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THE FIRST FORTY YEARS

1947-1987

BROOKHAVEN NATIONAL LABORATORY
Upton, Long Island, New York 11973

MASTER

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The First Forty Years

On January 31, 1947, the contract creating Brookhaven National Laboratory was approved by the Manhattan District of the Army Corps of Engineers, the forerunner of the Atomic Energy Commission. At that time, the Brookhaven staff numbered 72, in addition to more than 300 employees of the War Department who had been maintaining the Camp Upton site and were transferred to the Laboratory's payroll soon after.

Thus it was that a few hundred people began the work of turning a former Army camp into what is now an internationally renowned scientific research institution.

Today, forty years later, Brookhaven has facilities valued at over \$1.9 billion and a fiscal year 1987 budget of about \$257 million. Our employees number 3,200, with an additional 1,800 guests, collaborators and other visiting researchers who come throughout the year to use BNL's facilities and work with our staff.

Brookhaven 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.

When BNL was established in 1947 on the former Camp Upton site, the Laboratory inherited hundreds of barracks, several recreational facilities and even a stockade for prisoners of war. Within a year, though, the look of the place had already started to change, as old buildings were removed, others renovated and new construction begun to accommodate the growing scientific research center.

Brookhaven:
A National Resource

Brookhaven: A National Resource

In the post-World War II United States, hope was high that exploration of the nuclear sciences would unlock more secrets of the universe as well as lead to peaceful applications of atomic energy.

To do this, powerful, expensive machines were required — nuclear reactors, in particular — at costs well beyond the means of individual institutions. Up to this point, financial support of scientific research by the federal government had been relatively small and selective. But this was about to change.

In his 1945 report for the federal government on a "Program for Postwar Scientific Research," Vannevar Bush, director of the Office of Scientific Research and Development, wrote, "The Federal Government should accept new responsibilities for promoting the creation of new scientific knowledge and the development of new scientific talent in our youth."

Thus, in this climate, was Brookhaven National Laboratory born, one of the national laboratories created to pursue these objectives, with the financial support of the federal government and its blessing to operate independently.

Brookhaven's mission was to be research in nuclear science and related fields, performed with unique, large-scale research tools. It

was to embrace both fundamental and applied science, as well as applications to engineering, biology, chemistry and other fields. Its staff of scientists was to represent many disciplines, and active participation by scientists from universities, industry and other laboratories was anticipated. It was to be a cooperative enterprise in the national interest.

To organize this new laboratory, representatives of nine leading northeastern universities came together in an association known as the Initiatory University Group (IUG). This association grew out of a caucus of 21 major research organizations located within 100 miles of New York City and a similar group centered in Cambridge, Massachusetts. Originally, the goal was to

In October 1948, the construction site of Brookhaven's Graphite Research Reactor was toured by (from left) George Pegram, Columbia; Harold Dodd, Princeton; Frank Fackenthal, Columbia; Karl Hartzell, AUI; David Gurinsky, BNL; Leland Haworth, BNL; Dwight Eisenhower, Columbia; Charles Seymour, Yale; William Watson, Yale; George Brakely, Princeton; Edmund Sinnott, Yale; and Isidor Rabi, Columbia.

Astronaut Joseph Allen (right) was at Brookhaven in 1970 to give a lecture. He came at the request of physicist Harvey Wegner (left), who had gotten to know Allen during his frequent visits to the Laboratory from 1963-67. During those years, Allen used BNL's 3.5-MV Van de Graaff to study properties of nuclear energy levels in a nuclear reaction, for his doctoral thesis at Yale University.

obtain a nuclear reactor and, later, both groups united in a desire to have a government research laboratory available to the entire scientific community of the Northeast.

Through IUC's efforts, a non-profit educational corporation, Associated Universities, Inc. (AUI), was formed to manage the Laboratory for the government. Its officers were appointed by a Board of Trustees. The nine universities represented on the Board, and that still serve, are Columbia, Cornell, Harvard, Johns Hopkins, Massachusetts Institute of Technology, University of Pennsylvania, Princeton, University of Rochester and Yale.

In January 1947, AUI signed a contract with the newly formed Atomic Energy Commission (AEC) for the construction, maintenance and operation of Brookhaven National Laboratory. As the arm of the government primarily responsible for the funding of this laboratory, the AEC approved plans, budgets and research programs in accordance with policies agreed to by AUI.

In 1969, these youngsters were among the thousands of visitors who came to BNL to get a close-up look at a piece of the moon. The 12-gram lunar sample was part of a larger rock brought back to earth by Apollo 11 astronauts. Using low-level gas counters developed for Brookhaven's solar neutrino experiment, Laboratory researchers analyzed numerous samples of lunar rocks and soil. They found, for example, that the particular rocks they measured had been on the surface of the moon from 30 to 50 million years.

A more detailed report of Brookhaven's major research over the last 40 years is given in subsequent chapters, but here is a brief look at some of this research and how it evolved.

The Atomic Energy Commission

Under the aegis of the AEC, Brookhaven's mission was basic research in the nuclear and related sciences. This was the theme of the Laboratory's first 25 years, although amendments to the Atomic Energy Act did open up the use of the facilities for research in health fields unrelated to atomic energy, as well as research on the production and use of energy.

