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BROOKHAVEN HIGHLIGHTS

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1984

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MASTER

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A Word About BNL

Brookhaven National Laboratory is a multiprogram laboratory which 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. The Laboratory employs over 3,000 people.

Established in 1946, BNL is located on Long Island, New York, on the site of what was known as Camp Upton, a training camp for U.S. soldiers during World War I and World War II. Now, in the center of the 5,265-acre site, over 250 buildings and other structures make up BNL's physical plant.

Brookhaven Today

With this issue we inaugurate a new format and a new policy for the Brookhaven Highlights. We are returning to an annual review, rather than continuing the biennial publication of the last 14 years. We are also making Highlights just that — highlights of the work accomplished by the Laboratory staff, with a brief summary of the overall mission of each department. Every year, we will highlight different aspects of the scientific and technical advances made at BNL. In addition, we shall include information about personnel and budgets, awards and honors, and the dozens of meetings the Laboratory hosted on an array of scientific topics.

One of the Laboratory's primary functions continues to be the building, operation and research use of large scientific machines. This involves high energy physics at the Alternating Gradient Synchrotron (AGS), nuclear physics at the Tandem Van de Graaff accelerator, and basic energy sciences at the National Synchrotron Light Source, the High Flux Beam Reactor (HFBR) and the Scanning Transmission Electron Microscope.

It is our intent to build and expand upon these strengths.

A step in this direction, a tunnel linking the Tandem Van de Graaff to the AGS, permitting the acceleration of ions as heavy as sulfur up to relativistic energies, has been approved and construction has begun. In our budget request for fiscal year 1986 is a booster synchrotron which, when inserted into the Tandem/AGS system, will not only appreciably increase the available proton intensity of the AGS, but will also extend the mass region of the relativistic heavy ion beams, up to gold. Long-

range plans include a relativistic heavy ion collider where the Tandem/Booster/AGS will inject relativistic heavy ions into a colliding beam machine for the next generation of even higher energy interactions, and an upgrade of the HFBR to more effectively utilize the source of cold neutrons by adding substantial floor space for nine new advanced experimental instruments.

An interesting and valuable outgrowth of the variety of investigations made possible by our facilities is the rapid increase in the number of industrial scientists who have been added to our visitors list. This broadened community of users (complementing our academic and Laboratory personnel) and a more progressive governmental attitude toward patent policies are encouraging the use of Laboratory facilities and staff to assist in the country's technological development.

The Laboratory also opens its doors to students from high school through graduate school. The training programs are many and varied, and some are designed for science teachers to enable them to keep up with their research and with the latest scientific advances.

While the stories in this issue highlight only the major happenings of the last 18 months, ongoing research in many areas proceeds at a steady pace. As a multipurpose laboratory, BNL has directed its attention not only to physical sciences, but to energy technology, applied sciences, life sciences, and to various kinds of technical assistance for the U.S. Department of Energy and the Nuclear Regulatory Commission.

I hope the following pages will convey to you the breadth of our research, the enthusiasm of our staff and our part in the national scientific effort.

Nicholas P. Samios

Nicholas P. Samios
Director

The AGS: An Anniversary Salute

Since it began operating in 1960, Brookhaven's Alternating Gradient Synchrotron (AGS) has generated protons for both high energy and nuclear physics experiments. Now, about to celebrate its silver anniversary, the AGS also continues to generate superlatives.

The "World's Highest Energy Accelerator" — that's what the AGS became almost as soon as we began to circulate protons through the accelerator at energies as high as 33 billion electron volts (GeV). Though this happened almost 25 years ago, the idea that made the AGS possible surfaced about eight years earlier, in 1952. At that time, our pride centered on our newly operating Cosmotron, which could reach energies of 3 billion electron volts. Behind the scenes, however, we were already asking, "What would we do differently to build a bigger and better Cosmotron?"

The revolutionary answer was "alternating gradient" or "strong" focusing. We found that the particles could be focused more strongly, and thus confined to much smaller dimensions, if the magnets through which they travel were arranged in such a way that the field gradients of successive magnets were alternated, first inward, then outward.

The smaller beam created by strong focusing permitted the use of magnets with much smaller cross sections. Because these were smaller and less expensive than larger magnets, they could be made stronger, bringing the accelerator to new energy plateaus. Since that time, alternating gradient focusing has been used worldwide as one of the guiding principles behind every new accelerator.

The AGS first reached its design energy on July 29, 1960, and the experimental program was off and running. It has been a most fruitful program, yielding an impressive number of significant discoveries, two of which, the J/psi particle and CP violation, have earned the AGS the distinction of having produced two discoveries which were awarded Nobel Prizes, in 1976 and 1980 respectively.

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2020	First AGS beam line
2021	First AGS beam line
2022	First AGS beam line
2023	First AGS beam line
2024	First AGS beam line

Main AGS Control Room on Friday, July 29, 1960, at approximately 4:00 p.m.

The AGS: An Anniversary Salute (continued)

Superlatives continued to mount for the AGS in 1984. By the end of the year, the AGS had accelerated over 10^{21} (1,000,000,000,000,000,000,000) protons in its lifetime, more than any other high energy machine, earning the title of "World's Most Prolific Accelerator."

In 1984, the AGS also became the "World's Most Polarized Accelerator." The AGS claimed this distinction in July, when we began delivering beams of polarized protons to experimenters.

In order to accelerate polarized protons, which spin in the same direction, we had to modify the AGS rather extensively. This work began in 1982, and included:

- creating and commissioning a new ion source for polarized negative hydrogen (H^-) ions.
- developing a new pre-accelerator, a radio frequency quadrupole (RFQ), to replace the Cockcroft-Walton.
- building, then installing in the AGS ring, 12 fast (1.6 microseconds) pulsed quadrupoles and power supplies for 96 correction dipoles.

Milestones came quickly. On June 17, 1983, we set a new world record for output of polarized ions with the new source; on February 14, 1984, the RFQ worked beautifully on its first try, accelerating 40% of the injected beam; on February 23, a beam of polarized protons was accelerated to 200 MeV in the AGS injector, the Linac; on March 8, polarized protons were accelerated into the AGS ring for the first time; and on July 13, researchers began experimenting with these spin-aligned particles.

BLIP, CLIF and MEIN

Near the end of their journey down the 537-foot-long, 200 MeV Linac, some excess particles are diverted for use by non-high energy physics experiments. The Brookhaven Linac Isotope Producer, or BLIP, is a facility of the Medical Department, which regularly ships BLIP radioisotopes to both medical users and industry. The Chemistry Department has a research facility known as the Chemistry Linac Irradiation Facility (CLIF), which is used to produce radionuclides. CLIF includes a Medium Energy Intense Neutron facility (MEIN), where neutron-rich radionuclides are produced for study.

AGS Physics Program

Today, exciting research abounds at the AGS. To accommodate many different types of experiments, the AGS can deliver

protons in three modes and send protons to as many as 11 experiments simultaneously. These experiments were part of the approved AGS physics program in 1984 though not all were ready to receive beam.

Type of Experiment	No.	Beam Line	Collaboration
Rare K Decays These experiments, which probe mass scales in the tens of TeV (trillion electron volt) range, could lead to a new breakthrough in the understanding of such fundamental questions as the origins of flavors and mass.	777	D3	BNL/Yale/SIN/Washington ($K^+ \rightarrow \pi^+ \mu^+ e^-$)
	780	A3	BNL/Yale ($K_L^0 \rightarrow \mu e$)
	787	C4	BNL/Carnegie-Mellon/Columbia/Princeton/TRIUMF ($K^+ \rightarrow \pi^+ \nu \bar{\nu}$)
	791	B5	Stanford/UCLA/Penn/Temple ($K_L^0 \rightarrow \mu e$)
Polarized Protons Exp. 748 focused an unpolarized beam on a polarized target and found spin effects to be three times greater than predicted. Exp. 782 collected data on spin-spin effects, and Exp. 785 measured the asymmetry in the distribution of specific produced particles when polarized protons strike non-polarized hydrogen.	748	D1	Michigan/BNL/Maryland/Miami/Notre Dame/Texas A&M/ETH Zurich/Copenhagen
	782	D1	Mich/BNL/Maryland/Miami/Notre Dame/Rice/Texas A&M/ETH Zurich
	785	C1	BNL/Minn/SE Mass
Neutrinos To test the Weinberg-Salam theory of electroweak interactions, Exp. 734 measures elastic neutrino-electron scattering. Exp. 776 searches for signs that neutrinos oscillate, to determine whether they have mass.	734	U	BNL/Brown/KEK/Osaka/Penn/Stony Brook
	776	U	Columbia/Illinois/Johns Hopkins
Antineutrons A unique tagged antineutron source was used to study the interactions of antineutrons in hydrogen.	787	C8	BNL/Houston/Penn/ETH/Rice
New Particle Search In 1963, a long-lived state with mass about 2220 MeV was detected at SLAC. Exp. 789 looked for this particle in antiproton-proton interactions.	789	C1	NYU/BNL
QED A test of QED, this experiment precisely measured the energy difference between levels in muonic helium.	745	D4	Columbia/CERN/BNL

RFQ Preaccelerator

Until this year, we accelerated H ions to initial energies of 750,000 electron volts only in the Cockcroft-Walton. But we knew this huge preaccelerator would be very clumsy for polarized protons. So, we turned to a new concept: the much smaller radio frequency quadrupole, or RFQ.

On March 19, 1984, we ran the two-meter-long RFQ for the first time, accelerating 4×10^9 protons in the AGS, while preserving 60% polarization to above 4 GeV and 25% to above 6 GeV. The RFQ became the first such device to be used in an operating accelerator. Our RFQ is also unique in that it is the only one that accelerates polarized negative hydrogen ions, which, after electrons are later stripped away, end up in the AGS as polarized protons.

Machine Upgrades

In addition to an upgrade of the On-Line Data Facility, our construction efforts at the AGS in 1984 resulted in:

- an internal target for Exp. 778, to study nuclear fragments in FY85.
- a betatron tune meter, a monitor which measures, once per acceleration cycle, the horizontal and vertical tune of the AGS.
- an injection position monitor, which measures the position and angle of the beam at injection, and a similar device that also measures the positions of individual bunches of particles, the individual bunch coordinate monitor.
- a series of five new extraction magnets.
- a new U target station to provide for a 50% increase in neutrino beam flux.

The AGS: An Anniversary Salute (continued)

Type of Experiment	Beam		Collaboration
	No.	Line	
Glueballs The Multiparticle Spectrometer (MPS) is used in searches for glueballs — pure, yet-to-be-observed particles made of pure gluons, the stuff that holds quarks together.	747	A1	BNL/CCNY
	769	A1	Notre Dame/Brandeis/BNL/CCNY/Duke
	771	B2	BNL/Florida/SE Mass/Indiana
Hyperon Decays The MPS was also used by Exp. 751 to study the radiative decay modes of hyperons.	751	B2	Brandeis/SE Mass/Notre Dame/Duke
CP Violation This experiment can determine whether the superweak CP violation models are correct — that there is no difference in the neutral to charged two-pion decay ratios of the K_L^0 and K_S^0 mesons.	749	A3	BNL/Yale
Omega Minus This study of Ω^- production and decay uses a processor that can handle 100,000 omega minus events per second.	786	B5	Columbia/Mass/Mexico/Fermilab
Two-Body Exclusive Reactions This test of QCD predictions observed how particles recombine when the angles of their collisions change.	755	C1	BNL/Minn/SE Mass
Nuclear Transparency The energy loss of energetic protons in a variety of nuclei was measured by Exp. 790.	790	C1	BNL/MIT/Minn/SE Mass
Dibaryons, Hypernuclei With the hypernuclear spectrometer, Exp. 773 searched for particles called strange dibaryons. Exp. 781 studied the effect of spin on lambda hypernuclear levels.	773	C2	Brandeis/BNL/Houston/CMU/MIT/New Mexico/Vassar
	781	C2	BNL/MIT/CMU/Houston/NTU/Vassar
Magnetic Moments This experiment measured the magnetic moment of the radiative sigma hyperon.	723	C4	W&M/Boston/CMU/CIT/Wyoming
Strangeness Spin A spinoidal science experiment, this study probes lattice structures with muons.	754	D2	Bell Labs/BNL/W&M/George Mason/Virginia State

Any machine which can accelerate both polarized and unpolarized protons, deliver protons to experimenters in three different beam modes, and serve up to 11 different experimental beams at one time is certainly a candidate for another superlative: "World's Most Versatile Accelerator." And future plans for the AGS make its claim to this title even stronger.

We have already begun working on a project which will introduce a whole new type of physics research at the AGS — the transfer of heavy ions from the Tandem Van de Graaff and the acceleration of heavy ion beams for experiments with fixed targets, planned to begin in 1986. Last fall, with funding from the Nuclear Physics Division of the U.S. Department of Energy (DOE), we began to construct the 2000-foot-long heavy ion transfer line.

The future of the AGS was the subject of an intensive study by the AGS II Task Force, formed by the High Energy Discussion Group. The Task Force held a series of four meetings in the winter of 1983-84 and reported on its recommendations in February 1984. Based in part on those recommendations, a five-year plan was submitted by BNL to DOE in March, emphasizing the following objectives:

In the next three years, to

- improve AGS operating reliability from 70% to 90%.
- increase the overall duty factor from 20% to 40% (90% microstructure and 45% macrostructure).
- increase intensity to $3\text{--}5 \times 10^{13}$ protons per pulse by adding a 1 GeV booster ring.
- provide increased flexibility in multiple beam operation.

Completing these near-term objectives would require, among other efforts, a major revamping of the AGS control system and the construction of a second RFQ to replace the Cockcroft-Walton.

In the longer term, to

- increase the duty factor for the slowly extracted beam by adding a stretcher ring.
- increase intensity to 10^{14} protons per pulse by further improvements to the AGS and the booster.

The booster ring, which figures importantly in both our long-term and short-term plans, would be built between the existing 200 MeV Linac and the structure which housed the original AGS 50 MeV Linac injector, to serve both the proton and heavy ion programs at the AGS. This booster is also critical to our plans for a Relativistic Heavy Ion Collider (RHIC). A proposal for RHIC has been submitted to DOE. If it is approved, the AGS will go on to still another duty, serving as the injector for this large accelerator, which would collide ions up to $A \sim 200$ at ~ 100 GeV/nucleon at a luminosity of $10^{27} \text{ cm}^{-2} \text{ s}^{-1}$.

Right, above: Larry Ratner of BNL (standing) and Alan Krisch, University of Michigan, monitor the data on the control room computer screen as polarized proton experimentation begins at the AGS.

An aerial view of the Alternating Gradient Synchrotron. The Linac (upper left) is the injector for the AGS ring. The large building in front of the ring houses the Accelerator Department and the AGS control room. Other structures in the area are used to service the accelerator and for experiments.

The Big Machines

Brookhaven has always maintained a strong spirit of cooperative research. Large numbers of visiting scientists, primarily from universities, use the Laboratory's unique facilities to do research not possible otherwise. BNL also encourages interaction with industry in the application of new knowledge.

Close to 30 facilities are available for non-proprietary, usually basic, research. Proprietary research may be performed under a formal agreement between BNL and the outside user.

Previous pages described Brookhaven's Alternating Gradient Synchrotron, a venerable machine that has served literally thousands of users in its 25-year history. Highlighted on these pages are BNL's other major facilities that serve the scientific community of the world.

National Synchrotron Light Source (NSLS)

The NSLS is the world's brightest source of ultraviolet radiation, and x rays will be available to users in 1985. A wide range of research equipment is available for basic and applied studies in condensed matter, surface studies, photochemistry and photophysics, lithography, crystallography, small angle scattering and x-ray microscopy. Proprietary work can be done on a full-cost recovery basis, with the option of retaining title to inventions. In 1984, 137 scientists did experiments at the NSLS.

High Flux Beam Reactor (HFBR)

The 60-megawatt HFBR provides an intense source of particularly pure thermal neutrons. Emphasis is on the study of fundamental problems in solid state and nuclear physics and in structural biology and chemistry. Various instruments are available, and special equipment exists for experiments at high and low temperatures, high magnetic fields and high pressure.

Tandem Van de Graaff Accelerator Facility

A wide selection of light and heavy ion beams are available at this machine for applications in materials research. Efforts are made to facilitate users' work by having the machines operate around-the-clock, by developing easy-to-use equipment and by providing technical assistance in setting up experiments.

The Big Machines (continued)

Scanning Transmission Electron Microscope (STEM)

STEM provides a 2.5-angstrom resolution on biological specimens. The microscope can also determine molecular weight and mass distribution within single macromolecules and complexes. Research time on the machine is allocated in one-week blocks by the STEM Advisory Committee.

MAJOR RESEARCH FACILITIES SUPPORTING UNIVERSITIES OR INDUSTRY

EXTERNAL USE IN %

100

Alternating Gradient Synchrotron

Tandem Van de Graaff

National Synchrotron Light Source

High Flux Beam Reactor

Scanning Transmission
Electron Microscope

OPERATING COST

(IN THOUSANDS OF \$)

60,000

TOTAL OPERATING COST

79,000

Accelerator Department

Since 1947, when we first conceived the Cosmotron, Brookhaven has been a leader in advanced accelerator technology. Under the auspices of the Accelerator Department, we have incorporated that technology into the development and operation of high energy facilities, as well as non-accelerator applications.

At present, our principal facility is the Alternating Gradient Synchrotron (AGS). We are also preparing concepts for future accelerator applications. Some of our skills are being applied to the national effort behind the proposed Superconducting Super Collider. During 1984, we also submitted two proposals to the U.S. Department of Energy, one for a booster ring to push AGS particles to higher energies and one for a Relativistic Heavy Ion Collider.

Probably our best-known spin-off is the Power Transmission Project, a prototype system for the inexpensive transmission of electrical power. The techniques for cooling the superconducting cables which act as the system's power transmission lines were borrowed from accelerator technology.

