.

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In a magnet assembly area of the Accelerator Development Department, (from left) Kenneth Sexton, Kenneth Vogel, Raymond Ceruti and Bill Themann work on the iron yoke containing the superconducting coil of a RHIC magnet.

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Kathy Warburton, Department of Applied Science, uses an optical microscope to examine a sample of RHIC cable. The microscope has a specially designed inverted stage that holds the sample upside down, allowing the sample surface to be perfectly parallel to the lens below. The resulting image has no distortion.

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BNL surveyors Robert Anderson (foreground) and Jim Carroll stand inside the RHIC tunnel, which is about six meters in diameter and stretches 3.8 kilometers around in a circle. The tunnel will house the superconducting magnets for the collider.

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DATE FILMED

8/10/92