During these years, many of Brookhaven's complex research machines came into existence. The world's first reactor specifically designed for peacetime research purposes, the Brookhaven Graphite Research Reactor, began operation in 1950. In 1965, it was succeeded by the High Flux Beam Reactor, which continues to be the leading U.S. reactor for research involving external neutron beams.

In high energy physics, the Cosmotron was the first accelerator in the world to accelerate particles to the multibillion-electron-volt region (3.3 GeV in January 1953) and the first synchrotron to provide external beams of primary particles. Later came the the 33-GeV Alternating Gradient Synchrotron (AGS), which began operations in 1960, generating protons for both high energy and nuclear physics experiments. Today, the AGS can accelerate both polarized and unpolarized protons, deliver protons to experimenters in three beam modes, and serve up to 11 different experimental beams at one time. In 1986, with the transfer of heavy ions from the Tandem Van de Graaff, heavy ion physics was added to the tasks of that venerable facility.

The Tandem Van de Graaff, an electrostatic accelerator used to study nuclear reaction mechanisms and the structure of compound nuclei, was completed in three stages from 1950 to 1970. Other low-energy accelerators constructed during the Laboratory's first 25 years and still in use are the 3.5-MV Van de Graaff accelerator and the 60-Inch Cyclotron (one of the original irradiation facilities). Also still in operation, since 1959, is the Medical Research Reactor.

The BNL discovery of the strong focusing principle made the AGS possible, and, in turn, the AGS made possible two discoveries that led to Nobel Prizes in physics. In 1963, Val Fitch and James Cronin, both then of Princeton University, did the experiments at the AGS that brought them the Nobel Prize in physics in 1980, for discovering CP violation. In 1974, Samuel Ting, of the Massachusetts Institute of Technology, and his team discovered a new particle at the AGS. They called it the J particle and, in 1976, Ting shared the Nobel Prize with Burton Richter of the Stanford Linear Accelerator Center, who had simultaneously made the same discovery in California.

The Cosmotron and the AGS produced many other new particles. Among those found at the Cosmotron were the K^0 meson and the first vector meson, the ρ (rho). The muon-neutrino and the Omega-minus particles were discovered at the AGS.

Nuclear science was explored not only at the big machines, but in all the scientific departments. In the Medical Department, for instance, L-dopa, which made dramatic headway in the treatment of Parkinsonism, evolved out of a research program in which researchers used radioisotopes to study the role of trace elements in the body and their relationship to neurologically based diseases.

In 1967, Brookhaven's solar neutrino experiment got under way in a gold mine one mile underground in

South Dakota. For the next 18 years, researchers kept watch on a tank filled with 100,000 gallons of perchloroethylene (a dry cleaning solvent), looking for neutrino interactions. The startling discovery was that the number of energetic neutrinos from the sun was far lower than had been predicted, a finding which has had profound implications for theories of stellar evolution and structure.

Brookhaven chemists proved that art and science do mix. Neutron activation techniques were used by nuclear chemists to reveal the struc-

Berkner Hall was filled to overflowing in September 1981, when then-New York Governor Hugh Carey came to announce that the New York Power Authority (NYPA) would supply power to the Laboratory. By the end of fiscal 1986, the Laboratory was receiving 82% of its electric power from NYPA. The cheaper electricity, which comes from an upstate nuclear power plant, has helped Brookhaven operate in the face of escalating energy costs and tighter budgets.

ture of old paintings and, in some cases, identify forgeries. Ceramic pieces unearthed in many parts of the world have also been analyzed and their place of origin determined by a combination of analytical and radiochemical techniques.

Under the AEC banner, Brookhaven researchers worked in the fields, as well as in the lab. A radioactive cobalt source was placed in the center of a field on site, specifically for the purpose of doing basic research on the effects of radiation on crops grown in the field. A 50-acre stand of pine and oak, this

time with a cesium-137 source, was the field lab used for the investigation of radiation-induced changes in natural vegetation.

Brookhaven researchers saw the possibilities of superconductivity early in the 1960's when they began studying how the phenomenon could be used in accelerator magnets. Following the studies of the 60's, BNL's first superconducting magnet was built in 1973, and the technology is now in use for the proposed Relativistic Heavy Ion Collider and the Superconducting Super Collider.

J.B. Horner Kuper (right) was the first person to do business when the new bank opened for the budding BNL community in November 1947.

Energy Research and Development Administration

With the creation, in 1975, of the Energy Research and Development Administration and the Nuclear Regulatory Commission, the Atomic Energy Commission was no more. The nation's most pressing need now was energy, any kind of energy. As a result, some of the Laboratory's programs took a stronger turn towards applied programs in energy technology.

Polymer concrete, a composite of concrete and plastic, proved to be one of the most enduring and durable of Brookhaven's applied programs. It proved its worth in the repair of sewer pipes, road surfaces, runways and bridges and is now one of the Brookhaven "products" whose technology has been transferred to industry, where it is being further developed and marketed.

With fuel shortages looming on the horizon, Brookhaven explored ways of storing hydrogen safely and compactly. It is an abundant element but not easily contained. The

Laboratory developed a metal hydride-forming alloy made of iron and titanium, which can store the greatest amount of hydrogen per unit weight. It has made its way out of the research phase and into promising demonstration projects.