...There Stands a Source

From the Linac to the AGS ring, down the experimental beam lines to the targets, all our efforts at the Alternating Gradient Synchrotron (AGS) are geared towards one goal: successful high energy and nuclear research. But behind all this — behind every successful accelerator, in fact — there stands a source.

That source is the wellspring for all the particles that circulate through the accelerator. In the AGS, these particles have always been protons, but over the years those protons have been derived from several different sources. At present, we at BNL are working on two source projects, with our primary goal to increase experimental opportunities at the AGS.

The first of these sources — an intense polarized negative ion source — is a key component in the new high energy polarized proton program at the AGS. The negative hydrogen (H^-) ions produced in this source are polarized, which means they all spin in the same direction.

The creation of polarized H^- beams begins with the separation of hydrogen molecules, each into two hydrogen atoms. From these, we magnetically weed out all particles having one spin direction, leaving neutral hydrogen (H^0) atoms, all with the same polarization. These H^0 atoms then collide with an energetic, neutral cesium beam (Cs^0). The collision promotes a charge exchange which yields a beam of H^- ions. After entering the AGS ring, the polarized H^- ions pass through a very thin carbon foil. There, two electrons are stripped from them, leaving only polarized protons.

Work on the polarized negative ion source began in early 1981. In July of 1983, we measured beam currents in excess of 15 microamperes (μA), a new world record for this type of source. By September 1984, that had climbed to 25 μA .

The present current from the polarized negative ion source is sufficient for the polarized proton

research that began at the AGS in July 1984. These beam currents, however, are considerably lower than beams extracted from our regular negative ion source, which is still used for the other experimental programs at the AGS. Now we are trying to prove that it is possible to construct a single source from which we can extract milliamperes of either unpolarized or polarized negative ions. Not only would this permit us to serve all our present types of experiments with only one source, but the availability of such a source would also open up a completely new experimental physics domain. Our challenge here, then, is primarily to create an ion source that can achieve intensities sufficient for polarized and unpolarized experimentation.

Satisfying those demands requires that we create a next-generation source capable of beam currents as high as 25 milliamperes, in both the polarized and unpolarized beam modes. We believe a combination of two new features should help us realize that goal.

Like the present polarized negative ion source, the new source will start with neutral hydrogen atoms. But we will bring these H^0 atoms to very low temperatures — down to around seven kelvins. The cooling will slow the atomic beam considerably, increasing its density (and the final beam intensity) by at least an order of magnitude.

The second increase in intensity will come from using negative deuterium (D^-) ions, rather than neutral cesium atoms, in the charge exchange process. To do this we will build a ring magnetron, which will surround the oncoming H^0 beam with D^- ions that will cross-collide with the atomic beam. Theoretically, this could increase the polarized H^- intensity by two orders of magnitude.

Feasibility tests will be conducted on this idea, now in the conceptual stage, in 1985. Based on the successful outcome of those studies, we would design and construct the next-generation polarized ion source in 1986.

One measurement of just how busy the sources at the AGS have been is the total number of protons accelerated in any given year. The chart at left, which covers each fiscal year since 1981, accumulates that total month by month. How that correlates with the hours available for experimentation can be seen by comparing these charts. The number of hours the AGS runs varies from year to year, depending on the the current levels of funding and maintenance requirements.

James Alessi gives the polarized negative ion source a once-over, while Ahovi Kponou (foreground) monitors its performance with an oscilloscope.

The Focus Is on Neutrinos

Exploring the particle world requires huge amounts of experimental planning and support activities. A case in point is neutrino experimentation, which benefited from many of our efforts in 1984 at the Alternating Gradient Synchrotron (AGS). In particular, we developed an experimental area for a new neutrino experiment, 776, and designed and constructed a particle focusing system to serve both 776 and existing experiment 734.

Though both experiments rely on the newest in detectors and accelerator technology, the neutrinos they focus on have been around as long as our universe, having evolved with the weak interaction, the force associated with radioactivity and nuclear decay.

Brookhaven's association with these elusive particles is not new either. In 1962, AGS physicists performed the world's first high energy experiment, which resulted in the discovery of the muon-neutrino. Then, in 1974, an unusual neutrino event occurred when neutrino experimentation at Brookhaven moved to the 7-foot bubble chamber. This later proved to be the first single charmed particle, a charmed baryon. Today, researchers here look for neutrinos with huge detectors. The detector for Exp. 734, for example, weighs about 200 tons, and Exp. 776's weighs over 300 tons.

Since 1981, Exp. 734 has been measuring neutrino-electron elastic scattering, to test the Weinberg-Salam theory of electroweak interactions. Beginning in November 1984, Exp. 776 will search for signs that neutrinos can change from one type of neutrino to another (oscillate), to determine whether they have any mass. If the mass is small, that change would occur at AGS energies, slowly and over a long distance, so the detector for Exp. 776 is located almost one kilometer (0.6 miles) north of the AGS ring. In addition to providing a building there, we support the experiment with utilities,

carpentry, cooling and surveying. Another of our contributions was to build, test and measure the five toroid magnets used in the detector system, each of which weighs about 38.5 tons and is 18 feet in diameter by seven inches thick.

When the first beam of neutrinos strikes the toroids in November 1984, particles will also pass through two new narrow-band neutrino horns for the first time. Called neutrino horns, (because each of the two major components resembles a long, slim horn), the 33-foot-long focusing system will rarely see a neutrino. What will pass through it will be the pi (π) mesons produced when the AGS fast extracted proton beam strikes a tungsten-rhenium target. The horns will focus the π mesons into a parallel beam with a well-defined energy, which will travel out of the horns and down the U-line tunnel toward the experiment. Along the way, a large fraction of the π 's will decay, and one product of the decay will be neutrinos.

The new horns represent a several-fold improvement over previous horns. First, because the location has been moved to allow a longer decay space, and because the larger horns can focus more π mesons, we will get more decay products and thus more neutrinos, for an increase of about a factor of ten in neutrino intensity, for narrow band running.

Much of our effort went into horn design. Earlier horns, placed in earthen tunnels to shield against radioactivity, were difficult to repair or change. The components of the new horns are positioned on flatbeds for mobility and shielded by movable

concrete slabs 25 feet thick, so the new horns will be both safer and easier to maintain.

Several other AGS activities have also enhanced the neutrino experiments, particularly our continuing effort to increase AGS intensity. While important to all experiments at the AGS, the record intensity of 1.62×10^{13} protons per pulse that we achieved in December 1983 is particularly helpful to the neutrino experiments: the more protons available, the more π mesons will be created to decay into neutrinos.

Similarly, our increased understanding and refinement of the AGS

radio frequency system is helpful because it allows us to accelerate more of the protons injected into the AGS. And with 10% more operating time in 1984, experiments like 734 and 776 had more time and more neutrinos, so that researchers were able to collect more data.

If pi mesons could see, this would be their view as they enter the new neutrino horns at the AGS. The two parts of the focusing system are called neutrino horns because, after passing through them, the pi mesons decay into the neutrinos that are analyzed by the detectors of Experiments 734 and 776.

A Quest for Quark Matter

Understanding our universe has been somewhat like peeling the layers of an onion. First, physicists looked into the atom and found a nucleus surrounded by orbiting electrons. Then they peered into the nucleus and learned it was composed of particles called neutrons and protons, known collectively as hadrons. Now they contemplate those hadrons, which are believed to consist of fundamental entities called quarks, held together in combinations of three by other fundamental entities called gluons.

The quark-gluon symbiosis is so tight that free quarks and/or gluons have never been observed. But theory indicates that if heavy atomic nuclei collide head-on at energies approaching the speed of light (relativistic), some nuclei will become heated to temperatures and densities so extreme that their constituents will temporarily lose their identities as neutrons and protons, and become a hot gas of quarks and gluons. That would create a new form of matter: a quark-gluon plasma. Known to physicists as quark matter, we believe its properties would reflect the conditions that existed at the earliest moments following the birth of the universe.

There is great interest in creating quark matter, both on the part of nuclear physicists, who have always studied nucleus-nucleus collisions, and high energy physicists, who have long used high energies to probe the most basic constituents of matter. During 1984, Brookhaven was a center of activity for both physics communities in formulating the proposal for RHIC, a relativistic heavy ion collider designed to recreate the conditions necessary to form quark matter.

Our RHIC proposal, which was formally submitted to the U.S. Department of Energy (DOE) at the end of 1984, calls for construction to begin in 1987 on a collider to be completed in 1991. Brookhaven is an ideal location for a relativistic heavy ion collider, because most of the

injector system and the conventional facilities already exist.

Central to a RHIC injector is the existing Alternating Gradient Synchrotron (AGS), as well as two other components which are independently important to new physics research at the AGS and should be completed well before RHIC construction would begin. The first component, for which ground was broken in the fall of 1984, is a transfer line that will send heavy ions from Brookhaven's Tandem Van de Graaff accelerator to the AGS. A proposal for the second component, a booster ring to push the heavy ions to higher energies before they enter the AGS, was submitted to DOE in mid-1984.

The 2.4-mile circular tunnel that would house RHIC already exists on the north side of the Laboratory property. Also, there are the tunnels from the AGS, support buildings, three experimental areas, a central control building and a complete helium refrigeration system, the world's largest. All were built for the Colliding Beam Accelerator (CBA) project, before the project was terminated in July 1983. Our CBA work also left us with an experienced superconducting magnet group and very large facilities for constructing, assembling and testing superconducting magnets.

The collider that would make use of these attractive assets would accelerate all the ion species, up to and including uranium, while the design is optimized for beams of gold. Heavy ions would circulate in two opposing rings, colliding at six points with an energy near 100 GeV per nucleon in each beam — more than enough energy, it is predicted, to form quark matter. This is equivalent to about 250 GeV for protons, which RHIC could also accelerate.

To reach this energy, while holding costs down, RHIC's superconducting magnets would operate at the relatively low magnetic field of 3.5 tesla. The bunches of heavy ions injected would fill the RHIC ring in box-car fashion, one after the other, an approach that is both simple and cost effective.

Another consideration in our RHIC design was the effect of intrabeam scattering, which occurs within a beam when two particles traveling together interact with each other. When observed elsewhere in protons, this scattering had had little impact. But our calculations now show that intrabeam scattering will cause a bunch of heavy ions to grow, increasing the beam's dimensions and promoting a loss of beam particles, which is undesirable. Larger apertures to contain the beam, more quadrupole magnets for stronger focusing and more powerful radio frequency apparatus to provide voltage will help RHIC accommodate this effect.

That has been the crux of our challenge: to take advantage of existing assets while meeting the new demands presented by heavy ions. RHIC may be designed to fit into an existing tunnel, but in its design and its implementation, it is a new and truly unique machine which should allow us to enter a completely uncharted region to study the fundamental properties of a new state of matter — quark matter.

The RHIC proposal would have heavy ions traveling through several of Brookhaven's facilities. From the source at the Tandem Van de Graaff accelerator, heavy ions would travel through a 2000-foot transfer tunnel to the proposed booster ring, which would be built between the Linac and the AGS, to be raised to higher energies. Then they would enter the AGS, be accelerated to AGS energies, and exit to the beam injection tunnel to enter RHIC's two rings. There, traveling at energies of 100 GeV per nucleon, the heavy ions would collide at six points around the ring for study by researchers at four experimental areas.

Physics Department

Theory and experimentation go hand in hand in each of the areas of fundamental research explored by the Physics Department: elementary particle (or high energy) physics, solid state (or condensed matter) physics, and nuclear physics. Our solid state research is concerned with the cohesive forces that bind atoms together to form the various phases of condensed matter. The basic nature of the structure of nuclei and nucleons, as well as their interactions, command our nuclear physicists' attentions. And in high energy physics, our elementary particle physicists probe the fundamental properties of the world of the incredibly small. Now engaging the interest of a growing number of our nuclear and particle physicists are the study of very high density matter and the methods for production of quark matter with the Relativistic Heavy Ion Collider proposed by the Laboratory.

The Implications of CP Violation

In their search for a fundamental theory of nature, physicists often use simplicity and symmetry as a guide. But Nobel Prize-winning work done at Brookhaven in the early 1960's showed that one basic symmetry principle breaks down in a tiny corner of the subatomic world. Today at Brookhaven, our high energy theorists and experimentalists continue to try to understand this interesting phenomenon, known as CP violation.

It was long thought that the physics would be identical if, in any process, all particles were replaced by their antiparticles (charge conjugation, or C) while all of their motions were replaced by their mirror images (parity, or P). Under this symmetry, for example, the rate at which a lambda particle decays into a proton and a negative pion would equal the rate at which a lambda antiparticle decays into an antiproton and a positive pion, i.e. $\Lambda \rightarrow p + \pi^- = \bar{\Lambda} \rightarrow \bar{p} + \pi^+$. And, indeed, this symmetry is true for the strong and electromagnetic forces that hold nuclei and atoms together. It is also true, to an extremely high degree of accuracy, for the weak forces associated with radioactive decay.

It was only in 1964 that this symmetry principle was thrown into doubt, when James W. Cronin, Val L. Fitch and their collaborators did an accurate measurement of the decays of neutral K mesons (K^0) at BNL's Alternating Gradient Synchrotron (AGS). Only after all other attempts to explain their results failed was the strongly held belief in this symmetry principle overcome. For discovering CP violation, Cronin and Fitch received the Nobel Prize in physics in 1980.

Today, 20 years after that discovery, there has been no experimental evidence of CP violation in any system other than the weak K^0 decays. Brookhaven theorists recently calculated the predictions of the currently favored theory of weak decays — the

Kobayashi-Maskawa model — and found that the predicted size of other CP violations are always very small. For example, the predicted difference between $\Lambda \rightarrow p + \pi^-$ and $\bar{\Lambda} \rightarrow \bar{p} + \pi^+$ is less than one part in a million. For some new particles, especially those containing the bottom quark, much larger differences have been found, but the basic process itself is rare, so the prediction has not yet been tested by experiment.

The K^0 s, however, are an exception, in terms of the amount of CP violation in the system, and so have been the focus of many BNL experiments. The K^0 and its antiparticle, the $\bar{K}^0$, share nearly all the same properties. Most important, they have exactly the same mass, as well as the same charge. As a result of a fundamental principle of quantum mechanics, they can "mix" and form two new particles, which are partly K^0 and partly $\bar{K}^0$. It turns out that these new particles have nearly the same mass, but very different lifetimes before they decay, two features that make them excellent probes of CP violation.

This was the basis of a very sensitive experiment aimed at uncovering the source of CP violation, which was completed at the AGS in 1984. Experiment 749, a BNL/Yale collaboration, asked the basic question: Does the CP violation result from the mixing of the K^0 and the $\bar{K}^0$, or is there some fundamental violation of CP in the interaction of the quarks which make up the K meson?

The so-called "superweak" theories say the CP violation comes entirely from the mixing, while other theor-

quark. As things now stand, with the long lifetime of the B and the near equality of the ratios of the K^0 decay rates as determined by Exp. 749, the Kobayashi-Maskawa model predicts a lower bound for the top quark mass.

Both theoretical and experimental work is continuing in this exciting area, where physicists are on the verge of making a definitive conclusion about the nature of the weak decay interaction. Contributing to that will be BNL's unique capability of studying unusual and rare decays of the K mesons. These decays provide a sensitive means for learning about the fundamental forces of nature, and we have committed many resources over the next few years to carrying out several rare K decay experiments at the AGS.

Ling Lie Chau (left) and William Morse discuss the data collected by AGS Experiment 749 and its ramifications for theories of CP violation.

ies, like the Kobayashi-Maskawa model, predict additional CP violation effects. If the phenomenon results entirely from the mixing, then the ratio of the rate of the long-lived K decay into any particular particles, to the ratio of the rate of the short-lived K decay into the same particles, *must* be the same for all possible final particles.

Experiment 749 was designed to compare, precisely, this ratio for the two possible final states, $\pi^+\pi^-$ and $\pi^0\pi^0$, using the intense K beams at the AGS. About ten times the world's previous sample of the rarest of these decays, the $K_L^0 \rightarrow \pi^0\pi^0$, was

accumulated. This was important because accurate measurement of this ratio requires that many decays be measured. Based on these data, we concluded that the ratios could, at most, differ by a small amount.

This result is important to theories of particle decays. Our theorists have been involved in an extensive program to determine the precise form of the interactions that give rise to these decays. These studies are closely related to three topical issues: the lifetime of the recently discovered B meson, the nature of CP violation as measured in Exp. 749, and the mass of the anticipated top

Measuring Magnetic Moments With X Rays

New ground was broken by Brookhaven's solid state physicists in 1984, when we successfully performed synchrotron-based, magnetic x-ray scattering measurements of the rare earth metal holmium (Ho).

Until recently, the only practical means for direct study of the long range magnetic order and critical behavior displayed by magnetic materials has been neutron diffraction. But already, intriguing new results for the magnetic structure of Ho have been revealed by the high resolution provided by synchrotron radiation. Because they probe an unexplored regime of the interaction of light with matter, magnetic x-ray scattering experiments may ultimately reveal new and unexpected physics in both two- and three-dimensional systems.

Although the theory of magnetic x-ray scattering was published in 1970, and a few experiments subsequently performed, the technique never became a useful tool for studying the magnetic properties of solids, largely because x-ray sources have not been sufficiently intense. However, the advent of new, high brightness synchrotron sources, such as BNL's National Synchrotron Light Source (NSLS), will make such measurements possible, even routine.

Of particular interest to us in planning to use the NSLS are the structure and phase transitions of two-dimensional materials, such as the surface and adsorbate layers of solids. The development of the field of two-dimensional physics has been rapid over the last 15 years, both because of its fundamental interest and the wealth of technologically useful information it has produced. But because of the difficulty of the experiments, x-ray scattering from two-dimensional structures and surfaces has begun only in the last several years.

As part of the preparation for doing two-dimensional structural and magnetic x-ray scattering exper-

iments at the NSLS in 1985, we spent 1984 doing magnetic x-ray scattering experiments with Ho. First we used the weaker, rotating anode source located in our BNL laboratory, and then the world's most intense x-ray beam line at the Stanford Synchrotron Radiation Laboratory, built in collaboration with Exxon and Lawrence Berkeley Laboratory.

When x rays strike a crystal, they interact with and are scattered by the electronic charge of each atom, while neutrons are scattered by the atomic nuclei. Since both x-ray and neutron scattering techniques are sensitive to the positions of the constituent atoms in a solid, they may be used to determine its crystal structure and to understand the nature of its structural phase transitions.

In addition, both neutrons and x rays are sensitive to the magnetic moment of each atom in a crystal, and so are also sensitive to the crystal's magnetic structure. But while the scattered nuclear and magnetic intensities are roughly comparable for neutrons, the magnetic scattering of x rays is much weaker than the charge scattering. In Ho, for example, the magnetic x-ray scattering cross section is about 10^5 times weaker than the charge scattering.

Nevertheless, the brightness available from a synchrotron source makes such a small signal detectable. This is an exciting prospect, since for certain materials and for small volume samples, such as two-dimensional structures, magnetic x-ray scattering may be the only technique available for studying long range magnetic order.

Ho was chosen for our first magnetic x-ray scattering experiments because it has a large magnetic moment ($10\mu_B$), its magnetic peaks are well separated from the charge peaks, and both the peak intensity and position vary with temperature. These features gave the best chance for the magnetic data to be distinguished from the structural data and from the background.

Our work with Ho has resulted in some new findings. First, the precise

dependence of the magnetic peak position on temperature shows a weak oscillation in holmium's simple spiral phase, a phenomenon not previously observed in rare earth metals. In addition, the magnetic peaks become nearly six times as broad as the temperature is reduced below 20 kelvins, which is characteristic of the appearance of short range magnetic order. We are currently at work interpreting these effects.

These initial experiments prove the viability of the magnetic x-ray scattering technique and demonstrate its potential for providing new information about magnetic materials. In the immediate future, we plan to explore possible polarization and resonance effects in the spin-dependent cross section for Ho and to extend the technique to study some new materials.

A recent finding from Brookhaven's magnetic x-ray scattering experiments at the Stanford Synchrotron Radiation Laboratory is that holmium's (Ho) magnetic peaks broaden, as the temperature is reduced below 20 kelvins (K). This is vividly depicted in this chart, which contrasts magnetic peaks above and below 20 K, at 80 K and 13 K respectively. The y-axis gives the number of photons per second scattered from the incident x-ray beam by the Ho sample at a particular value of l (inverse angstroms). The x-axis gives the direction of the scattered beam in units of l .

From left, Doon Gibbs, Kevin D'Amico and David Moncton at work in the x-ray laboratory at BNL. Gibbs is framed by a spectrometer that measures scattered x rays.

Hyperons: The Inside Story

Looking inside an atomic nucleus is as predictable as gazing at a clear nighttime sky. Just as we expect to see certain stars and planets in the heavens, we count on "seeing" protons and neutrons (nucleons) in the nucleus. Still, unexpected things like shooting stars and satellites sometimes mingle with the constellations. In the subatomic world, some strange things, like lambda and sigma particles, can enter a nucleus.

Collectively, these strange particles are called hyperons, and when they wander into a nucleus, they join with the nucleons there to form a hypernucleus. Hyperons, like the nucleons, are composed of three fundamental entities called quarks. With hyperons, however, one of those quarks is a strange quark, which accounts for the particle's "strangeness."

In a continuing program at the Alternating Gradient Synchrotron (AGS), our nuclear physicists are forming hypernuclei, to study their properties, to learn about hyperons and the quarks of which they are made, and, in particular, to understand the interactions of the lambda particle.

Until a few years ago, the hypernuclear program centered on magnetic analysis of the processes by which hypernuclei are formed — using magnetic spectrometers to measure the energy difference between a normal nuclear state and a hypernuclear state. But the amount of information obtained in an experiment is directly related to the energy resolution of the technique. With magnetic analysis this was only about two million electron volts, so we began looking at gamma ray transitions as another approach.

A gamma ray is a high-energy photon, a massless particle usually emitted by an ordinary nucleus during an electromagnetic transition between energy levels. But gamma rays may also be emitted by a hypernucleus, as it decays from a more excited state to a less excited state, possibly to the hypernuclear ground state. When we detect gamma emissions with sodium iodide (NaI), the

energy resolution is about 100 thousand electron volts (keV), or about 20 times finer than it is with magnetic analysis.

Our NaI detectors revealed some hypernuclear secrets in 1983. We learned that the energy levels of a hypernucleus with one lambda particle are very close to the levels of the core, the basic nucleus without a lambda particle. This indicates that the interaction has a very small spin dependence (the energy of the interaction depends very little on the direction of spin of the lambda particle).

Knowing that the spin dependence is weak, we identified these states as core transitions, where the presence of the lambda particle perturbs the nuclear core, causing changes in its energy levels. We also knew that the spin of the lambda particle is one-half, so it is either oriented in the same direction as the spin of the core, or in the opposite direction. This meant that the energy levels of the core have to be split into doublets, where two hypernuclear levels exist for each core level.

Our goal during 1984 was to look at the transition between these doublet levels, to measure the spin dependence of the lambda-nucleus interaction directly. Because we needed even finer resolution than NaI could provide, we used detectors

made of germanium, which gave us a resolution of 2 keV, 50 times better than NaI.

Measuring spin dependence requires studying the various facets of spin dependence, known individually as spin-spin, tensor and spin-orbit interactions. We knew that if we could observe a spin-flip transition of a lambda particle, we would learn something about these terms in a hypernucleus.

When spin-flip occurs, if the spin of the lambda particle were oriented in the same direction as the spin of the core at the upper member (excited state) of the doublet, it would flip and be in the opposite direction to the core when the transition was completed, with the particle at the lower member of the doublet, in this case, the hypernuclear ground state. Lambda lifetime, however, is very short, so there was a

possibility that the particle would not survive long enough to make the transition.

Data from our 1984 experiment, however, show that the transitions do, in fact, occur. We observed the spin-flip transition of the lambda particle, and as a result of these observations, we are beginning to understand some of the facets of spin dependence. To continue that progress, our next experiment will focus on the third aspect — the spin-orbit interaction. We will try to measure this interaction in a carbon nucleus made hypernuclear by the addition of a lambda particle.

At the hypernuclear spectrometer at the AGS, Morgan May (foreground) checks data in an experimental logbook, while Dick Sutter tests the spectrometer's main magnet.

Department of Applied Science

The Department of Applied Science generates a base of scientific, economic and technical data on selected energy technologies and on the effects of energy-related activities on the environment. The department engages in a broad spectrum of research activities, ranging from the fundamental to the applied. These efforts are organized into three main areas. Under energy science programs are specific divisions working on chemical sciences, metallurgy and materials science, process sciences, atomic and applied physics, and energy economics systems analysis. Environmental science programs include atmospheric sciences, oceanographic sciences, terrestrial and aquatic ecology, biomedical and environmental assessment, environmental chemistry, and environmental systems analysis. Finally, technology base programs cover work on materials and electrochemistry, fuels and catalysis, architectural and building systems, thermal applications, and energy applications and analysis.

A New Angle on Materials

The experiment was simple, but the result was striking. We took an ordinary glass slide, coated it with a thin film of gold, and put it in an x-ray beam at a small angle. The x rays were absorbed only by the gold and re-emitted with a fluorescence signal strong enough to detect. Thus, an old technique was used in a new way and proved valuable in the study of material surfaces and interfaces.

The technique is called EXAFS, for Extended X-Ray Absorption Fine Structure. EXAFS is commonly used to study materials and biological and chemical specimens. It is a popular method because it provides local structural information on an atomic scale and can be used on systems which are difficult to study by x-ray diffraction

techniques. Normally, EXAFS involves measuring fine structure in the absorption edges of different materials. It can be used in studying the absorption of x rays as they pass through a sample, but it can also be detected in a reflected beam or in fluorescent x rays re-emitted from the sample.

In October 1983, when Brookhaven first used reflection EXAFS, we wanted to see how useful the technique would be in analyzing surfaces of materials and the interfaces between layers of materials. For that kind of work, however, we had to be sure the x rays would not penetrate deeply into the sample. Also, we anticipated trouble detecting only the x rays absorbed by the surface layer of gold because of a large background absorption in the much more numerous substrate atoms. To solve these problems, the standard EXAFS procedure was modified by aiming the x rays at a small, almost glancing angle. In addition, fluorescence detectors were used to measure what was re-emitted from the slide. Since the fluorescence detectors could be tuned to detect primarily the gold signal, the background from the substrate was minimized.

That first experiment showed us that we could make the x rays barely penetrate the surface of the gold layer.

The idea for combining grazing incidence angles with fluorescence detection evolved at Brookhaven, in collaboration with researchers from the University of Washington in Seattle. No one before, in any kind of study, had tried this new twist in using EXAFS.

It turns out that by controlling the angle, the x rays can be made to penetrate a sample, for studies of

interfaces, or to barely penetrate, for surface studies. The angles where this is possible range from one-quarter to one-half a degree.

In addition, a better signal is obtained by detecting the x rays that fluoresce — those that are absorbed by the sample and re-emitted in a different energy range — as opposed to those that are reflected. Because a fluorescence signal is so strong, we can measure minute amounts of a particular material in a sample.

BNL's modified EXAFS is a powerful new tool for studying the surface modification of materials, an active field today because of the need for materials for use in extreme conditions such as the harsh environments often found in energy generating plants, in the first walls of fusion reactors, etc. For example, one might want to put a layer of protective coating on a material so it can be used at high temperatures or in a corrosive environment. What are the conditions under which these coatings are stable? How do they adhere? Why do some materials bond strongly to others? To answer these kinds of questions, more fundamental studies are needed on the composition, structure and nature of chemical bonding. EXAFS, as used by BNL, provides that kind of basic information.

In general, EXAFS can be done on any tunable, intense source of synchrotron radiation. Our initial experiments were performed on a source at Cornell. Surface studies were carried out on thinly layered material on glass; on ion-implanted materials, where the ions are below the surface; and on multilayered materials.

Recently, experiments were begun at BNL's National Synchrotron Light Source (NSLS). The NSLS provides better optics, giving us more control over angles.

Now that BNL's EXAFS technique is proven, future work will be directed at examining a variety of material surfaces and interfaces. As more is learned about how materials stick together, Brookhaven will make that knowledge available to others so we can all do a better job of bonding materials.

LIGHT (FIBER OPTICS)

X RAYS

BNL's EXAFS illustrates a basic principle of optics. X rays, visible light and any kind of electromagnetic radiation can undergo total reflection at incidence angles which depend on the index of refraction (n). Fiber optics is an example of total internal reflection — the light stays within the fiber because it is traveling at very small angles to the internal surface, and the index of refraction of the fiber is larger than that of the surrounding air. The same is true for x rays, except the index of refraction is less than for air. Below a critical angle, x rays are totally externally reflected. To study just the surface of a material, the x rays are sent in at angles less than the critical angle. To study an interface, the x rays are aimed at an angle great enough to penetrate the surface, but not enough to penetrate the interface, so that they are refracted at the first surface and reflect off the interface.

Facing page: Steve Heald takes vacuum readings on the EXAFS beam line at the National Synchrotron Light Source.

Making Methanol a Best Seller

In 1983, BNL took a new approach to methanol synthesis and, in the process, discarded 60 years of tradition. The U.S. now produces over six billion pounds of methanol a year. Most of it is used as raw material out of which other chemicals are synthesized, such as formaldehyde, esters, acetic acid and higher alcohols. In daily life, methanol might be used as a solvent or an additive to increase octane.

Methanol is a highly reactive molecule which could have even greater potential, if it were cheap to make.

The truth is, it's not. The conventional method of synthesizing methanol uses catalysts that work only under high pressures and high temperatures. That's expensive. Plants have to be built to operate under severe conditions, with expensive compressors and intricate gas separators. Since single pass conversions yield

as little as 5%, the gases must be recycled many times to achieve reasonable production.

The methanol catalysts used in this process are very similar to the original methanol catalysts developed in Germany in 1921. Before then, methanol was made by distilling wood, hence the common name "wood alcohol." Making methanol out of wood was inefficient and resulted in many other products. So catalysts that selectively synthesized methanol were considered a breakthrough in those days. Even more,

the catalysts synthesized methanol out of carbon monoxide and hydrogen, which can be made from a wide variety of materials.

For years now, the prevailing attitude has been, "If it works, why change?" At BNL, we have taken the opposite approach. Recognizing the tremendous potential of methanol, we have worked on developing cheaper ways to make it.

It turns out that high temperature and high pressure go hand in hand with low yield. Theoretically, if the temperature were lowered, pressure would also go down and the yield would go up.

To attack the temperature problem, we began by studying the methanol reaction mechanistically. Coupling the information gained with previous studies using the BNL oxide theory, we developed catalysts that do the job.

The BNL catalysts work at temperatures around 100°C, as opposed to conventional catalysts that require temperatures in excess of 225°C. They also work under pressures less than half of what is conventionally required. Our achievable yield is 97%, compared to about 25% obtained in industry. And the BNL reaction is more than ten times faster.

Our results are based on laboratory work in which the methanol is made in small batches. We expect, however, that our new catalysts

would perform just as well in a plant operation. To prove that, in 1984, we began doing detailed chemistry and engineering studies in preparation for building a small, bench-scale unit to synthesize methanol continuously. This would allow a test of the new catalysts under more realistic conditions.

BNL's long-range goal is to drop the final cost of methanol production. A significant decrease would open up new markets. Ethylene is a good example. A key component of the 500 billion pounds of chemicals produced by the U.S. each year, ethylene is currently made out of petroleum and ethane. Using methanol to make ethylene would reduce U.S. dependence on foreign petroleum.

Methanol can also be converted to gasoline (which is now done in New Zealand) or even diesel fuel. Ideally, it can be used by itself as a fuel. Methanol burns cleanly, it has high octane, it's easy to handle and safe to store.

For similar reasons, electric utilities find methanol a good fuel for use during periods of peak power demand. Although electric consumption has slowed to an increase of 1-2% annually, demand for peak power has been growing quickly.

Methanol could become one of the most important commodities of the future. We think BNL catalysts will help pave the way.

Formulating Methanol

A single molecule of methanol, CH_3OH , is made up of one carbon atom, four hydrogen atoms and one oxygen atom. It is not to be confused with methane, CH_4 , the main component of natural gas and a product of decomposing organic matter, such as garbage.

Methanol can be made from a variety of feedstocks. Currently, it's synthesized primarily from carbon monoxide and hydrogen (synthesis gas), generated by the partial oxidation of methane with water.

Facing page: William Siegeir (right) prepares a catalyst to be used in converting synthesis gas into methanol, while Devinder Mahajan tests another formulation for methanol synthesis in a pressure reactor.

Left: Thomas O'Hare (left) and Richard Sapienza review data for catalyst improvement.

Airborne

All of the northeastern United States and southeastern Canada served as a giant laboratory for a field experiment in September and October 1983. Brookhaven scientists joined others from the U.S. and Canada in the study, called CAPTEX for Cross Appalachian Tracer Experiment.

The point of CAPTEX was to use a tracer gas to simulate the long-range transport of pollutants in the atmosphere. The study had three objectives: test the tracer technology over long distances, gain an understanding of the atmospheric processes that disperse plumes during extended travel times, and obtain data to evaluate and improve computer models of long-range pollution dispersion.

Brookhaven has been active in this area of research for many years. In the 1970's, we developed an ideal tracer gas, perfluorocarbon, for long-range tracer studies. Perfluorocarbon is inert, harmless and easily detected at low concentrations. During the same period, we developed a portable sampling unit, called BATS for Brookhaven Atmospheric Tracer Sampler. Battery operated and self-contained, the BATS unit can collect up to 23 consecutive samples.

CAPTEX was a full-scale test of tracer technology, and it made use of both the perfluorocarbon tracer and BATS. The tracer gas was released from a selected site, meteorologists predicted its path, and the plume was measured by ground sampling stations and by airplanes, both equipped with BATS.

The release sites were Dayton, Ohio, and Sudbury, Ontario, chosen because the Ohio Valley and Sudbury areas are considered to be significant sources of pollution affecting air quality in the northeastern United States and southeastern Canada. Specifically, the sampling area was east of Ohio, south of Ontario and north of Pennsylvania, about 250,000 square miles.

During the field study, the tracer gas was released six times — four

from Dayton, during weather movement from the west or southwest, and two from Sudbury, with flow from the northwest.

Brookhaven directed all aircraft sampling operations from a control center at BNL. For each release, seven airplanes were sent from their home bases in Ohio, New York and Canada to an airfield near the expected path of the tracer plume. Based on continuous meteorological forecasts, BNL directed the planes to sample the plume at selected distances from the source and at selected altitudes. One BNL plane was equipped with a newly developed real-time sampler for locating the plume and measuring its dimensions and concentration.

About 3000 ground samples and 1600 air samples were collected. A preliminary review of the data shows that the tracer gas was found during all six releases, as far away as 600 miles. The sampling methodology and equipment worked as planned; the experiment was a success.

Clearly, air pollution travels great distances and across international borders. A study like CAPTEX reveals how well we can predict the movement of pollution, based on meteorology. With growing regional and international concern about air pollution, especially acid rain, scientists have become increasingly engaged in studying pollution and estimating

concentrations. More specific information on how much pollution is coming from what source is essential for politicians and other decision-makers who are considering legislation to control emissions.

CAPTEX and similar future experiments will lead to a better understanding of dynamic meteorological processes, improved models for predicting long-range diffusion and more understanding of how air pollution travels from source to receptor.

To support field experiments like CAPTEX, Brookhaven's research aircraft is outfitted with sensitive instruments to measure chemical and physical properties of the atmosphere.

The Crew

Hurry up and wait. That could have been the motto of the BNL researchers who crewed the CAPTEX airplanes based in New York.