Energy conservation was high on the list of national priorities. In 1976, the first of three demonstration houses appeared on site, houses designed to incorporate energy-saving ideas in construction techniques. In 1980, the passive use of solar energy with natural thermal storage was used in what became known throughout the country as the Brookhaven House. And in 1985, innovative, energy-conserving techniques in prefabricated construction were imported from Denmark, when the Danes built a house on site.

Department of Energy

On October 1, 1977, ERDA was phased out and, in its place, a 12th Cabinet-level department was created — the Department of Energy (DOE). DOE absorbed not only ERDA, but the Federal Energy

By 1986, the Vacuum Ultraviolet Ring of the National Synchrotron Light Source (NSLS) had become so packed with experimental beam lines and equipment that scientists practically rubbed shoulders as they went about their work. That year, both rings at the NSLS in total accommodated over 900 researchers from all over the country, studying topics that ranged from lithography to angiography.

Administration and the Federal Power Commission. It also took over some areas of the Department of Defense, the Interstate Commerce Commission, the Department of Commerce and the Department of Housing and Urban Development. Brookhaven is under the jurisdiction of DOE's Office of Energy Research in Washington, D.C., and, regionally, under the Chicago Operations Office. A DOE Area Office is on site.

The design, construction and operation of large research facilities is still Brookhaven's primary function. Of major importance also are extended programs in the basic sciences that have potential long-term payoff. And, with DOE, Brookhaven's contributions to the technology base of the nation continues.

In this decade, the Laboratory lost a bright new star and gained another.

In 1983, ISABELLE, or CBA, Brookhaven's colliding beam accelerator, was discontinued midway through construction in favor of a proposed much larger national effort — a Superconducting Super Collider (SSC). This was a serious blow to the Laboratory, but it rallied and came up with a plan for a Relativistic Heavy Ion Collider (RHIC).

This initiative would take advantage of the construction already completed for CBA and, more importantly, make possible the study of nuclear matter under extreme conditions of temperature and pressure similar to those existing at the time of the start of the expansion of the universe. The RHIC proposal received the endorsement of the nuclear science community, and, while awaiting approval from the federal government, Brookhaven began preliminary R&D on magnet designs and brought together potential users to plan the physics that would be carried out on the machine.

The Laboratory also threw its expertise into the design of the SSC magnets, a joint venture with Lawrence Berkeley Laboratory and

An 8-inch Newtonian telescope is used by members of the the Astronomical Society, (from left) Cesar Sastre, Robert Mills and Garman Harbottle. Some 40 clubs, administered by the Brookhaven Employees' Recreation Association, offer a broad program of social, cultural and athletic activities to all employees.

Fermi National Accelerator Laboratory. In 1985, this joint design was chosen as the focus of future R&D for the SSC, and construction of prototype full-length magnets began.

Also in the DOE era, the National Synchrotron Light Source, the world's brightest source of x-rays and ultraviolet radiation, was designed and built, attracting hundreds of researchers to its two rings. Within just a few years of its dedication in 1982, the Light Source building had to be enlarged to add more office and experimental areas, and new advanced beam lines were built, bringing the total to 90 beam lines available to the scientific community.

A point of emphasis in the last decade has been technology transfer — the transfer of federally-owned technology to state and local governments and to the private sector. An Office of Research and Technology Applications was established at BNL to identify Laboratory research with commercial potential and to assist in the transfer to industry.

One of the new directions on the national scene is the Strategic Defense Initiative (SDI). To try and answer some of the technical questions posed by this program, the Laboratory has recently completed

Laboratory Staffing Over the First Forty Years

Engulfed by hundreds of model bridges made of balsa wood, Janet Tempel (left) and Jackie Mirzadeh check a list of the 750 high school students who registered for BNL's Model Bridge Contest in 1983. An annual event, the contest is one of a number of educational programs the Laboratory sponsors.

Members of the 1948 women's softball team practice their game. At bat is Alice Gillman; the catcher is Rose Ann Grattan. In the background are (kneeling, left to right) Barbara Carroll, Marjorie Morse, Julia Jacobs, (standing) Joan Simecek, Beatrice Wageli, Jennie Vivenzio, Viola Bowie and Florence Batvinis.

the construction of an experimental beam line to be used for the study of radiation effects on materials. The second part of the SDI effort at BNL is the building of an extension to this beam line for the study of beam neutralization and diagnostics. This project will have become operational by the 1990's.

For forty years, scientists from around the world have come to Brookhaven for periods ranging from a week to a year or more, to perform either their own or collaborative experiments. From the beginning, it was agreed that BNL facilities were to be made available to all qualified scientists. This visiting program is one of the best illustrations of BNL's role as a national laboratory, and the resulting scientific interaction between visitors and staff is stimulating and productive for both.

The Laboratory has also been open to undergraduate and graduate students of universities the world over. Providing them access to the best of scientific minds and instruments is an important contribution to the future welfare of this nation.