During the six-week field experiment, they flew six missions, tracking the plume through parts of New York, Pennsylvania, New Jersey, Maryland, Connecticut, Vermont and Canada. Each mission began with a telephone call from the aircraft control center on site at BNL, with news of an imminent tracer release and instructions on just where to go in the 250,000-square-mile sampling area. Depending on the weather, the plume could take anywhere from 12 to 36 hours to reach the area designated for air sampling. So the crews took off right away.

When they arrived at the field, the researchers checked with the control center for further instructions. Sometimes they went up to sample immediately, sometimes they had to wait.

Each of the four BNL planes carried a BATS unit. The sampler was hooked up to a side air vent, and steady air flow was maintained by a pump pulling air through the unit. One of the planes was also equipped with instruments for monitoring meteorological conditions such as wind and temperature.

For the CAPTEX flights, the BATS were set to collect continuously, ten minutes for each tube. The planes stayed up for about three hours at a stretch, making one pass through the plume. Each plane flew at an assigned altitude, ranging from 4,000 feet up to 10,000 feet. At the end of two passes, the plume had usually gone by, ending the mission. Then it was time to fly home.

Back in New York, the samples were taken to BNL for analysis, the planes and equipment were put in order for the next mission, and the wait began again.

National Synchrotron Light Source Department

The attention of the National Synchrotron Light Source Department was focused on two phases of development in 1984. Phase I was devoted to building and commissioning the Vacuum Ultraviolet (VUV) and X-ray Rings. Under this program, VUV Ring users enjoyed a second year of increasingly more reliable and fruitful operations at the world's brightest light source. At the same time, X-ray Ring users began gearing up for full-scale experimentation in 1985. Phase II, a project which will expand the present building and develop six highly advanced experimental beam lines, was given Congressional approval in July 1983. During 1984, final plans for the conventional construction were approved and the detailed design of four new beam lines was started.

Goals and Gains

In commissioning a synchrotron like the National Synchrotron Light Source (NSLS), there is no precise moment of completion. Rather, there is a continuing effort to improve the accelerator — first to meet design specifications, and then to surpass them.

We are well into the operational stage at the Vacuum Ultraviolet (VUV) Ring, where the research program has been under way for two years. During 1984, 137 users from over 25 separate institutions participated in experimentation at the VUV Ring. As the number and complexity of the experiments increased, we also worked to improve the light coming down the beam lines, with the following results:

- **High energies** — The VUV Ring routinely operates at 750 MeV (million electron volts), well above its design energy of 700 MeV.
- **Increased current** — An increase in current translates into an increase in the number of photons available for research. By September 1984, currents reached 385 milliamperes (mA), as compared to 215 mA reported in March 1983.
- **Smaller beam size** — The more compact the beam, the brighter it will be. VUV Ring design calls for a beam of synchrotron radiation 0.2 millimeters (mm) high and 0.5 mm wide. Although the overall beam size is half as big as it was a year ago, it

The staggering number of components and details that went into commissioning the NSLS Vacuum Ultraviolet Ring, as well as building the experimental beam lines scattered around it, can be appreciated by comparing these two photographs, taken three years apart from the same vantage point. The top picture shows research in full swing in 1984. In the bottom picture, taken in 1981, only the ring magnets are in position; yet to come are a concrete shield wall and beam lines.

is still twice the design specification, and we continue to work towards that goal.

■ **Longer beam lifetime** — The VUV Ring design calls for the stored beam to be maintained for several hours before requiring more electrons to be injected. In March 1983, operating at 235 mA, beam lifetime was one hour. In the fall of 1984, operating at 385 mA, beam lifetime was close to two hours. (Further improvement is expected before the end of the year.)

Much of the limited manpower and resources of the NSLS was diverted during 1984 to the commissioning of the X-ray Ring. Our near-term goal at the X-ray Ring is to achieve a current of 100 mA at 2.5 GeV (billion electron volts) with a four-hour beam lifetime. While we ended the fiscal year at 50 mA at 2 GeV with a two-hour beam lifetime, we expect to see dramatic improvements in all parameters as we install a second radio frequency drive system (energy), continue injection studies (beam current) and use glow discharge to increase the speed of our vacuum pumps (beam lifetime).

Recognizing how close we were to our goal, last spring we began alignment at the 15 ports that will send x-ray photons to the 35 beam lines which will serve the initial experiments at the X-ray Ring. By the end of September 1984, eleven of those ports were aligned successfully, and our plans were to install the equipment to complete the alignment of the other four beam lines by the end of the calendar year. Our efforts to bring the X-ray Ring and its beam lines on at a comparable rate will continue, and we expect to have a full experimental program at the NSLS X-ray Ring in 1985.

A Reader's Guide to the NSLS

Definitions of NSLS terms:

Electromagnetic radiation — Radiowaves, infrared, visible light, ultraviolet, x and gamma rays.

Electron — A light, negatively charged particle.

Electron volt — The amount of energy given to an electron when accelerated through a potential of one volt.

Photon — The basic unit (quantum) of electromagnetic radiation. It has neither mass nor charge. All of the research at the NSLS is based on the interactions of photons with different forms of matter.

Synchrotron — A ring-shaped device for accelerating particles like electrons in closed, constant orbits.

Synchrotron radiation — Electromagnetic radiation emitted by a rapidly moving charged particle when it moves in a curved path, e.g., when electrons are circulated in synchrotrons. The way this radiation, particularly ultraviolet light and x rays, interacts with matter has unique applications in most fields of science.

Ultraviolet (uv) radiation — Light in the wavelength range of 40 to 4400 angstroms; beginning at the short-wavelength limit of visible light, vacuum ultraviolet light overlaps the wavelengths of the longest wavelength x rays.

X ray — Electromagnetic radiation with wavelengths less than 40 angstroms.

Unique properties of the NSLS:

Brightness — The number of photons emitted into a given angle from a given area. The higher the brightness the higher the resolution, which is the amount of detail that can be seen. The NSLS Vacuum Ultraviolet Ring is the brightest uv source operating anywhere in the world. The NSLS X-ray Ring will be 100,000 times brighter than conventional x-ray tubes.

High polarization — Light from the NSLS is horizontally polarized.

Tunability — Synchrotrons radiate white light, which includes all the "colors" of the light spectrum, from x rays through ultraviolet and visible light and into the infrared region. Using devices called monochromators, users can select a narrow band of any one of those wavelengths to use in their experiments. (Most conventional sources of x-ray and uv light emit one or a few bands of wavelengths only and are of low brightness.)

Pulsed time structure — Electrons are injected, or pulsed, into the NSLS rings in bunches at fixed time intervals. Many experimenters depend on using a pulse of photons to excite a molecule. Then they measure the way in which the excitation is dissipated in the time between pulses. The measurement is repeated with each successive pulse.

Variety at the VUV Ring

The interdependence of various scientific disciplines is nowhere more evident than at the Vacuum Ultraviolet (VUV) Ring of the National Synchrotron Light Source (NSLS). For over two years, beams of ultraviolet light from an electron storage ring developed by accelerator builders have been welcomed by biologists, chemists and physicists for use in a wide variety of studies.

The researchers at the VUV Ring fall into two groups: general users and Participating Research Teams (PRT). PRTs include both our own scientists and researchers from outside Brookhaven who have designed and constructed beam lines on which to

conduct their large, long-range programs. In return for this investment, each PRT has priority for up to 75% of its beam line's time. General users, who usually have a less continuing need for a beam line, are scheduled for the remaining 25% of the PRT's beam line operating time, as well as for lines built specifically for use by the general user community.

The PRT policy, which will also be used at the NSLS X-ray Ring, has made it possible to build up scientific capabilities at the VUV Ring in a number of different areas simultaneously. An extensive range of equipment is now available for basic research in biology, chemistry and physics, and for such diverse applications as lithography, surface studies and x-ray microscopy.

VUV Ring Research Program

Altogether, 20 beam lines radiate from the VUV Ring's 14 operating beam ports. This table indicates the Participating Research Teams that designed

and constructed the experimental equipment at each port and the type of research that apparatus is intended to support.

Type of Research	Port	PRT Members
EXAFS/SEXAFS The techniques of Extended X-ray Absorption Fine Structure (EXAFS) and Surface EXAFS (SEXAFS) can provide local structural information on an atomic scale for systems difficult to study by x-ray diffraction. With EXAFS and SEXAFS, researchers study materials, and biological and chemical specimens.	U1	Exxon
	U4	Bell Labs
	U7	BNL/SUNY Stony Brook
	U8	IBM
	U14	NSLS
XPS & ARUPS Photoemission techniques, such as x-ray photoemission spectroscopy (XPS) and angle-resolved ultraviolet photoemission spectroscopy (ARUPS), measure the energies of electrons ejected from atoms when struck with photons, for information about the electronic structure of semiconductors and metal surfaces and help in studying photo-ionization processes of gases.	U1	Exxon
	U3	Los Alamos, Sandia, Lawrence Livermore Nat'l Labs/U. Calif.
	U4	Bell Labs
	U7	BNL/SUNY Stony Brook
	U8	IBM
	U12	Penn/ORNL/Xerox
	U14	NSLS

Type of Research	Port	PRT Members
Lithography With a view towards producing integrated circuits, VUV light is used to expose circuit patterns on photo-sensitive materials. Features as small as 0.25 microns have been replicated with high aspect ratios.	U6	IBM
Gas Phase Spectroscopy In photoemission, an ion is created and photoionization has occurred. Researchers study these processes in the valence shells of atoms and molecules in the gas phase.	U11	NSLS/BNL Chem
X-Ray Microscopy This PRT has constructed a soft x ray scanning microscope that is providing the first pictures of the internal structure of living cells in aqueous solutions, while imparting a minimal radiation dose to the sample.	U15	NSLS/SUNY Stony Brook
Fluorescence Molecules emit fluorescent radiation during a transition between excited states or from an excited state to a ground state. This can provide information about the lifetimes of the various states, the shapes and motions of molecules, and the fate of the energy they absorb.	U9	BNL Chem/NSLS
	U9	BNL Bio/NSLS
	U10	Tenn/NBS/ORNL
Dichroism Circular dichroism is a spectroscopic technique that uses circularly polarized light of two wavelengths to investigate the shapes of molecules like DNA, RNA and proteins. To study the electronic structure of a molecule's components, a magnetic field is added (magnetic circular dichroism).	U9	BNL Bio/NSLS
Optics & Diagnostics At port U2, optical components that help narrow the uv light to one wavelength are designed and tested. At U14, the beam is monitored, so problems can be diagnosed and corrected as they arise.	U2	NSLS
	U14	NSLS
Free Electron Laser This device produces a laser beam by passing electrons through an undulator, a magnetic device that can significantly enhance photon intensity and/or brightness over specified energy regions.	U5	NSLS

Accounting for Differences

The scientific community has long recognized that the electrons in an atom's outermost orbit affect the physical characteristics of solids and liquids. But what is it about those electrons that differs from material to material? What is it that causes those electrons to control every known aspect of behavior in a solid or liquid, including such physical properties as color, mechanical strength, thermal characteristics, magnetism, electrical conductivity, and whether the material is a semiconductor or a metal, soft or hard?

The differences in the energies of the outermost electrons seem to account for the physical differences we see in materials. Photoemission studies can take us towards a clearer understanding of this premise. At the National Synchrotron Light Source (NSLS), about 80% of the operating beam lines at the Vacuum Ultraviolet (VUV) Ring in 1984 supported photoemission experiments designed to help determine the energies of those electrons.

For individual atoms, the energy of the electrons in each orbit is well known. But atoms like to form groups known as molecules, in which electrons in their outermost orbits overlap. This sharing of electrons also binds solids and liquids together.

The energies of most of the bonding electrons are not known, but could be very important to our fundamental understanding of materials, as well as to their practical applications. At the NSLS, we hope to understand how energy differences

Gwyn Williams (right) works with general user Chris Blinn at U14, one of the first beam lines to be commissioned at the VUV ring. In the foreground at the front of the beam line is the photoemission chamber which, under ultra-high vacuum, holds both the sample and the detector that measures the electron energies. Directly behind it is the monochromator, the device that selects the wavelength of interest from the broad ultraviolet spectrum.

become responsible for physical differences by measuring electron energy by photoemission.

To do photoemission studies, we first select a particular wavelength of synchrotron light, which means we know the exact energy of the photons. Then we train that light upon a solid or a liquid in order to cause an emission — the ejection of an electron from the outermost orbit — so we can measure the electron's energy. If the incoming photon, for example, had 50 electron volts (eV) of energy and the ejected electron was measured at 40 eV, then, according to the inviolable principle of energy conservation, there are 10 eV unaccounted for. This must have been the amount of the energy which bound the ejected electron in the molecules of the target material.

Researchers from IBM and Bell Labs use this technique to study semiconductors, examining their physical and surface properties and analyzing the metals used in electrical contacts.

Scientists from Exxon and Brookhaven are developing photoemission as a tool for examining the interactions between metal surfaces and other reactants, which could be the key to such processes as oxidation (rusting). Some of our efforts are being concentrated on analyzing materials for the proposed Superconducting Super Collider.

Alloys, superconductors, catalysts and polymers are also among the systems being scrutinized by Brookhaven and other users with this probe. These analyses are possible because of several unique features of the NSLS: a broad energy range, which allows us to tune to match the binding energies of electrons; high brightness, which translates into high resolution; polarization, which is helpful in uncovering a molecule's specific geometry; and high energies, which let us study more electrons, including those deep down in the atom.

Probing those inner electrons by photoemission has had an unexpected payoff. We have found they play a role in determining a mate-

Atoms in molecules (solids, liquids or gases) share the electrons in the outermost orbits. The energies of these electrons, as well as those at even higher, unoccupied levels, control all the physical properties of materials. They are studied using photoemission, in which either (A) a photon of known energy directly knocks out an electron, which is collected and measured, or (B) a photon sends an inner core electron to an unoccupied level (1). This subsequently decays (2), releasing energy or an electron (3), which is then measured.

rial's physical properties, and, most important, that they can be used to study the role of the crucial outermost electrons. They can also be used to study outer orbits normally without electrons, as we measure what happens when the core electrons are excited into those states.

In related work, we have used the high brightness of the NSLS to probe the highly important carbon K-edge — the innermost electron orbit of a carbon atom contained in a carbon monoxide molecule. Our measurement of the energy involved in ejecting an electron from the K-edge to an outer orbit was done at such a high resolution, that the energies of vibration of the molecule could also be seen.

Chemistry Department

The wide variety of research done in the Chemistry Department encompasses a broad range of experimental and theoretical work directed toward a fundamental understanding of the properties and reactions of nuclei, atoms and molecules. Special facilities, apparatus and techniques available at Brookhaven are used to make unique contributions to the standard fields of organic, inorganic, physical and analytical chemistry. Other important areas studied include nuclear and radiation chemistry, radio-pharmaceuticals, and the use of neutron diffraction and scattering to study solids.

Cluster Ions: Micro-Tools for Multipurposes

From a better understanding of catalysis to insights into energy transfer processes, the applications of cluster ion research promise to be far-reaching. Brookhaven chemists began studying cluster ions only five years ago. Some of our latest experiments are documented by startling photographs of thin films of material after they have been bombarded by cluster ions. The clusters have made minute and uniform holes in the films, a phenomenon that suggests cluster ion applications in micromilling and microdrilling, and patent protection is being sought to cover the novel features of that discovery. Clearly, Brookhaven is in the forefront of an exciting field of research.

Clusters fit somewhere between a single molecule and a large group of molecules that form a solid. In terms of energy, they fall somewhere between systems that have discrete energy levels and those that have continuous energy levels.

Brookhaven's cluster ion research actually grew out of our work with mass spectrometry, which began nearly four decades ago. Mass spectrometry is the 20th century equivalent of the analytical balance. Using it, we can weigh samples as small as several trillionths of a gram. As such, mass spectrometry is the basis for modern quantitative chemistry.

Initially, we used the technique for isotope analysis. Next came the first demonstration of its structural application, when Brookhaven proved the arrangement of atoms in an unknown molecule.

We went on to biological applications, developing a rapid heating technique for studying fragile molecules — molecules that are difficult to produce intact in the gas phase. Then we became interested in expanding our techniques to study molecules of great mass. When we started, we could weigh molecules of less than ten thousand daltons (atomic mass units). Today, we can weigh molecules with a mass range up to half a million daltons. Because we now have a mass spectrometry

system with such a high mass range, we are able to study cluster ions.

Cluster ions contain anywhere from a hundred to several thousand molecules. To make them, we start with a source of a gas cooled to around its boiling point and held at a relatively high pressure. A supersonic nozzle connects the source to a region which is maintained at relatively low pressure. An electrode is positioned close to the nozzle and carries a potential such that at least a portion of the gas is ionized in the source, before it travels through and expands from the nozzle. The ions in the expanding gas act as "seeds" about which clusters readily form.

The clusters are then separated by a quadrupole mass analyzer using direct current and radio frequency fields that whip along only those in resonance. In the acceleration process, the clusters reach speeds over 10^7 centimeters per second (over 60 miles a second, although they travel only a few meters to the target).

Of course, cluster ions moving at that speed are impossible to see, but with the Biology Department's transmission electron microscope, we have examined their impact on surfaces. Studies have shown that clusters can produce very small holes in thin carbon films. Besides the obvious potential for micromilling and microdrilling, cluster ions can be used to generate surfaces with special properties.

Another project we are working on looks at the difference between penetration of a solid and crater formation on the surface. When a cluster hits a target, it can act as an atomic projectile that penetrates the material or as a micrometeorite that creates a crater, compressing the surface and sending shock waves through the material. We are seeking answers to such questions as: Where is the transition between projectile and micrometeorite? Is there a change in energy transfer?