FY 1947 — Cost Elements

Salaries and Wages	51.0%
Fringe Benefits	3.4%
Materials, Supplies, Etc.	43.3%
Fuel, Electric Power	2.3%

FY 1987 — Cost Elements

Salaries and Wages	53.6%
Fringe Benefits	13.6%
Materials, Supplies, Etc.	26.3%
Fuel, Electric Power	6.5%

The cost of operating the Laboratory in fiscal year (FY) 1947 was \$7.5 million, as compared to the cost in FY 1987 of \$213 million (estimated). The accompanying charts show the breakdown of how these funds were used forty years ago and how they are allocated today.

Associated Universities, Inc.

Associated Universities, Inc. (AUI) was founded in 1946 to meet a newly emerging national need. The resources of academia and the government were brought together to carry out, centrally and cooperatively, research endeavors not normally appropriate within the structure of a single university. AUI's primary purpose, unchanged to this day, was to advance scientific research in all frontier areas of interest to universities, industry and government.

In establishing Brookhaven National Laboratory (BNL) in 1947, AUI pioneered in expanding the concept of a multidisciplinary laboratory. Nuclear science, with its large reactors, particle accelerators and related facilities, was initially the central activity, but it was accompanied by broadly based programs in related areas in all of the physical and biological sciences and, as well, in the medical sciences. Over the years,

with the development of the Cosmotron and the Alternating Gradient Synchrotron, the central activity gradually shifted to high energy physics as this science blossomed. The focus of the other scientific programs also evolved to keep up with the pace of discovery. It is interesting to note that today, in response to major new scientific opportunities, there is renewed interest in nuclear physics that is expected to culminate in a new forefront facility, the Relativistic Heavy Ion Collider.

As Brookhaven flourished, AUI turned to another area of science where the need for large centralized facilities had become of pressing importance. In establishing the National Radio Astronomy Observatory (NRAO) in 1956, AUI provided the world's radio astronomy community with an extraordinary assemblage of radio telescopes at Green Bank, West Virginia. The success of this observatory soon led to the development of

the Very Large Array telescope near Socorro, New Mexico. This massive instrument is the backbone of modern radio astronomy. It is soon to be joined by an equally impressive instrument, the Very Long Baseline Array, components of which will span the nation between Hawaii and St. Croix.

From its founding, AUI has followed simple guidelines in fulfilling its charter to support national programs in scientific research and education. These are:

- Developing, acquiring, operating and maintaining at the state of the art the large-scale research tools and other specialized facilities and laboratories that best serve academia, industry and the government in an open, "national laboratory" setting.
- Promoting the productive use of these facilities by scientists from all fields, without regard to affiliation.
- Assisting the government in the solution of problems and the performance of tasks for which available personnel and facilities are appropriate.

In meeting its oversight responsibilities, AUI creates management structures and appoints Directors for each institution, to ensure effective and successful accomplishment of each laboratory's research programs. The government provides the necessary operating funds for BNL principally through the Department of Energy and for NRAO through the National Science Foundation; however, the entire staff at both institutions are employees of AUI.

Through the dramatic developments of the past forty years, Brookhaven has been successfully operating with a mandate and a mission statement that have remained virtually unchanged on all basic issues. The same is true for NRAO over its thirty-year history. This is a tribute to the foresight and adventurous spirit of the founders of AUI who established the corporation and, soon

Gathered for a meeting of the Board of Trustees in March 1947 were (clockwise from foreground) William W. Watson, John Van Vleck, Jerrold R. Zacharias, Franklin A. Long, Robert D. Fowler, P. Stewart Macaulay, Isidor I. Rabi, Philip M. Morse, Eldon C. Shoup, Edward Reynolds, Malcolm R. Warnock, Joseph Campbell, George B. Pegram, Arthur S. Adams, George A. Brakeley, James R. Killian Jr., Milton G. White, George B. Collins, Louis N. Ridenour and H.W. Tripp.

thereafter, Brookhaven, relying upon simple and enduring principles.

History

After World War II, Isidor I. Rabi and Norman F. Ramsey returned to the Physics Department at Columbia University from their respective wartime research at the Radiation Laboratory of the Massachusetts Institute of Technology (MIT) and at Los Alamos. Reviewing the rapidly changing scene in "big science," they concluded that peacetime research in nuclear science was going to require major new facilities such as nuclear reactors and large particle accelerators.

In further discussions with Columbia's Dean George B. Pegram, they agreed that such large projects did not fit readily into a university research structure. In addition, competition was keen and nuclear reactor research was classified at that time. A cooperative venture that would be located at a convenient off-campus site was suggested. Dean Pegram convened a meeting in January 1946 of 21 major institutions, both academic and industrial, located between Philadelphia and New Haven.

Subsequently, a proposal to establish a regional laboratory in nuclear sciences was transmitted to Major General Leslie R. Groves, head of the Manhattan District of the Army Corps of Engineers, the forerunner of the Atomic Energy Commission.

Soon after this, nine northeastern universities united in general agreement to support the project. In early March, a letter to General Groves stated that the proposed laboratory "should be operated by a single institution as the contractor, preferably a single university, but that the scientific direction should be in the hands of a board representing the sponsoring institutions and appropriate government agencies."

Late in March, the nine universities formed the Initiatory University Group (IUG), for the purpose of establishing in the northeast region a government research laboratory for nuclear science. Subcommittees were quickly established for site selection, contract negotiation, security and classification policy, personnel policy, and technical planning for "electro-nuclear machines" (particle accelerators) and for nuclear reactors.

After animated discussions in the ensuing months, the IUG and the Manhattan District agreed that the operation of such a laboratory should be managed by an independent corporation sponsored by the IUG, rather than by a single university. Accordingly, on July 18, 1946, Associated Universities, Inc. was chartered as a non-profit research and educational institution by the Board of Regents of the University of the State of New York.

An initiatory staff, which eventually grew to about 50, was housed temporarily at Columbia University, and preliminary plans for research programs and facilities were developed. On January 31, 1947, the Manhattan District approved a contract creating BNL. Thus, over the course of a single year, the original concept had evolved into Brookhaven National Laboratory, managed by Associated Universities, Inc.

AUI Today

AUI is governed by a board of twenty-five trustees. Historically, the majority of the trustees have been drawn from the founding institutions that sponsored AUI — Columbia University, Cornell University, Harvard University, The Johns Hopkins University, Massachusetts Institute of Technology, University of Pennsylvania, Princeton University, University of Rochester and Yale University. Over the years, one-quarter of the

trustees has been affiliated with other universities, research institutions and industrial organizations, both national and international. Since AUI is an independent corporation and not a consortium, individual trustees do not represent their home institutions on the board.

A great strength of AUI is the fact that its Board of Trustees maintains a broad balance of expertise in all major areas of science, as well as extensive experience in senior administration. BNL and NRAO have steadily grown in size and complexity as major national and international institutions, and the Board, in turn, has continued to restructure itself to ensure broad institutional participation in its membership.

Adding even more breadth to the corporation, six Visiting Committees provide the Board with independent, expert appraisals of the scientific programs at Brookhaven and NRAO. The committees are composed of distinguished scientists drawn from the national and international scientific communities in universities and industry.

In the late 1940's, the concept of having large government-owned facilities under the management of private institutions was still in the "new frontier" category. Wartime pressures had resulted in the establishment of an immense laboratory complex operated by major industries. Individual universities such as Chicago, Harvard, Johns Hopkins, MIT and the University of California also ran large laboratories that, at that time, were primarily directed towards national defense.

The founding of AUI broke new ground in establishing a unique partnership between the university community and the government. There soon followed a host of comparable arrangements, principally based upon contracts with consortia of universities. Thus was born the modern system of national laboratories and national centers.

The Evolution Of the Site

The boundaries of Brookhaven National Laboratory encompass 5,265 acres. Close to 1,000 of these acres are occupied by the Laboratory's physical plant, consisting of over 300 buildings and other structures. The buildings are surrounded by trees and grass, and the site resembles a university campus. It was not always so.

Back in 1917, this was the site of Camp Upton, a training center for new recruits in World War I. The land was cleared of the scrub pine, oak and undergrowth to construct the 1,400 buildings needed to fulfill the needs of an Army camp. The camp was active until 1920, but, in August 1921, everything — from stoves to complete buildings — was sold at public auction and removed from the Yaphank base.

For the next 20 years, the site lay dormant, except for some reforestation done during the Depression by

the Civilian Conservation Corps. Then in 1940, with World War II on the horizon, the Army decided to rebuild Camp Upton. The camp functioned first as an induction center, then as a convalescent hospital and rehabilitation center until 1945. It was declared surplus in that year, but not dismantled.

Early in 1946, a new government research center was in the making, and a search was on for a suitable site "as near as possible to New York City." The search was being conducted by the Initiatory University Group, later chartered as Associated Universities, Inc., an association of nine universities that were promoting the establishment of a scientific center in the Northeast.

Seventeen sites had been proposed but were rejected for one reason or another. The final selection came down to a choice between Camp Upton on Long Island, New York, and Fort Hancock near Red Bank, New Jersey. An engineering study made of both sites favored Camp Upton, approximately 60 miles from New York City, and so the choice was made. In January 1947, what had been a rough, noisy Army base began its transformation into a landscaped and orderly research center named Brookhaven National Laboratory.

Immediately, the small staff moved into some of the existing Army buildings, and modifications were started on others. In 1947, work began on the Brookhaven Graphite Research Reactor and, in 1948, on the Cyclotron and several Van de Graaff accelerators. Also in 1948, 106 Army buildings were torn down, as it would have been too

While a recruit at Camp Upton during WWI, Sgt. Irving Eerlin (center) wrote "Yip, Yip, Yaphank," with its hit song, "Oh, How I Hate to Get Up in the Morning." The show was produced in 1918 at New York City's Century Theatre, featuring an all-male cast.

costly to rehabilitate and maintain them. In 1949, the old PX building was remodeled into the Biology Department, and an array of masonry classrooms became the Chemistry complex. The Medical Research Center was housed in what was once part of Camp Upton hospital.

Early in the 1950's, the Cosmotron began operations, and, later that decade, a new medical facility was built to include a research hospital, an industrial medicine branch and a nuclear reactor, the first in the world designed specifically for medical use.

The 1960's brought a surge in

construction, including such buildings as Berkner Hall, (the cafeteria/meeting complex) and a new home for the Chemistry Department. Major machine projects completed were the Alternating Gradient Synchrotron and the High Flux Beam Reactor.