Energy transfer refers to how energy can be stored in materials. In a solid, there are several classes of energy which account for the vibrations, rotations and excitations of

This electron micrograph shows the small, uniform holes, magnified here 200,000 times, that resulted when a thin film of carbon platinum alloy was bombarded with cluster ions of water.

electrons. Converting energy from one category to another is the key to determining the rates of chemical reactions, and understanding this energy transfer is a major challenge of chemistry. Cluster ions can be useful here.

Perhaps our most basic quest will lead to more information about stars. When cluster ions hit a target with sufficient energy, the impact creates, for an instant, conditions similar to those that exist in stars — extremely high temperatures, pressures and densities. We want to learn something about the properties of matter under those conditions, which again will tell us more about energy transfer.

Brookhaven is moving quickly in the new field of cluster ion research. We know it is a profitable area, promising rewards in basic chemistry as well as practical applications in many fields.

In the shadow of a cluster ion acceleration terminal, Lewis Friedman checks data patterns on an oscilloscope.

Molecules in Motion

A molecule can be as simple as two atoms of hydrogen, or as complex as DNA. Whatever its size, most of the time, a molecule is in its ground state, in which the nuclei and electrons are in their lowest or near lowest energy state. With some extra energy, however, a molecule can go from its ground state to an excited state, in which the relative motions of the nuclei and electrons have been excited. These excited states are always available to a molecule. It's just a matter of hitting it with the right amount of energy. At BNL, we have the latest generation of tools for providing that excitation energy — the National Synchrotron Light Source (NSLS) and a new laser laboratory in the Chemistry Department. These two facilities, although technically very different, complement each other in support of Brookhaven's basic research which contributes to our understanding of molecules and their interaction with light.

The laser studies focus on neutral excited states lying below the ionization energy threshold (the minimum energy required to remove an electron from the molecule), while the higher energy photons from the NSLS are used to prepare so-called "super-excited" states lying above the ionization threshold. In both techniques, the optically prepared states are driven to ionization, at which point measurements on the ion or electron product yields are made.

In 1984, experiments on the Chemistry beam line at the NSLS focused on the non-radiative decay

At the National Synchrotron Light Source, photoionization apparatus is installed at the U11 beam line on the Vacuum Ultraviolet Ring. Special equipment (center) is used to prepare molecular clusters by supersonic molecular beam techniques. The molecular beam (moving right to left) intersects the photons emitted from the ring (located behind the concrete shielding blocks). From left are J. Robb Grover, Michael White, Edward Walters and John Densieski.

(autoionization) of super-excited states in several small molecules. As these states lie in an energy region where ordinary laboratory light sources are weak, studies of this kind have become possible only with the construction of intense, continuous synchrotron radiation sources such as the NSLS. By measuring which electronic and vibrational levels are populated following the decay of the autoionizing state, we have been able to map out how an excited molecule partitions its excess internal energy between the resulting ion and ejected electron. Such measurements form the basis for understanding non-radiative decay processes, which play a major role in the decomposition of highly excited molecules.

The new Chemistry laser system provides pulses of intense, tunable, visible and near ultraviolet light. With successive hits, the target molecule goes from the ground state to an excited state and is then

ionized (the process is called resonant multiphoton ionization). By adding electron energy analysis to the multiphoton ionization technique, we have been able to explore the electronic and vibrational structure of molecular excited states at a detailed level not readily attained by other methods.

Compared to the laboratory vacuum ultraviolet sources used in conventional photoionization experiments, laser and synchrotron radiation offer tremendous new experimental opportunities. The extreme intensity and high resolution capabilities of modern laser systems enable photoionization techniques to be applied to neutral excited states, which in favorable cases can be prepared at the single quantum state level. Synchrotron radiation from the NSLS offers tremendous advantages over conventional laboratory light sources in both intensity and energy range. At Brookhaven, we have the best of both worlds.

In the Chemistry Department's laser laboratory, Michael White directs visible laser radiation into a target vacuum chamber (left) for photoionization studies of excited molecules.

Rubipy Causes a Reaction

Friends call it Rubipy, but its real name is tris(2,2'-bipyridine)ruthenium(II). Rubipy plays a major role in Brookhaven's fundamental studies of electron transfer processes, which occur widely in nature.

At the center of the Rubipy complex is an atom of the transition metal ruthenium, which shares electrons with six nitrogen atoms. Each nitrogen forms a ring with five carbon atoms. In turn, four of the carbons are each bonded to a hydrogen atom (not shown). The fifth carbon in a ring is bonded to a carbon atom of an adjacent ring such that the six rings are actually divided into three sets of two bonded rings. The complex, with a net charge of 2+, shares the electrons of its rings freely in a relatively spherical electron cloud that engulfs the entire molecule.

About ten years ago, we began investigating electron transfer in excited states of molecules — reactions induced by light. A bonus of this basic research is that it has interesting practical applications. We now have designed systems that use Rubipy to capture light and initiate chemical reactions that can produce useful fuels. One system generates hydrogen from water, and a second shows promise for reducing bicarbonate to formate, which is a starting point for making certain fuels.

Rubipy consists of a central atom of the element ruthenium, buried in a cluster of six nitrogen atoms. The nitrogens form an aromatic ring with five carbon atoms, each bonded to a hydrogen atom (see illustration). Brookhaven was the first to use Rubipy for light conversion studies, and other researchers have since followed our lead. Because it strongly absorbs visible light and readily undergoes electron transfer reactions, Rubipy is an excellent catalyst for these reactions.

The reaction begins when Rubipy absorbs light energy. In this process, an outer electron of the ruthenium atom is "promoted" to a higher energy level. In fact, the promoted electron has relocated to an electron cloud surrounding the aromatic rings, and this is called the excited state. Putting an extra electron onto the electron cloud gives it a negative charge and leaves a positively charged hole in the ruthenium atom. This change in their charges makes the aromatic rings and the ruthenium center very reactive.

Normally, the excited state will live for only a microsecond before the electron drops back to its original position on the ruthenium atom. When it does, some of the energy is

given up as light, called phosphorescence. Most is simply given off as heat.

To compete with the decay of the excited state (to the ground state), chemistry is done either to remove the electron from the aromatic rings or to block the hole on the ruthenium atom. These reactions of the excited state with electron accepting or donating molecules (Q) are called quenching reactions:

followed by

or

Thus, the energy originally introduced into the system by a single molecule absorbing light is used to generate an electron and a hole on two separate molecules.

The next step is to prevent the back-reaction of the two molecules. This problem requires another series of reactions, and it is these secondary reactions that ultimately yield hydrogen, oxygen or some other useful fuel.

This work might be thought of as artificial photosynthesis. In nature, green leaves turn sunlight into energy, which the plant uses for growth. Essentially, we are trying to do the same thing, only instead of growing a plant (which can be burned for fuel), we want to channel that energy directly into making hydrogen.

With our current understanding of the chemistry taking place during electron transfer reactions, we have been successful in solving the difficult problem of back-reaction under certain conditions, and have developed a system which produces hydrogen with 30% efficiency. But while that efficiency is high enough per single reaction, the net efficiency drops as the reaction is repeated many thousands of times. Side-reactions occur that interfere with subsequent chemistry.

These same side-reactions occur in photosynthesis, and when they overwhelm the system, the plant repairs itself by dropping leaves and growing new ones. Unfortunately, our chemical system has to be self-contained, and the undesirable side-reactions have to be eliminated, or at least held to a minimum. This is the challenge of our future work.

In 1984 additional studies were done to ascertain the factors that determine the rates of quenching and back-reactions. Also, we charac-

terized the properties of the hydrides, which are the immediate precursors to hydrogen, as well as the properties of certain intermediates in oxygen generation, the process complementary to hydrogen formation.

Norman Sutin aligns a laser used for photochemical studies involving Rubipy and various quenchers. The neodymium laser, with a pulse width of 25 nanoseconds, is used to convert the Rubipy into its excited state.

Medical Department

The Medical Research Center is divided into three sections: research laboratories, the Clinical Research Center, and the Occupational Medicine Clinic which serves BNL.

At the Clinical Research Center, human subjects participate in clinical studies on conditions which include pulmonary disease, osteoporosis, chronic lymphocytic leukemia and neuropsychiatric disorders. Animal subjects, housed and cared for in our large- and small-animal facilities, are used in studies of such areas as inhalation toxicology and mammary carcinogenesis.

Overall, research falls into five categories: environmental health sciences, medical applications of nuclear technology and medical physics, host defense sciences, nuclear medicine, and genetics and biochemical sciences. Each of these categories covers a broad range of research, as illustrated by the following glimpse into our work in genetics and biochemical sciences.

More Evidence For Cancer Prevention With Vitamin A

Vitamin A deficiency has been associated with an increased risk of various types of cancer in humans. And there is a growing body of evidence that retinoids (a chemical group which includes vitamin A, its derivatives and analogues) are effective in reducing certain kinds of cancers, at least in animals.

Some of that evidence comes from Brookhaven's research into carcinogenesis. Since 1981, with funding from the National Cancer Institute, we have conducted a study to evaluate the ability of retinyl acetate, a vitamin A derivative, to inhibit the development of breast tumors in rats.

We looked not only at the total number of tumors, but at the proportion of rats with breast tumors, over a period of 1,113 days — equivalent to a 95 to 100-year human life span. Concluded at the end of September 1984, this has been the only life span study of retinoid inhibition of any tumors in any species. Further, it has provided the only existing data on the inhibition of radiation-induced and spontaneous breast tumors in rats.

To begin the experiment, a population of 625, 55-day-old female rats was divided into eight groups. Two groups were given a single oral dose of the carcinogenic chemical compound dimethylbenz[a]anthracene (DMBA) in sesame oil, while two control groups received only sesame oil. Two of the remaining groups were given a sub-lethal, whole-body dose of x rays, while the final two control groups were sham-irradiated.

Seven days after these treatments, we began putting retinyl acetate in the food of one half of the

Claire Shellabarger (left) watches as John Stone (seated) operates on a rat to remove a mammary tumor. Seymour Holtzman records the information about a tumor removed earlier, in a log-book containing tumor histories of all the rats in the study.

rats, and those rats remained on this diet throughout their lifetimes.

From then on, each rat was checked weekly for breast tumors. Tumors with a diameter of one centimeter or larger were surgically removed and histologically classified. Two types of mammary tumors were observed: benign fibroadenomas and malignant adenocarcinomas. Adenocarcinomas in rats, however, do not metastasize as often as they do in humans.

As the data were tabulated, they showed that whether tumors were induced by DMBA or x rays, retinyl acetate inhibited both the proportion of rats with adenocarcinomas and the total number of adenocarcinomas per group. A similar inhibition of both incidence and number of chemically and radiation-induced breast tumors was observed with fibroadenomas.

Most interesting, however, were the results with rats that received no carcinogen — the ones which could only develop spontaneous tumors. In those put on the retinyl acetate diet, the proportion of rats with a tumor was significantly inhibited. Overall, in the control groups, rats that were not fed retinyl acetate developed one or more spontaneous tumors five times more often than the controls fed retinyl acetate.

The results of the first 650 days of this study were reported in the previous Highlights (Jan. 82 - Mar. 83). At that time, too few spontaneous tumors had appeared in the control groups to evaluate the effects. But at 700 days (about 60 years in human terms), the proportion rose dramatically, underscoring the value of a life span study such as this. Since most humans

are not normally exposed to the relatively large doses of carcinogens given to the rats, the spontaneous tumor data may most accurately reflect the human condition.

Charted here is the proportion of female rats which developed a mammary adenocarcinoma during the 1,113 day study. Note that whether the rats were exposed to the chemical DMBA, to x rays or to no carcinogen at all, significantly fewer cancerous breast tumors occurred in the rats that were fed retinyl acetate on a daily basis. (For charting purposes, data from the four control [sham] groups are combined into two lines).

The Free Radical Connection

Ozone, asbestos, radiation, smoke — these are among the agents that can wreak havoc in the human body, if introduced in sufficient quantities. Some do damage by poisoning the system, while others are carcinogens.

In Brookhaven's continuing research in biochemistry, we have looked for connections between the reactions that produce these seemingly unrelated toxicities. We now believe that the presence of free radicals supplies that connection. Free radicals are chemical compounds which have at least one unpaired electron, and, in their search to complete the pair, they tend to be very reactive.

Free radical reactions have been implicated in such conditions as inflammation and edema from various causes, reperfusion injuries (injuries that occur when blood

flow returns to oxygen-starved tissue, as after a heart attack), toxicity resulting from too much oxygen, and the toxic side effects of some cancer drugs. They are also being linked to aspects of the aging process.

The cycles that produce these damaging reactions can go on for hours, days or even longer. Some of the oxidative reactions involve metals found in the body, such as iron and copper, and can culminate in the production of a free radical called the hydroxyl radical ($\text{OH}\cdot$). When $\text{OH}\cdot$ is formed close to or in a cellular membrane, it can react with the polyunsaturated fatty acids, or lipids, that comprise most of the membrane, to begin oxidative reactions that form lipid peroxy free radicals ($\text{LOO}\cdot$) and lipid hydroperoxide (LOOH). Reactions of $\text{LOO}\cdot$ or LOOH that start in a cell's nuclear membrane can ultimately affect the DNA in contact with it.

Basically, this lipid oxidation is the same reaction that occurs when fats turn rancid in foods. And it appears to be the process that, in some cases, causes the ultimate damage to living tissue. In other cases, the membrane lipid oxidation results from primary damage elsewhere in the cell. With a carcinogen, only one cell may carry residual damage in its DNA, and the damage, after being silent for many years, may or may not develop into a cancer. In the case of a general cell toxin, however, many cells are affected simultaneously, disrupting organic function.

For one of our models of this free radical type of toxicity, we chose paraquat, perhaps best known as the weed killer used to destroy marijuana fields. This herbicide biodegrades in sunlight in three days, but if even very small amounts are ingested, paraquat is

almost always fatal to humans, due to these oxidative and free radical reactions occurring on a massive scale in the lung.

Paraquat becomes concentrated in the lung and initiates the reaction sequence that results in a constant production of $\text{OH}\cdot$, which then attacks the lipids in the lung membranes, producing edema as a result of breaking down the cells lining the pulmonary vessels and air passages. If the dose is high enough, the victim essentially drowns in edema fluid, dying of acute respiratory insufficiency. Even those who survive the first few days may die of chronic respiratory insufficiency over the next several weeks.

Our primary tool in studying these mechanisms has been Electron Spin Resonance (ESR), a method for specifically identifying free radicals, monitoring their reaction rates and inferring the reaction mechanisms. Using ESR in conjunction with other techniques, we have gathered conclusive evidence that, in the case of paraquat, metals play an obligatory role in connecting the initial oxidation processes. It is also now clear that metal-driven oxidative free radical cycles can operate within membranes as well as within the watery regions of the body.

We are now applying this basic information to search for a therapy for paraquat toxicity. Our first attempt, one in which rats were given large doses of a compound known to remove iron from body fluids and liver cells, failed. This experiment, however, did contribute to unraveling the complexities of the interrelated oxidative and free radical mechanisms of toxicity in the body, and more work with paraquat is planned.

Our efforts in the broad and important field of health effects of oxidative and free radical damage will continue, emphasizing the impact of environmental exposures and, perhaps, eventually opening the door to successful interventions.

In its ability to cause damaging reactions, paraquat is similar to some other toxic agents. In this example, (1) paraquat is ingested and (2) becomes concentrated in the lung, initiating a reaction sequence that depends on oxygen and results in a prolonged production of the free radical known as the hydroxyl radical, or $\text{OH}\cdot$. (3) The $\text{OH}\cdot$ attacks the lipids in the lung membranes and other vital components of cells, breaking them down. (4) The damage to the lung blood vessels, cells, and air passages can result in a dangerous buildup of edema fluid, in the lung tissue.

Karen Schaich (seated) and Donald Borg (standing) use electron spin resonance to study free radicals. As Schaich injects a solution containing free radicals into the sample cavity between the poles of the spectrometer's magnet, Arthur Forman works with the laboratory computer to collect and analyze data from the experiment.

Of Chemicals and Chromosomes

When a chromosome aberration occurs, the genetic material has been changed. Such variations are surprisingly wide-spread, arising spontaneously, or from exposure to agents such as radiation or chemicals. Generally, these changes have no effect on an individual and go unnoticed. In some cases, however, they can initiate a cancer or cause birth defects in future generations. But how much exposure is necessary to cause a detectable increase in chromosome aberrations? Do they occur more frequently in an exposed population than in the normal population?

In the 1960's, these kinds of questions were answered by a study which provided baseline measurements of exposure to ionizing radiation in a normal population, for comparison with measurements from exposed populations. Unfortunately, the aberrations produced by ionizing radiation are different from those produced by chemical exposure, for which comparable analyses were never done. Thus, recent cases of chemical crisis, such as Love Canal and Agent Orange, took place without baseline data against which to measure claims that Love Canal residents or Vietnam veterans suffered more chromosome aberrations than the normal population.

That situation is in the process of being rectified by our five-year baseline study of chromosome aberration due to chemical exposure, a collaboration between Brookhaven and Oak Ridge National Laboratory that began in 1982. Supported by the National Toxicology Program (NTP), the study is epidemiological in its approach to generating a random sample and cytogenetic in the techniques used to measure chromosome aberrations. The marriage of these two disciplines assures that our cytogenetic studies are designed properly and gives us confidence that we have controlled the signifi-

cant confounding variables — age, sex, medical background, personal habits, etc. — in a statistically significant sample population.

For the first three years, the study sample was drawn from BNL employees, nearly 400 of whom volunteered to answer our questionnaire and donate a 10-milliliter blood sample. Though men and women responded about equally, we concluded the first three years with a sample limited in terms of race and age, and our aim in the final two years is to extend the study in these directions.

Examining the white cells from the participants' blood samples, our cytogeneticists are looking for two end points: chromosome aberration and sister chromatid exchange (SCE). Though SCE was discovered at Brookhaven in 1957, methods for applying it to large groups of people became available only a few years ago. Now we are evaluating the sensitivity of both SCE and chromosome aberration as a measure of the effect of chemicals in the environment and the workplace.