Later years saw the construction of additional major facilities, including the Tandem Van de Graaff, dedicated in 1970, and the National Synchrotron Light Source, which began operating in 1982.

BNL's big machines have long attracted visiting scientists from across the country and around the world. To accommodate these users,

it was necessary to supply temporary housing, as there was little available in the surrounding community. Early in the Laboratory's history, buildings that once contained the camp hospital were converted into apartments and dormitory rooms. In the 1960's, additional housing was added in the form of efficiency apartments and summer cottages.

Throughout the years, the site has remained attractive. It is well planned and well maintained. The old buildings blend in with the new, and while the most sophisticated science is pursued inside the buildings, outside the deer run free.

Back in 1947, this was the main entrance to Brookhaven National Laboratory. Present BNL employees know it as the South Gate, at one end of Upton Road on the southern boundary of the Laboratory.

Directors of BNL

Philip McCord Morse
Director, 1946-1948

Philip Morse, the first director of BNL, was a professor of physics at the Massachusetts Institute of Technology (MIT), and his interests ranged from underwater acoustics to astrophysics. He was awarded the Presidential Medal for Merit for his contributions to the Navy's anti-submarine campaign in World War II. It was his job to staff and equip the new research laboratory on the site of what had been an Army camp. Morse was on leave from MIT when he headed the Laboratory, and he remained affiliated with MIT until his death on September 5, 1985.

Leland John Haworth
Director, 1948-1961

Leland Haworth is credited with building a fledgling laboratory into a world-renowned center for research, particularly in high energy physics. Among the "big machines" designed and put into operation under his direction were the Brookhaven Graphite Research Reactor, the Cosmotron and the Alternating Gradient Synchrotron. From 1951 to 1960, Haworth also served as Vice President of Associated Universities, Inc. (AUI) and as President from 1960-61.

He was appointed a member of the U.S. Atomic Energy Commission in 1961 and, in 1963, President Kennedy asked him to become Director of the National Science Foundation, a post he held for six years. He supported the policy that basic research should be the Foundation's chief concern, but at the same time he recognized the need for a tie to applied research. His ideas eventually found fruition in legislative changes in the NSF's authority.

Haworth returned to AUI in 1969 as Special Assistant to the President and retired in 1975. A mesa in the Antarctic and an asteroid are named in his honor. He died on March 5, 1979.

Maurice Goldhaber
Director, 1961-1973

Maurice Goldhaber came to Brookhaven in 1950 from the University of Illinois, where he had been on the faculty since 1938. He was made Director in 1961 and remained in that post until 1973. During his tenure, the High Flux Beam Reactor and the Tandem Van de Graaff were built. A number of important discoveries were made in particle physics, while the Laboratory also moved further into interdisciplinary research in non-nuclear fields.

An AUI Distinguished Scientist since 1973, Goldhaber has remained active in research, particularly on proton decay. In 1982, he served as President of the American Physical Society, and he is currently a consultant to the Physics Department. His research contributions are in nuclear physics and fundamental particles, and cover experiments, systematics, technique and theory. He received the National Medal of Science in 1985.

George Hoagland Vineyard
Director, 1973-1981

George Vineyard came to Brookhaven from a faculty position at the University of Missouri. He joined the staff of the Laboratory's Physics Department in 1954 and was named Chairman of the department in 1961. From 1966-1972, he served successively as Associate Director and Deputy Director of the Laboratory.

During Vineyard's nine-year administration, Brookhaven pursued a strong program in basic research and, in response to national needs, considerably increased its applied research, particularly in energy programs. Also during his tenure, the National Synchrotron Light Source was developed and constructed.

When Vineyard resigned as Director at the end of 1981, he returned to full-time research in solid state theory, focusing on lattice dynamics and related problems.

In January 1987, he became President-elect of the American Physical Society and would have become President in 1988. He died on February 21, 1987.

Nicholas Peter Samios
Director, 1982 to present

Nicholas Samios, the present Director, was appointed in 1982. A high energy physicist, he joined the staff of the Physics Department in 1959, coming from Columbia University, and was made group leader of the Nuclear Interactions Group in 1965. Under his leadership, the Omega-minus particle and the first charmed baryon were discovered. For this work he received, in 1980, an E.O. Lawrence Award as well as the New York Academy of Sciences Award in Physical and Mathematical Sciences.

Samios chaired the Department of Physics from 1975-1981, then moved to the Director's Office as Deputy Director for High Energy and Nuclear Physics. In January 1982, he was appointed Acting Director and was confirmed as Director in May of that year. His administration has seen the expansion of major existing facilities, such as a booster for the Alternating Gradient Synchrotron and an addition to the National Synchrotron Light Source. Also, there have been proposals for new facilities, such as the Relativistic Heavy Ion Collider.

8/19

Fulfilling a Mission — Brookhaven's Mighty Machines

Fulfilling a Mission — Brookhaven's Mighty Machines

Though Long Island's terrain is notoriously flat, Brookhaven does boast one sizable hill. When the site was Camp Upton, this area was appropriately known as Headquarters Hill. Later, the BNL staff called it Rutherford Hill.

But the name wasn't the only thing about the hill that changed. First, the buildings that once housed company headquarters were removed. Then, on August 11, 1947, ground was broken for the Brookhaven Graphite Research Reactor (BGRR). In the next three months, some 27,000 cubic yards of earth were removed, reducing the hill to about 30 feet below the natural ground level. Less than three years

later, the missing earth had been replaced by a building 80 feet high, half of it underground, which contained the first chain-reacting "atomic pile" ever built specifically for peacetime research in atomic energy.

When the BGRR started operation, on August 22, 1950, Brookhaven began to fulfill a major role: to provide the scientific community with facilities whose construction and operation would be too costly and difficult for an individual institution. BNL was envisioned as a place where scientists from universities, industry and other laboratories would come to do research with such "big machines."

At the north face of the Brookhaven Graphite Research Reactor (BGRR), a technician makes an adjustment to the fast neutron chopper that began operating there in 1953. The fast chopper was so named for its ability to rapidly take neutrons from the BGRR in very short bursts — a convenient method of using them in studies of neutron energies. Such studies contributed to knowledge of the properties of atomic nuclei.

Brookhaven Graphite Research Reactor

As the Laboratory's first big machine and the first such reactor to be constructed in the Northeast, the BGRR produced neutrons for scientific experimentation. In a research reactor like the BGRR, neutrons are captured by uranium nuclei in the fuel elements, causing some of them to undergo fission. Resulting from the fission process are two large fragments and two to three neutrons. These neutrons are then available to initiate new fission processes.

If, on the average, one of the neutrons from a fission produces another fission, a chain reaction is taking place. When the chain reaction is self-sustaining, the reactor is said to have reached criticality. The neutrons not inducing fission reactions are either absorbed in the material of the reactor or are available for experiments.

Originally, the BGRR was fueled with natural uranium, but, in 1958, a new kind of fuel was introduced that used uranium enriched in the normally rare U^{235} . The reactor then operated at 20 megawatts (MW), with a maximum flux of about 2×10^{13} neutrons per square centimeter per second (n/cm^2-s).

The air-cooled BGRR had a cube-like design, with the top and three sides available for experimental use. At its inception, the BGRR could accommodate more simultaneous experiments than any other existing reactor. Scientists and engineers from every corner of the U.S. came to use the reactor, which was not only a source of neutrons for experiments, but also an excellent training tool.

Researchers used the BGRR's neutrons as tools for studying atomic nuclei and the structure of solids, and to investigate many physical, chemical and biological systems. Scientists also studied the effects of radiation on materials. An estimated

25,000 irradiations were performed over the reactor's lifetime, on specimens ranging from seeds to art treasures. In one such irradiation, engine piston rings were studied in the reactor to determine wear and other characteristics. This work led to the development of multi-grade motor oils, such as 10W-30, now commonly used in automobiles.

Neutrons also served as probes, to study the structure and behavior of other materials. "Loop" experiments were another important area of research, in which measurements were made of the radiation-induced changes in the properties of liquids and gases as they flowed through the reactor. Radioactive isotopes produced at the BGRR were especially useful in medical diagnosis and therapy and in industrial technology. The radioisotope

technetium-99m, an important clinical diagnostic tool, was developed at the BGRR.

The BGRR gave 18 years of essentially trouble-free service before it was placed on standby in June 1968 and subsequently decommissioned. The shutdown had been anticipated in the Laboratory's original program plans, which called for a second, much higher flux reactor at a fairly early date. But this program was not immediately undertaken, in part because the BGRR was so effective. By 1955, however, it was clear that the neutron fluxes available at the BGRR and at research reactors elsewhere were not high enough to support proposed experiments. So by 1958, a new reactor concept designed at Brookhaven had been approved by the Atomic Energy Commission (AEC) for construction.

The High Flux Beam Reactor (HFBR) was invented by five Brookhaven scientists. For signing a patent application for the Atomic Energy Commission in 1961, each of the co-inventors received a \$25 honorarium. Here Clarke Williams, then Nuclear Engineering Department Chairman, presents a check to (from left) Jack Chernick, Julius Hastings, Joseph Hendrie, Ken Downes and Herbert Kouts. The HFBR became an operating reactor in 1965.

Medical Facilities

Since the Laboratory's early days, the Medical Department has always boasted unique facilities. For example, to meet scientists' needs for neutrons for medical research, the Medical Research Reactor was built to BNL specifications. This reactor, which was the first to be constructed specifically for medical research, reached criticality on March 15, 1959. It produces a maximum neutron flux of about 2×10^{13} (20 trillion) neutrons per square centimeter per second.

One of the reactor's four faces is equipped for the irradiation of large objects, while the holes that penetrate another face permit irradiation

of samples, activation analysis and production of short-lived radioisotopes. From the remaining two ports, streams of neutrons travel to treatment rooms, for carefully controlled animal and clinical studies.

For measuring various substances in the body, neutrons are also produced in the Medical Department's Total Body Neutron Activation Analysis (TBNA) and Prompt-Gamma Neutron Activation Analysis facilities. The TBNA, for example, measures total-body phosphorus, sodium, chlorine and calcium. One current use is for studies of osteoporosis, which is related to the body's calcium content. With the TBNA, a patient is

exposed to neutrons, which temporarily activate the calcium, making it radioactive. This radioactivity can be measured in another Medical Department device, the Whole Body Counter, to determine the amount of calcium in the body.