The protocols under which the blood samples are studied are precisely the same as those used in a previous study (1982-3), for which we collaborated with the Center for Disease Control (CDC) and Oak Ridge to investigate the incidence of chromosome aberrations in residents of Love Canal and a control group from the nearby Niagara Falls area. The CDC study was undertaken to resolve controversy raised by an earlier study (1980) conducted without a control group, which suggested that Love Canal residents did have increased chromosome aberrations. But when the results of Brookhaven's study were released in May 1983, they showed no difference between residents and controls.

Though our findings resolved many of the concerns raised by the control-deficient effort, we realized at the outset of the CDC study that baseline measurements would increase our confidence in the con-

trol data. That is why we initiated the current NTP study: to provide guidelines for looking for variables that might affect the choice of controls and the size of the control group, when setting up a study of exposed populations.

Seen through the laboratory door is Beatrice Pyatt (foreground), who prepares to analyze a slide containing a few drops of blood. Pyatt is looking for chromosome aberrations. Results of previous analyses are being scrutinized by Robin Leonard (seated) and Michael Bender.

The Other Side Of the Story

It is said that there are two sides to every story, and the story of our chemical baseline study is no exception. The other side is our basic research on the molecular mechanisms involved in causing chromosome aberrations.

As part of this research, we study diseases with DNA repair deficiencies. One of these is ataxia telangiectasia, a genetic disease where the sufferers are extremely sensitive to radiation and abnormally cancer prone. The number of affected persons is very small, while the number of carriers is much larger. We ask such questions as: What accounts for these phenomena? Are carriers also at an increased risk of getting cancer? Are they also more radiosensitive than other people?

In search of answers, we irradiate cells from both sufferers and carriers, then study the production of chromosome aberrations during the different phases of the cell cycle. We have found that in one phase, the sufferers' cells are chromosomally radiosensitive, but only the usual types of aberrations occur. Cells in another phase, however, are not chromosomally radiosensitive in the usual sense, but instead display abnormal aberration types. We have not yet detected similar events in the cells of carriers.

We see these findings as a clue to understanding the molecular mechanisms behind the formation of chromosome aberrations. And as we continue our basic research, perhaps the rest of the story will unfold.

Biology Department

Research in the Biology Department falls into three main areas: the design and operation of unique experimental facilities that are used extensively for structural biology; the structure, function and control of normal cellular activities; and the responses of cells to radiation and chemical damages. In 1984, a Center for Structural Biology was established within the department to assume responsibility for the department's Scanning Transmission Electron Microscope (STEM) and for the structural biology instruments at the High Flux Beam Reactor and the National Synchrotron Light Source.

T7 and Genetic Engineering

Twenty years ago, Brookhaven selected an obscure virus named T7 for studies of DNA. We picked T7 because it contains a single piece of DNA with only about 50 genes, in contrast to a plant or animal cell containing thousands of genes. Today, this simple virus has carried the Laboratory into the vast arena of genetic engineering.

The bacteriophage T7 magnified 365,000 times.

T7 is a bacteriophage, or "bacteria-eating" virus. When T7 invades a host cell, it makes proteins that turn off the host genes and turn on the T7 genes. In this way, it converts the entire cell to making new T7 viruses. In a short time, the host cell dissolves, releasing hundreds of T7 virus particles to infect other cells and repeat the process.

We have learned in great detail how T7 works. We understand its genetics; we've determined the sequence of the nucleotides in its DNA, all 39,936 base pairs; we've cloned virtually every gene; and we have mutants of almost all the genes. Such complete information is powerful stuff and allows us to manipulate the system in novel ways.

Several years ago, Brookhaven began applying this knowledge of T7 to make particular proteins in large amounts. The idea was to mimic the way T7 works.

To express a gene (to take information in the gene and use it to make a protein), the cell makes a messenger RNA, which carries information from DNA to the ribosome, a protein factory. The key to T7's successful invasion of a host cell lies in its ability to control which messenger RNAs are made.

Messenger RNA is made by an enzyme called RNA polymerase. The signal that tells the RNA polymerase which messenger RNAs to make is called a promoter. When T7 invades a host cell, it makes an RNA polymerase that recognizes only a very specific promoter already found in T7

DNA — and not found in the DNA of the host cell. At the same time, T7 takes an additional step to ensure its success: it deactivates the host polymerase, preventing any production of messenger RNA from the host DNA. Hence, the only active polymerase is T7's, which reads only promoters in its own DNA.

T7 uses this strategy to its own advantage, and we can use it too, to make any protein at will. We start by cloning the T7 gene that produces RNA polymerase, so the polymerase can be made separate from the T7. The specific promoter is added and, next to it, the gene for the protein we want to make. And there it is: we've engineered a system to make proteins.

We can also fine-tune the system so that a lot of protein is made. Each messenger RNA contains signals to tell the ribosome where to start and stop in making a protein, and how much of the protein to make. Because T7 has to make many new virus particles in a short time, T7 messenger RNAs have signals that tell the ribosomes to make lots of protein. In principle, these signals can be used to boost the amount of any protein, and we are incorporating them into the messenger RNAs for the proteins we wish to make.

Brookhaven is by no means the only laboratory to develop a system that makes proteins. Many others have — witness the big business today in engineering new drugs such as interferon, agricultural proteins such as pesticides, enzymes for food processing, growth hormones, and the missing clotting factor in hemophiliacs. One advantage of our T7 system may be its ability to direct all the action to a single gene, while shutting off all other genes in the cell.

Through the years, T7 has become an intimate friend, giving up its secrets to our constant prodding. Brookhaven's exhaustive research on this virus was undertaken to learn about the fundamental processes of life. Now it promises to pay off in practical contributions to genetic engineering as well.

William Studier (left) and John Dunn check the results of an analysis of protein production.

Through the Eyes of STEM

Through the eyes of STEM, Brookhaven's scanning transmission electron microscope, objects appear ten million times bigger with such fine resolution that scientists can see biological molecules and even single heavy atoms.

Joseph Wall (left) and James Hainfeld watch an image of a sample reconstructed on a TV screen as the sample is scanned by STEM in the background.

An electron microscope illuminates a specimen with electrons and magnifies and focuses with magnetic fields. The main difference between an ordinary electron microscope and a scanning transmission electron microscope is that the latter scans a specimen one point at a time and is much more sensitive to small objects.

In Brookhaven's STEM, electrons are focused to a tiny point 2.5 angstroms in diameter (one angstrom is about the diameter of an atom). Probing a specimen sequentially, the electron beam builds a picture the

way a TV does. Electrons passing through the specimen are picked up and analyzed by sensitive detectors, and the signals fed into a computer, which reconstructs an image on a TV screen. Because it can make an image of a specimen as well as precisely measure the number of electrons that interact with atoms in the specimen, STEM is a powerful tool in the study of biological structure.

Specifically, the microscope is used to make mass measurements of proteins, nucleic acids, and complexes of the two, such as viruses. Mass measurements provide a direct link between the image of a specimen and biochemical information on that specimen. When the measurements are correlated with the biochemistry, they can be used to identify objects in an image and determine the arrangement of internal components (mass mapping).

In 1984, we added a new dimension to mass mapping by developing new techniques for labeling molecules, techniques which allow us to highlight specific chemical sites on a molecule.

One method uses as a label a cluster of eleven gold atoms. Eight angstroms in diameter, the gold cluster is ten times smaller than conventional microscopic labels. The smaller the label, the more detail can be seen. So far, three experiments have been done: confirming the position of the carbohydrate on haptoglobin; finding the biotin binding site on avidin (work done in collaboration with the University of Pennsylvania); and labeling lysine residues on proteins.

The second labeling technique uses a single platinum atom. In one experiment (done in collaboration with the National Institutes of Health), the platinum atom was attached to an adenosine triphosphate molecule (ATP). This complex was then bound to glutamine synthetase, a bacterial enzyme, to locate that enzyme's 12 binding sites for ATP. Previous biochemistry work had shown that six binding sites were on the top and six on the bottom. Our experiment revealed the exact loca-

tions of these sites at the edge of the molecule.

STEM operates full-time for Brookhaven scientists as well as for those from other laboratories, universities and industry. The busy research program testifies to the microscope's reliability and capability. A new electron source has been developed so that doses to the samples can be reduced, thus decreasing radiation damage. Also, major advances have been made in sample preparation and in image analysis techniques. As a result, the mass measurements continually improve, and we expect to achieve a useful resolution of 5.0 angstroms on essentially undamaged biological specimens.

Performing one step in the long and exacting process of preparing a sample for STEM, Kristin D. Chung uses a pipette to place a drop of sample onto the surface of a microscope grid so small it appears as a black dot at the tip of the pipet. In her other hand is filter paper used to absorb excess sample from the grid.

The worm-like object is really a polymer chain of ten avidin molecules magnified about 1.4 million times. The avidin has four locations where biotin binds tightly. The pairs of black dots are gold atoms which label the locations of biotin-binding sites on avidin. The experiment is the first time this labeling method has been used successfully to mark a biochemical site in a molecule for electron microscopy.

Counting Kernels for Better Crops

Each year, Brookhaven plants two to six acres of corn on Lab property and a tenth of an acre on the fertile island of Molokai, Hawaii. At harvest time, the succulent ears are destined not for the cafeteria lunchtables, but for certain biology laboratories, where our work in molecular genetics will be of long-range benefit to plant breeders.

Molecular genetics is the study of inherited characteristics at the DNA level. Brookhaven uses corn for molecular genetics research for two main reasons.

The genes are often visibly expressed in the kernels, making it possible to correlate changes at the DNA level with observable changes on the plant. And corn is easier to manipulate genetically than most other plant species.

Frances Burr applies a sample of corn protein to a gel in preparation for electrophoresis, which will separate the proteins. This is one of a number of biochemical and molecular techniques applied to practical problems in plant breeding.

Today, new analytical techniques have been developed that can aid the plant breeder. For example, the DNA can be marked to identify genetically important regions in different strains of plants. Also, studies are now possible on biologically important phenomena that confront the plant breeder.

In 1983, Brookhaven began a set of experiments on mutations. This work was initiated by the observation that when cells are grown in tissue culture, mutations occur frequently. We wanted to know what actually caused them. We also wanted to discover the mechanism of mutation and see if it could be made economically useful as a way to get desirable mutations.

For plant breeders working to improve major crops like wheat, soybeans, corn and rice, the advantages of selective mutations are clear. In the last 20 years, for example, mutant dwarf stock has been used to develop new hybrid wheat and rice varieties. The dwarf plants put more energy into growing the grain than into growing the plants.

Conventional plant breeding is done by looking at a very large

number of individual plants, making a selection and breeding only those selected. To get new genes into the pool, breeders regenerate plants from tissue culture, relying on that method to get new mutations.

We did a genetic analysis of the tissue culture method and confirmed that the process of regeneration in tissue culture is sufficient shock to produce mutations. In fact, the mutation rate is ten times higher than what would occur naturally.

What caused the mutations? We guessed that the tissue culturing activated genes to break out of their normal linear arrangement in a chromosome and move to different positions in the DNA. ("Jumping genes" were discovered by Nobel laureate Barbara McClintock.) To test our theory, studies were done on shrunken gene mutations, which cause indented kernels. When DNA from the shrunken genes was extracted and examined, we were surprised to find that it had not been rearranged; jumping genes were not the source of mutations.

That meant that something in the tissue culture medium was mutagenic.

We looked first at 2,4-D, a chemical used to proliferate corn tissue in culture. In low doses, it replaces a natural hormone in plants. In high doses, it kills broadleaved weeds. Our tests showed that 2,4-D is not mutagenic.

Most recently, we have begun to study ethylenediaminetetraacetic acid, better known as EDTA. EDTA chelates, or binds to, metal ions. Plants need very small amounts of different metal ions, and EDTA is added to the culture medium to hold the metal in solution.

Our initial tests indicate that EDTA is mildly mutagenic, increasing the natural level of mutations about six times. The next step will be to regenerate plants in tissue culture with and without EDTA (the second batch having an EDTA substitute so as not to disrupt regeneration). Once full grown, the plants will be examined for mutations in four categories: waxy, color, bronze and

Ben Burr and Marjorie Neuberger examine a corn plant.

shrunken. Waxy mutations can be detected in pollen, so that will be a first quick test to see if we are on the right track.

If EDTA is not triggering the mutations, another chemical is, and our studies will continue until the right one is found. We are convinced that the mutations are caused by some chemical in the culture medium.

Brookhaven's recent work on mutations has clear implications for plant breeding. Even though tissue culturing does result in new mutations, we now feel that mutations may be more easily induced by directly treating seeds or pollen with chemicals. Already, we know that chemical mutagenesis results in 100 times more mutations than occur in tissue culture, and the kinds of mutations due to chemicals are generally the same as those occurring in tissue culture.

Department of Nuclear Energy

The Department of Nuclear Energy conducts programs related to fission and fusion reactors. Work is performed in nuclear safety, nuclear waste management, nuclear material safeguards and development of advanced reactor systems. Also, the department serves the low energy nuclear science community by compiling and evaluating data from neutron physics, charged-particle reactions, and nuclear structure and decay.

In recent years, the safety of nuclear power reactors has become a highly emotional issue in this country. The department provides vital technical support to the Nuclear Regulatory Commission, which licenses and regulates power reactors. The following pages illustrate the depth of Brookhaven's research in the area of nuclear safety.

Faster Than Real Time

The nuclear power plant accident at Three Mile Island evolved over a period of several hours. It was several weeks, however, before a computer cranked out information which could have had an impact on the situation. By then it was too late to influence the events that had evolved.

Could the whole situation have been averted if the plant operators had had timely assistance from a plant analyzer computer system like the one recently developed by Brookhaven? Possibly yes!

Brookhaven's plant analyzer is a sophisticated mathematical model of the inner workings of a nuclear power plant, packaged in an advanced minicomputer. Our work on the plant analyzer began two years ago when we saw a need for a fast and reliable computer system that would replace, in part, the large central computing facilities now in use. We set out to develop a responsive, everyday work tool for people in three areas: plant operators on the job, operators in training and the U.S. Nuclear Regulatory Commission acting in its licensing and regulating capacity.

Late in 1983, we completed our plant analyzer for boiling water reactors. In 1984, we began to plan the work on pressurized water reactors.

Comparing the BNL plant analyzer to a large computer system, the plant analyzer has proven to be a hundred times faster, while still producing the same answers. In fact, it can compute a process ten times faster than real time.

That speed makes the plant analyzer seem like a crystal ball. Because of it, an operator can compute in advance what would happen if he closed a valve or shut off a pump or did neither. And the calculations can be done in minutes, giving the operator more time to decide the best course of action.

The plant analyzer predicts what happens in transients, which are events in progress. Ordinary transients include starting a plant, shut-

ting it down, or adjusting power to match demand. An accidental transient occurs when something goes wrong and the operator has to manually return the plant to a safe condition. A severe transient can lead to a shutdown — a costly event because of the power loss. Simulating severe accidents is the strength of our plant analyzer. Existing training simulators cannot predict severe accidents.

The BNL plant analyzer uses a newly available minicomputer that had been originally designed to simulate complex systems at faster than real time. Already, it's being used for aviation, space and military applications.

In the U.S., Brookhaven is the first to use this computer to simulate the flow of mixed fluid phases in nuclear power plants. That is the crux of simulating transients in reactors, because this two-phase flow affects whether the reactor core will be covered, hence under control, or uncovered and possibly melting.

The term "two-phase" refers to liquid and vapor. In a boiling water reactor, water boils and converts to steam that drives a turbine to make electricity. Since boiling water is a mixture of liquid and vapor, simulating the flow of that mixture through a reactor core requires treating the two phases individually, particularly in an accident, when vapor collects at the top of the reactor vessel, while the liquid falls and uncovers the top of the core.

In a pressurized water reactor, water in the core is heated and then circulated in heat exchangers that

generate vapor to turn the turbines. Under normal conditions, high pressure in the water system keeps the water liquid. If a stuck open valve releases coolant, a process which lowers the pressure, like a cap popping off a soda bottle, the liquid flashes into vapor. Again, the liquid sinks and the vapor rises.

Two-phase problems are difficult to analyze. They can be done on large computer systems, but the process is slow. One reason the BNL plant analyzer is significantly faster is that there has been rapid advancement in computer hardware. For example, because memory chips are so cheap today, we have computed numerous arithmetic operations ahead of time and stored the results in memory, to be used over and over again. Also, computers now contain multiprocessors, which handle data in paral-

lel fashion. Our plant analyzer's computer uses six multiprocessors.

To take even greater advantage of the machine's capabilities, we developed new, sophisticated models of the processes that occur during power plant transients, particularly in the difficult area of two-phase flow. Then we created mathematical formulations to represent those processes, and programmed them into the computer.

In the two years since we began working on the plant analyzer, BNL has proven that the right combination of machine and modeling results in a computer system far superior to the large systems in use now. We expect the BNL plant analyzer to become a useful tool for the nuclear industry and the Nuclear Regulatory Commission.

Wolfgang Wulff watches a computer display of system pressure and fission power response in a boiling water reactor, as simulated by the plant analyzer.

Cracking the Problem of Corrosion

Reports are starting to come in from all over the world that certain older nuclear power reactors are experiencing stress corrosion cracking in Inconel tubing. The seemingly widespread problem has sounded an alarm in the U.S. because out of the 81 licensed power reactors in this country, two-thirds of them are pressurized water reactors that use Inconel.

Stress corrosion cracking in Inconel (a trade name for a nickel-based alloy that also contains chromium and iron) is a main area of study at Brookhaven, under an extensive research program on materials problems at nuclear power plants. We are looking at the mechanism of the cracking, as well as trying to find and test solutions to the problem.

Rabindranath Bandy (left) and Daniel van Rooyen examine a U-bend of Inconel after it was tested in an autoclave for stress corrosion cracking.

Many thousands of feet of Inconel tubing are used in the steam generator of a pressurized water reactor (PWR). The tubing carries hot primary water from the reactor core into the steam generator, where the process of heat transfer turns secondary water into steam to run turbines, producing electricity. The tubing provides a boundary between the radioactive primary water and the non-radioactive secondary water.

Stress corrosion cracking is caused mainly by a chemical reaction between the metal and the high temperature primary water in the tubes. Radiation is not a factor. What is important, however, is stress in the metal.

A major source of stress occurs when a steam generator is built. The ends of the tubes are shoved into a cylindrical support called a tube sheet, which contains thousands of holes. Each tube is fitted into a hole and expanded to fit tightly. The expansion causes high tensile stress in the metal and leaves it significantly more vulnerable to cracking.

An additional problem occurs in older PWRs. In those, tube expansion was done only partway up the support holes, leaving crevices around the upper part of the tubes. The combination of inadequate flushing in those crevices and a concentra-

tion of non-volatile impurities (sludge) in the boiling secondary water causes a caustic reaction, leading to stress corrosion cracking from the secondary side.

Another form of corrosion associated with the build-up of impurities is called intergranular corrosion. Seen under a microscope, a cross section of metal looks granular. Intergranular corrosion occurs around the stress-weakened grain boundaries. It looks like a cancerous web, in contrast with stress cracking, which usually occurs only at a few grain boundaries.

A tube crack allows radioactive primary water to escape into the clean secondary water. While it is possible for that radiation to find its way out of the reactor, the amount escaping would be small, posing minimal health hazard. Actually, the bigger problem is cost, because when a significant leak is found, a plant has to be shut down for repairs, and down time means a tremendous loss of revenue.

The current remedy for cracks is to plug the tube, taking it out of service. There is a limit to how much plugging can be done, however. At some point, the reactor will lose efficiency. Also, since the steam generator is the means for cooling the reactor core, its capacity to transfer heat from the primary system to the secondary cannot be reduced below a certain level.

Fortunately, nuclear reactors are designed with an excess of tubing, and a certain percentage of plugging does no harm. But plugging doesn't solve the problem for certain reactors. In those, stress corrosion cracking combined with other secondary corrosion processes have made it necessary to replace the steam generators in six reactors, at considerable cost to the utilities and their customers.

At Brookhaven, we have combined our study of the mechanics of stress corrosion cracking with a search for an alternative to plugging. We know that another alloy, one that has a higher proportion of chromium, is more resistant to cracking. In new

plants, tubes could be made of the different material. But a method must be found to help the plants already in operation.

One approach to solving the problem has been to insert sleeves into the tube ends and expand the sleeves to fit snugly. Unfortunately, the technique creates additional troubles. A more promising remedy seems to be heat treatment.

Our tests have shown that extended high heat actually changes the structure of the metal, relieving stress and causing precipitates at the grain boundaries, both of which make the metal more resistant to several types of stress corrosion cracking. In general, the temperature must approach 700°C, hot enough to begin turning the metal red, and the heat must be applied for about 16 hours.

Recently, Brookhaven has been perfecting a heating method that uses coils to heat individual tubes. The alternative is a global treatment applied to the entire steam generator, no easy task since it's about the size of a living room, four stories high.

As we learn more about the mechanism of stress corrosion cracking and intergranular corrosion, that knowledge will be applied to the problem. In the U.S., where no new plants are on the horizon, it's too late for prevention, but never too late for cure.

Stress Corrosion In Boiling Water Reactors

Boiling water reactors in the U.S. are experiencing a recurring problem with cracking stainless steel pipes. The Nuclear Regulatory Commission (NRC) set up a task force to study the pipe cracking, and Brookhaven was asked to participate. The group met at the Laboratory in 1984 and drafted a report to the NRC.

Stainless steel pipe cracking results from intergranular stress corrosion. This is not a new phenomenon in nuclear reactor piping. It has occurred over the past 25 years in a range of pipe sizes. The recent concern is due to the fact that large recirculation piping is reported to be cracking.

In its investigation, the task force did not find any cracks leaking above NRC limits. In addition, there have been no structural failures caused by the cracking. Still, the problem is serious enough to require some changes in current regulatory practice.

Three basic recommendations were made by the task force: Materials now in use should be replaced with a stainless steel containing less carbon, for better resistance to intergranular stress corrosion cracking, and more nitrogen, to retain strength. Water chemistry should be changed to reduce the oxygen and to keep conductivity at a low level. And heat treatment should be done to relieve stresses in affected material which is not being replaced. The task force also called for better detection techniques to measure crack depths.

The final report has been sent to the NRC, which will make a policy decision.

Case Study: Diablo Canyon

The story of Diablo Canyon is a long one, and the final chapter is not yet written. But this is the part Brookhaven played.

The Diablo Canyon nuclear power plant, near San Luis Obispo, California, lies 2.5 miles from the Hosgri fault. When the plant was originally proposed in 1966, the fault was uncharted, hence the plant was designed to withstand an earthquake of 6.5 magnitude (M) on the Richter scale. Construction began accordingly. In 1973, the location of the Hosgri fault was confirmed, and the plant had to be scaled up to 7.5 M. Construction was complete in 1981, and the Nuclear Regulatory Commission (NRC) approved a low power license for the plant. Soon after, the power company itself flagged an error in construction, and the low power license was suspended pending an investigation. That's when the NRC turned to Brookhaven.

The Laboratory is becoming well-known for its broad research on the response of structures to various loads, such as an earthquake, a tornado, or an internal explosion. In the case of an earthquake, Brookhaven studies the interaction of structure and ground. An earthquake causes shock waves to travel through the ground. These waves can be amplified or reduced as they enter a structure, depending on the natural frequencies of the structure, the frequency spectrum of the input, and the nature of surrounding soils and the material used in the structure.

Until recently, studies of soil/structure interaction have been theoretical, not verified by actual data. Earthquakes have been recorded since the beginning of history. That experience has been used for some time in a rough manner to design structures. With the development of more precise measuring techniques and the development of the Richter scale in 1958, it became possible to apply quantitatively the science of dynamics to the design of structures. Finally, with the advent of large storage capacity digital com-

puters, complete evaluations of structures can be carried out.

In the last 15 years, seismic instruments have been installed in and around buildings in the U.S. and other countries, and data are accumulating. With this information, we have begun to verify the analytical computer methods used today to evaluate structural design.

In 1982, Brookhaven was asked by the NRC to examine what seemed at first to be a minor problem. Diablo Canyon has twin units that are designed in mirror image. While the units were under construction, the masses of components in the analytical seismic model used to design Unit I were put in the wrong positions in the calculations, which would have been correct positions for Unit II. In our investigation of that problem, others were found. Finally, it was decided to do an extensive review of the seismic design of Unit I's annulus section.

The annulus is a four-story metal and concrete frame structure composed of columns, girders, and walkways around the interior of the plant's containment wall. It is crisscrossed by pipes carrying cooling water, which is vital to the plant's safe operation.

To evaluate the design of the annulus, we applied a three-dimensional computer technique developed by Brookhaven. The method analyzed the potential stress produced by a 7.5 M earthquake, considering three directions of movement: vertical, horizontal side to side and horizontal front to back. These were seismic modeling methods that substantially improved on the ones used earlier during design, and they led to changes in calculated stresses.

As a result of this and other reviews, major structural changes were made to Unit I. Independent inspections were done. Brookhaven reviewed them, and we also did certain audits of our own. We are now satisfied that the reactor has been modified correctly and can meet the design requirements for the postulated 7.5 M Hosgri event.

This problem is not unique to nuclear plants, nor is it only caused by earthquakes. Every structure has a spectrum of natural frequencies at which it will vibrate. If one or more of these frequencies is excited, the structure can shake violently enough to destroy vital equipment. It can even shake apart, which was the fate of a bridge known as Galloping Gertie in the state of Washington. One particular windy day in 1940, the wind produced catastrophic motions at the natural frequencies of the bridge, causing it to undulate wildly until it fell apart.

In the U.S. today, 40 nuclear power plants are in various stages of construction, some on the verge of being licensed. Of these, Brookhaven's cur-

Poring over blueprints and computer calculations for a structural safety analysis of a nuclear power plant are (from left) Sushil Sharma, Morris Reich, A.J. Philippacopoulos, Charles Miller and Carl Costantino.

rent caseload is five reactors, including Diablo Canyon. On request from the NRC, we study a particular aspect of a plant, drawing on our expertise in structural dynamics and using computer models to simulate what would happen under various conditions.

Each plant is unique because of location and design. Brookhaven's job is to understand all the variables, make a judgment, and turn that information over to the NRC.

Support Activities

**Applied
Mathematics
Department**

**Reactor
Division**

**Safety
and Environmental
Protection Division**

**Instrumentation
Division**

Applied Mathematics

Basic research and basic service are the hallmarks of the Applied Mathematics Department. Our research in the mathematical sciences includes investigations in analytical and numerical methods, as well as statistical methods. Among the services we provide are assistance in the application of computational, statistical and mathematical techniques; operation of the Central Scientific Computing Facility; Lab-wide support of distributed computer equipment; and planning and development of future data processing facilities and tools.

The Dynamics of Chaos

What do electrical circuit theory, sleep/wake cycles, fluid motions, the national economy and chemical reactions share in common? To start with, all are complicated systems which do not always respond predictably.

These are examples of non-linear dynamic behavior. Although a complete description of such a dynamical system can be quite complicated, often there is a simple model locked inside, crying to get out. In 1984, we developed a unique software package to help in understanding those simple dynamical models.

The key to recognizing simple dynamical models is chaos. As a mathematical term, chaos refers to behavior in a dynamical system so simple it would appear to run like clockwork, but which, in fact, behaves unpredictably. Simple systems with chaotic dynamics can, for example, produce output signals containing broadband noise. Often, the chaotic behavior of a simple model can explain the unpredictability in a complicated system.

One application where this occurs is fluid dynamics. During 1984, we simulated a two-phase air/water flow experiment which involved twenty measuring probes, using a computer model which calculates over 500 quantities, such as velocities and

pressures, at each instant in time. Despite this complexity, the system can settle into chaotic behavior which could be explained by a simple model oscillating among three or four elementary modes of behavior.

To extract a simple model from a complicated system, we must find evidence of few-mode, or low-dimensional dynamic behavior, then attempt to identify the important modes and, finally, build a mathematical description of the dynamic interactions among modes. There are several techniques for doing this, either from experimental data, or from theories like the laws of motion or chemical reaction kinetics. Once a simple model is devised, our computer software can analyze the model by constructing the dynamic geometry of phase space.

Computer graphics are essential at this stage, because phase space is an abstract space which does not exist in the real world. Phase space has one dimension for each mode, or degree of freedom, in the model. So we can visualize the phase space of two- or three-mode models and, sometimes, of a four-mode model, if the right computer graphics software is available.

Three-dimensional phase space is most effectively visualized by animation, with three-dimensional shapes like the chaotic, or strange, attractor — the heart of the dynamics — viewed in continuous rotation. The

chaotic attractor is a topological structure in phase space which continuously kneads trajectories like a baker kneads dough, generating randomness by infinite repetition of a single basic folding action. Movie film is one way to view this, and, during 1984, we were the first group anywhere to apply a COMp80 micrographics processor to the study of chaotic dynamics in phase space, via computer-generated 16 mm movie film.

Understanding dynamics through the geometry of three-dimensional phase space has proved so revealing that we began to look for quicker ways of producing visualizations. In addition to continuing software improvements, an interactive graphics terminal will come on board next year, to allow us to view three-dimensional constructions rotating on the screen.

A glimpse of what we can achieve with our software and the COMp80 is shown in the accompanying phase space diagrams. These show the so-called "blue sky catastrophe" predicted for chaotic relaxation oscillations. The blue sky catastrophe was confirmed for the first time this year, using our software. The diagrams help us understand the simplest way in which a chaotic relaxation oscillation — including such examples as heart fibrillation, irregular economic cycles or wind-induced oscillation of a suspension bridge — can suddenly blow up. This is the most fundamental discovery made with our dynamical systems software to date, and we expect that geometric phase space analysis will continue to be useful in understanding otherwise unpredictable dynamics.

Shown here is the phase space geometry associated with a blue sky catastrophe, in which a chaotic (strange) attractor suddenly vanishes. On top is the attractor, in this case resembling a loop with

pinched beaks; a curved separator divides the stable and unstable regions of phase space. Below, the instability region has moved in to cut the attractor, whose former location is indicated.

Reactor

Since the neutron's discovery in 1932, research reactors — the primary source of neutrons — have added greatly to basic scientific knowledge. The Reactor Division operates the High Flux Beam Reactor, one of the most advanced research reactors in the world. Physicists, chemists and biologists use the reactor's neutron beams for basic studies in their respective fields. In addition, it is used for other activities such as the production of radioisotopes for medical and nuclear chemistry research; neutron activation analysis of meteorites; and radiation damage studies in superconductors and other materials, in support of a program on alternative energy sources.

About Cold Neutrons

The High Flux Beam Reactor provides hundreds of trillions of neutrons every second which have an average energy of 25 milli-electron volts and wavelengths of about 2 angstroms. But some experiments require neutrons that are not so energetic (1-5 milli-electron volts), with a longer wavelength (4-10 angstroms). Cooling down these neutrons is the work of Mark II, a neutron moderator which started operating in February of 1984.

The heart of the moderator is about 1.4 liters of liquid hydrogen contained in an aluminum chamber located near the reactor core. This is the business end of a 10-foot-long, especially large diameter, beam plug which runs through the reactor shield and fits into a beam thimble in the reactor vessel. Cold neutrons are guided through the reactor shield via three rectangular beam tubes which penetrate the plug.

The coolant (helium gas at 17 kelvins) circulates in a closed loop that envelops the chamber. It makes continuous round trips between the chamber and a room-size refrigerator outside the reactor and keeps the hydrogen cold. Neutrons from the surrounding heavy water in the reactor are moderated by scattering

from the cold hydrogen and are reduced to the lower energy required for specialized research.

The cold neutron moderator is located at experimental beam port H-9. H-9 can accommodate three beam lines, two of which are currently in use. Physicists use one for the study of condensed matter, such as long-range interactions between the atoms in a lattice, or the study of magnetic and structural phase transitions. The other beam is used by biologists to study the structure of membranes and other large biological molecules. Long wavelength, low energy "cold" neutrons are ideal probes for these types of experiments.

The moderator runs 24 hours a day, seven days a week for approximately three weeks at a time. In short, it corresponds to the reactor schedule. But occasionally there is a point at which it diverges.

For instance, last spring there was a momentary power failure in the area due to a major brush fire. The reactor kept on running, but the power failure caused the moderator to shut down completely — the valves opened automatically and the potentially explosive hydrogen was vented.

Obviously, the presence of hydrogen in the reactor is not to be taken lightly. In addition to the whole system being designed to contain an

explosion, a blanket of helium gas envelops the hydrogen to preclude the possibility of air leaking in. Multiple sensors are everywhere, monitoring pressure and temperature. If an abnormal reading is detected, for whatever reason, there is no delay. The liquid hydrogen is flushed out of the chamber and automatically vented outside the building into the air.

At BNL, the idea of a cold neutron moderator was provided for in the original design of the reactor, and a project to construct a cold moderator

was first seriously considered in 1968. But because there were other more pressing budgetary needs, and it took care and time to fine-tune the safeguards, the moderator was put on the back burner for a number of years. Mark I did not see the light of day until 1980. This machine was a prototype from which a lot was learned and which contributed a great deal to the current moderator's successful operation. One thing learned was that the cold neutron moderator is constantly subjected to a hostile environment — high radia-

tion and extremes in temperature — and that it was important to have a backup in reserve. Consequently we are now starting to build another cold neutron moderator, which will take about two years to complete.

Safety and Environmental Protection

This division provides technical services and carries out related research in the areas of health and safety. Major research programs include radiological monitoring of residents of the Marshall Islands; the assessment of chemical and physical hazards in the workplace; radiological physics; support for the U.S. Department of Energy's Radiological Assistance Plan; and groundwater surveillance, which is described here.

The Long Island Water Watch

Brookhaven is located at the center of Long Island, an island which has been designated by the Federal government as a "sole source aquifer." This designation means that groundwater is the only source of drinking water.

Obviously, keeping the water pure is of vital importance to both the residential and business communities. Throughout the years, numerous agencies at all levels of government have been keeping tabs on the groundwater, but from different points of view. Some, for instance, collect information only on the depth of water, others get data only on water quality at private residences. But no agency has the whole picture.

Two years ago, this division and the Department of Applied Science collaborated to find out what information was available, with the goal of putting it into a form useful to regional planners. By late 1984, we had developed techniques and prepared a guide book to assess regional aquifer conditions from disjointed data.

BNL was particularly well-suited to do this job. The Laboratory is a microcosm of the problems likely to be found on the Island: we have our own landfill, pump our own drinking water, use groundwater to cool equipment and have a sanitary system typical of the area. In addition, our staff on the project was experienced

in water resource engineering, computerized simulation models, statistical analysis of data, environmental monitoring, and data collection and analysis.

To begin with, we traveled the length of this 118-mile island to gather groundwater and related data from Federal, state and local agencies.

We wanted complete information (see accompanying chart).

The data amassed were difficult to use because various agencies had collected them for different purposes, the techniques of collection and analysis varied, and the information was presented in dissimilar formats. Our job, then, was to put this disparate data into an integrated format, do statistical analysis and look for relationships.

The guide book, which is the result of our interdepartmental expertise in overcoming these problems, provides a step-by-step procedure that any regional planner or decision-maker can use. Case studies of BNL and a town on Long Island are given as examples. Realizing that most users do not have sophisticated computer systems, we aimed the information at people with desk-top computers.

The book should do much to pave the way for an integrated ground-

Activity	Location	Pollution Data — Sources	Geohydrology
Cesspools, septic tanks etc.	Available	Variable information	Available qualitative
Sewering — Sewage treatment plants	Available	Variable information — certain parameters routinely analyzed	Available qualitative
Fertilizers/Agriculture	Available	Quality of fertilizer used/Area under agriculture	Available qualitative
Cooling towers/Industrial	Available	Variable information not directly applicable	Not available qualitative
Landfills: Sanitary	Available	Variable information	Available detailed
Industrial	Available	Available	Available detailed
Recharge basins: Storm water	Available	Variable information	Available detailed
Cooling	Available	Available	Available detailed

water management information system for other sole source aquifer areas. There are nine other such areas in the country, and 30 communities have applied to be so designated. Standardization of techniques and pooling data from regional planning boards will be of benefit to all of them.

In the course of our work, we have identified a number of important research needs in such areas as storm water recharge, quality assurance and graphic techniques for groundwater analysis. We hope to contribute to these areas.

Protecting our drinking water is everyone's concern.

Janakram Naidu (left) and Edward Kaplan examine a map of Long Island showing the relation of land use to groundwater quality.

Movement of Groundwater	Monitoring Program Groundwater	Chemical Analysis Groundwater	Water Pumpage	Recharges	Climatology Rainfall
Available qualitative	Function of activity — limited data	Limited, depending on monitoring program being in place	Indirect effect (remote) — Data not available	Leachate formation — Data not available	Available
Available qualitative	No data	No data	Available	Effluent release — Information available	Available
Available qualitative	Function of potential effects on ground water	Limited data, potential for pollution exists.	Available	Leachate formation — Data not available	Available
Not available	No data	No data	Available	No data	Available
Available	Available	Available	No data	Leachate formation — Data may be available	Available
Available	Available	Available	No data	Leachate formation — Data may be available	Available
Available	Available	Available	No data or variable	Data on recharge activity — Variable	Available
Available	Available	Available	Available	Data on recharge activity — Available	Available

Instrumentation

The Instrumentation Division continues to supply services such as electron microscopy, vacuum technology, printed circuit fabrication, repair of various scientific instruments, and computer maintenance. More and more, however, our bread and butter is doing research and development in such areas as nuclear particle and radiation detection, signal processing of all sorts, systems for acquiring data from and controlling experiments, and application of nuclear and atomic techniques in elemental analysis and other fields. But we get special satisfaction when we develop instruments or techniques that stretch the "state of the art" beyond its present limits. The following story illustrates this work.

Detectors: Better Than Ever

Traditionally, the recording of x-ray diffraction patterns has been done with photographic plates, with exposure times measured in hours or even days. Clearly, this means that only very stable samples can be studied. If a scientist is interested in the structure of a biological sample and how it changes in response to its environment, something very much faster is required.

With the X-ray Ring at the National Synchrotron Light Source nearing routine operation, the problem of getting sufficient intensity is solved, but the experimenter will not want to wait while a reel of movie film is processed to find out what happened.

Our answer is a very fast x-ray photon detector with position-sensing capability. Such a detector, with the appropriate electronics, will present the diffraction pattern on a TV screen, in real time, so that the experimenter can see what happens to the sample as it is subjected to various forces or chemicals.

Very fast detectors (handling a few hundred thousand particles per

second) with position location of a millimeter or so are usually gas-filled and operate on the proportional counter principle. A proportional counter (invented more than half a century ago) physically resembles a Geiger-Müller counter, but is operated at a lower voltage so the output pulse is proportional to the number of ions produced by the particle being detected. In the case of the gas detectors we have developed, the assembly consists of two flat plates with a large number of very fine parallel anode wires in the plane midway between the plates, forming in effect a large number of thin proportional counters parallel to each other. One coordinate of the position of the incoming particle is found by noting on which wire the charge is collected. The other coordinate may be found from the arrival times of the charge pulses at the two ends of the wire. Typically, a counter designed for x rays would be about ten centimeters square. This calls for a great deal of very fast and very small electronics.

One class of gas detector we recently developed can locate a photon to 0.1 millimeter, with an incoming flux of several hundred

Hobbie Kraner (left) and Rolf Beuttenmuller inspect a silicon detector in a fabrication room, which is kept free of dust. This particular detector has been developed for a high energy physics experiment planned for next year at CERN, a European accelerator facility.

thousand photons a second. Because many future experiments will require processing several million events per second, we are now developing a detector to process a hundred million events per second, with a position accuracy of about one millimeter. Gas-filled detectors for neutrons or high-energy particles are based on the same principles: a recently built neutron detector has a collecting area 50 centimeters square.

We have also been making position-sensitive detectors from semiconducting crystals such as silicon or germanium. In these, the ionizing particle produces electron-hole pairs in the semiconductor, which are then collected by narrow strip electrodes on the surface.

In making these solid detectors, a large number of very narrow (width of a human hair) conducting strips can be deposited on the crystal using techniques borrowed from the integrated circuit industry. The advantages of this approach are that high energy photons are much more likely to interact when passing through a solid than a low pressure gas, and it takes much less energy to create an electron-hole pair in a solid than to ionize a gas atom.

General and Administrative

The following information includes personnel statistics and highlights from certain areas of the Laboratory's administrative activities.

Personnel

Employment at the Laboratory has not changed significantly over the last three years (see statistical charts).

For 1984, unsalaried scientific guests and collaborators totaled 1,558. They represented 327 institutions, including 96 outside the United States. The summer program alone drew 131 visiting scientists and 180 students, from 83 different institutions.

Employee Suggestion System

The Suggestion System encourages employees to submit constructive ideas that can result in cost savings or other real benefit to the Lab. Suggestions are welcome on any aspect of Laboratory operations. If approved and implemented, a suggestion can earn an employee a cash award. From April 1983 through September 1984, the Suggestion Office processed over 185 suggestions concerned with numerous BNL functions. Ideas ranged from new ways to save energy and money, to novel changes in standard procedures, to creative methods for improving the Laboratory's appearance. Within this time frame, awards totaling more than \$3,000 were presented to employees.

Property Management

Information on BNL capital and sensitive equipment is now logged in a computer system that is accessible from terminals in every department and division. In addition, roughly 23,000 items with a combined value of \$175 million have been tagged with bar codes, providing a complete inventory of Lab equipment. All new equipment is similarly handled to keep the accounting up to date.

In 1984, a pilot program was started to provide departments with monetary credit for releasing equipment to other departments. Initially, the Exchange Credit Program will focus on personal computers and video terminals.

Affirmative Action Activities

In recognition of BNL's outstanding achievement in doing business with minority firms in 1983, the Laboratory received the Disadvan-

Employment Statistics

	1984	1983	1982
Scientific Staff*	709	752	726
Scientific Professional Staff	475	472	450
Nonscientific Staff	2064	2138	2084
Total	3248	3362	3260
Percent of total employees			
Minorities	14.8	14.9	14.7
Females	22.5	22.5	22.2

* Includes research associates and visiting staff.

Scientific Staff and Student Employees

	1984	1983	1982
Staff			
Senior Scientist	125	119	116
Scientist	347	340	314
Associate Scientist	75	98	124
Assistant Scientist	41	50	52
Senior Research Associate	4	4	4
Research Associate	46	45	46
Visiting Staff			
Senior Scientist	0	1	0
Scientist	10	8	7
Associate Scientist	0	1	2
Assistant Scientist	9	9	8
Student Researchers			
Senior Research Associate	4	7	4
Research Associate	9	14	18

tagged Business Award from the U.S. Department of Energy.

In 1984, trainee positions for electromechanical and mechanical technicians at the National Synchrotron Light Source were established for minorities and women. The positions are supported by operating funds.

A community outreach program was started in the nearby town of Riverhead. During the school year, volunteers from Brookhaven spent two evenings a week introducing youngsters to science and computers.

Employee Fitness

To encourage employee health and fitness, the new Parcourse Fitness Circuit was built in 1984. The Parcourse is a series of 18 exercise stations set up on a 1.57-mile serpentine trail in a pine woods. The course loops through the woods so that no station is very far from the entrance, allowing employees who exercise at lunch to complete as many stations as they can in the time allowed.

Energy Management

At the end of September 1984, building energy use at BNL had been reduced by more than 19%, compared to 1975, the base year set by the U.S. Department of Energy (DOE).

Two important programs have contributed significantly in holding down energy costs. Alternate liquid fuels (ALF), developed at Brookhaven, replace a large percentage of No. 6 fuel oil that would normally be used for heating. Also, the Laboratory receives less expensive electric power from upstate New York, through an agreement with the New York State Power Authority.

Through our Energy Management Program, Brookhaven received \$1.2 million in 1984 from DOE for energy conservation projects. That brings our total to \$13 million since this program started in 1977.

Administrative Actions

Martin Blume — Appointed deputy director of the Laboratory, with continuing oversight for low energy physics and chemistry. Also appointed acting chairman of the National Synchrotron Light Source Department.

Leonard Emma — Named head of a new division, Safeguards and Emergency Services.

Eugene Kelly — Appointed engineering deputy to the associate director for high energy physics research.

Thaddeus Kycia — Appointed scientific deputy to the associate director for high energy physics research.

Bernard Manowitz — Reappointed chairman of the Department of Applied Science for a term of five years.

Robert Palmer — Appointed associate director for high energy physics research.

Benno Schoenborn — Named head of the Biology Department's newly-created Center for Structural Biology with title of associate chairman for structural biology.

Richard Spellman — Named head of the Central Shops Division following the retirement of Robert Lehn.

Financial Report

The U.S. Department of Energy is our principal source of income and accounted for 78 percent of the fiscal year 1984 total of \$188.8 million in operating funds. Other Federal agencies, including the Department of Health and Human Services, the Department of Defense, the Department of State, the Nuclear Regulatory Commission, the Environmental Protection Agency and the National Science Foundation, contributed 20 percent of BNL's operating funds. Non-Federal agencies supplied the remaining two percent.

Capital equipment budgets are funded by the U.S. Department of Energy and, in fiscal year 1984, totaled \$12.1 million. These funds are used to purchase instrumentation, computers, scientific apparatus and office equipment.

Construction funds amounted to \$24 million. Among the items spelled out for fiscal year 1984 were Phase II construction at the National Synchrotron Light Source, upgrading of the steam plant, a new fire-house and the heavy ion transfer line between the Alternating Gradient Synchrotron and the Tandem Van de Graaff.

BNL COST ELEMENTS

BNL OPERATING FUNDS

MILLIONS
OF
DOLLARS

FY 1982

FY 1983

FY 1984

200

150

100

50

0

58.4

33.7

19.5

67.0

36.5

18.6

72.8

40.4

19.6

TOTAL 163.1

175.2

188.8

High Energy & Nuclear Physics

Basic Energy Sciences

Environmental R&D

Other DOE Programs

Other Programs

Meetings

For this report period, April 1983 to September 1984, over 50 scientific meetings were held at Brookhaven, bringing together researchers from across the nation and around the world to discuss their work and share their ideas.

In April 1983, the International Atomic Energy Agency (IAEA) held an Advisory Group Meeting, which was attended by over 50 physicists from 12 IAEA-member countries. Nuclear level density was the main topic of discussion during the meeting, titled "Basic and Applied Problems on Nuclear Level Densities."

Almost 300 physicists, both experimentalists and theorists representing more than a dozen nations, joined forces in September 1983 to discuss "Quark Matter '83" at the Third International Conference on Ultra Relativistic Nucleus-Nucleus Collisions. The conference brought together nuclear and high energy

physicists, who are eager to study high energy collisions between heavy ions.

The third National Conference on Synchrotron Radiation Instrumentation, held in September 1983, drew well over 200 physicists, chemists, biologists and engineers. Such is the growing popularity of synchrotron radiation as a research tool, that conferences are held on single aspects of synchrotron radiation, in this case, the instruments used in machines built to produce the radiation.

Also in September 1983, a four-day workshop was held to discuss the feasibility of using storage rings like Brookhaven's National Synchrotron Light Source (NSLS) to make free electron lasers. The workshop was

jointly organized by the NSLS Department and the Optical Society of America.

A month later, the NSLS co-sponsored another meeting, this time with the International Society for Optical Engineering. The conference was on advances in soft x-ray science and technology, with x-ray lithography as the dominant topic.

The world is full of good ideas, but getting those ideas to market is often a baffling and fruitless process for an inventor. In October 1983, Brookhaven hosted a two-day session on "From Idea to Product: Making It Happen." Some 16 workshops tackled such areas as legal protection, sources of capital and Federal programs to aid the inventor. The workshop was sponsored by the U.S. Department of Commerce, the U.S. Department of Energy, and local institutions and companies.

The AGS II Task Force, made up of users of the Alternating Gradient Synchrotron, was assigned to make recommendations about the important physics that could be pursued at this accelerator and about machine modifications that should be done to make such a program successful. In February 1984, the Task Force released its report. In brief, the group concluded that considerable forefront physics is still obtainable from the AGS, given suitable modifications and additions.

A week-long symposium on Gas-Liquid Chemistry of Natural Waters was held in April 1984. The symposium centered on the photochemistry and chemical reactions in fresh water, oceans, aerosols, cloud droplets and rain.

In May 1984, scientists gathered from around the world for a confer-

The Third International Symposium on the Production and Neutralization of Negative Ions and Beams was held in November 1983. Over 70 researchers, representing ten nations, met to discuss negative hydrogen ions and beams, polarized ions and heavier ions, for fusion and other applications. Work on negative hydrogen ion sources was pioneered at BNL.

Honors

ence on "Assessment of Risk from Low-Level Exposure to Radiation and Chemicals: A Critical Overview." Sessions focused on comparison of mechanisms of carcinogenesis by radiation and chemical agents, theoretical aspects of estimating risks, biological mechanisms, and response mechanisms.

Fifty health physicists and nuclear engineers from ten countries met at BNL in May 1984 to exchange information and hold discussions on "Historical Dose Experience and Dose Reduction (ALARA) at Nuclear Power Plants." Emphasis was placed on understanding causes for wide variations in radiation exposure from plant to plant and country to country, and on the radiation protection principle, ALARA, which stands for keeping worker exposures "as low as reasonably achievable."

At the end of September 1984, the Biology Department sponsored a symposium on "The Molecular Basis of Aging." Researchers and clinicians in the field were brought together to discuss cellular and molecular studies regarding the "wear and tear" hypothesis of aging, aging in cellular proteins, changes in DNA with age, and diseases featuring altered rates of aging. Three symposium lectures were opened to the public in the evenings and drew large audiences from surrounding communities who came to hear talks by noted authorities on aging research.

BNL is proud of the honors accorded the staff in the last year-and-a-half. We list here the highlights of this period:

Victor Bond (Director's Office) — Sr. U.S. Scientist Award from Alexander von Humboldt Foundation, Germany.

Richard Casten (Physics) — Sr. U.S. Scientist Award from Alexander von Humboldt Foundation, Germany.

Eugene Cronkite (Medical) — A conference on Hematopoietic Cellular Proliferation was held in his honor and was attended by over 400 of his colleagues and students. Delivered the Henry M. Stratton Distinguished Lecture, American Society of Hematology, December 1983.

Gordon Danby (Accelerator) — Won the 1983 Boris Pregel Award of the New York Academy of Sciences for his distinguished contributions in accelerator physics and superconducting magnet technology.

John Dunn (Biology) — Winner of 1984 Lawrence Award for contributions of great potential importance in determining modes of radiation damage, and to the understanding of mechanisms by which DNA is transcribed and processed into functional messenger RNA.

Anthony Fainberg (Nuclear Energy) — Selected by American Physical Society as a 1983-84 Congressional Scientist Fellow.

Maurice Goldhaber (AUI Distinguished Scientist) — Received an honorary Doctor of Science degree from SUNY at Stony Brook.

Garman Harbottle and Edward Sayre (Chemistry) — Joint winners of 1983 George Hevesey Medal for pioneering work in the application of nuclear techniques to art and archaeological problems.

Joseph Hendrie (Nuclear Energy) — Named President of the American Nuclear Society.

William Higginbotham (Nuclear Energy) — Awarded Institute of Electrical and Electronic Engineers Centennial Medal for outstanding record of technical accomplishment.

Alexander Hollaender (Biology Consultant) — Awarded the Enrico Fermi Award.

Hugh Isaacs (Applied Science) — Received 1983 Sam Tour Award from the

American Society for Testing and Materials.

Herbert Kouts (Nuclear Energy) — Received the American Nuclear Society's Tommy Thompson Award for reactor safety contributions.

Richard Lambrecht (Chemistry) — Named a winner of the 1983 IR-100 Award for the development of a radio-pharmaceutical delivery system.

John McTague (NSLS) — Appointed Deputy Director of the Office of Science and Technology Policy, Washington, D.C.

Roger Newman (Nuclear Energy), **Hugh Isaacs** (Applied Science), **Arthur Paskin** (Queens College), **George Dienes** (Physics) and **Karl Sieradzki** (Nuclear Energy) — Cited by DOE's Division of Materials Sciences for Outstanding Scientific Accomplishment in Metallurgy and Ceramics in the 1983 Materials Sciences Research Competition.

Vincent O'Leary (Director's Office) — Received DOE energy award for leadership and management of BNL's energy conservation program.

Veljko Radeka (Instrumentation) — Received 1983 Merit Award from the Nuclear and Plasma Sciences Society of the Institute of Electrical and Electronic Engineers. Also awarded Society's Centennial Medal for outstanding record of technical accomplishment.

M. Joseph Rose (Plant Engineering) — Received DOE energy award for developing Alternate Liquid Fuel.

Jane Setlow (Biology) — Received award from the Metropolitan Chapter of the Association for Women in Science for her contributions to science in biophysics.

Stephen Shapiro (Physics) — Awarded Yamada Science Foundation Fellowship.

David Welch (Applied Science) — Received the Best Article Award from the International Cryogenics Materials Conference for research on the interaction of stress with the martensitic phase transition in Al₅ compounds.

Alfred Wolf (Chemistry) — Received an honorary Doctor of Science degree from the University of Uppsala, Sweden, for his pioneering work in hot atom chemistry and the use of positron emitters in biomedical research.

Organization

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OPERATED BY
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