Until 1985, the Medical Department also operated the hospital of the Medical Research Center, which, when it opened in 1950, was the first hospital ever devoted to nuclear medicine. Originally, it was housed in buildings formerly occupied by the Camp Upton Hospital. In 1958, a new, 48-bed facility opened its doors. Patients were treated there for conditions ranging from pulmonary diseases to leukemia to obesity.

High Flux Beam Reactor

To gain a substantial increase in neutron intensity, the High Flux Beam Reactor (HFBR) was designed differently from the BGRR. In the HFBR, the neutron flux reaches its maximum outside the reactor core, where it is readily available for experiments, rather than inside the core, as with most reactors. The neutron beams come to experimenters through beam ports that come out of the core on a tangent, rather than radiating outward as was typical in previous reactors. This improvement yields more slow-moving neutrons, which are desirable for most research. Most research reactors built today incorporate these basic innovations, which have been key factors in the HFBR's success.

The HFBR first achieved a self-sustaining chain reaction on October 31, 1965. Over 20 years later, the HFBR is still one of the premier beam reactors in the world, matched only by the Institut Laue-Langevin reactor in Grenoble, France.

For 16 years, the HFBR operated at its design power of 40 MW, providing a neutron flux of 1.6×10^{15} n/cm²-s, a factor of 50 higher than the BGRR. Then, in 1982, after six years of preparation, the reactor power was increased to 60 MW. At the higher power, the neutron flux is 2.4×10^{15} n/cm²-s, an increase of about 50 percent.

Since most experiments are run until the number of counts measured is sufficient to give the desired statistical precision, the greater neutron flux cuts by a third the time needed to do experiments, which makes the reactor available to even more users. The higher flux also gives scientists a better chance of succeeding with certain innovative experiments that otherwise might not have been possible. And through the combination of regular efforts to upgrade the machine, and comprehensive safety, training and maintenance programs, the reactor has achieved an enviable record of availability as a dependable source of neutrons.

The HFBR has provided neutrons for an abundance of scientific exper-

William Schoenig transfers liquid nitrogen into a helium-3 refrigerator in place on a triple-axis neutron spectrometer at the High Flux Beam Reactor. The refrigerator cools the sample under investigation to within 300 millikelvins, which is very near absolute zero. Behind the spectrometer is the large reactor shield structure, which houses the reactor where the chain reaction occurs and from which the nine beam ports emanate.

iments. Outstanding research in solid state physics has included pioneering studies of solids exhibiting structural distortions, work that led to a more complete understanding of the microscopic interactions in solids. Experimental work in nuclear physics has revealed the first examples of three dynamical symmetries in atomic nuclei, thus opening up an entirely new approach to nuclear structure.

Some chemistry research at the HFBR has focused on the study of chemical charge-density distributions in crystals, which yield information on the density of bonding electrons between the atoms of a crystal. Other studies have dealt with transition metal hydrides and other organometallic compounds. Pioneering experiments in biology, done at the HFBR in 1968, proved that neutron diffraction could be used to do protein crystallography for studies of protein function and structure. As these experimental techniques improve, this work continues to be of major importance.

From the control room overlooking the approximately 2,000-ton Cosmotron magnet, which was covered by a white plastic "cocoon," operators could communicate with their colleagues elsewhere in the building. On the floor inside the ring-shaped magnet, which had an inner diameter of 75 feet, can be seen a variety of service equipment. Protons were accelerated in the Cosmotron from 1953 to 1966.

Cosmotron

Early plans for Brookhaven reflected the idea that the Laboratory should provide not only reactors for studies in nuclear physics, but also unique facilities for high energy physics research. In April 1948, the AEC formally approved a plan for a proton synchrotron to be built at BNL. Because the new machine would accelerate protons to energies comparable to those of cosmic rays in the outer atmosphere, it was to be called the Cosmotron.

There were accelerators before the Cosmotron, but BNL's proton synchrotron was the first accelerator in the world to produce particles at energies in the billion electron volt, or GeV, region. The Cosmotron started up in June 1952 and reached its full design energy of 3.3 GeV in January 1953.

Not only was the Cosmotron the world's highest energy accelerator, it was also the first synchrotron to provide an external beam of particles for experimentation outside the accelerator itself. Early on, the beam intensity was 10^{10} (ten billion) protons per pulse extracted for experiments. By 1966, intensity had been

increased nearly 100 times.

Behind these energies and intensities was a doughnut-shaped electromagnet, 75 feet in diameter and weighing about 2,000 tons, that guided the protons in a circular path. After one second of acceleration in the Cosmotron, the protons had traveled 135,000 miles and had reached an energy of about 3 GeV. At that energy, the protons were allowed to strike a target. The fragments of the nuclear collisions were observed on photographs of the tell-tale trails they left in cloud chambers, or with other detectors.

These observations proved to be tremendously important for a better understanding of the complex nature of many subatomic particles. In fact, the Cosmotron was the first machine to produce all the types of negative and positive mesons known to exist in cosmic rays, making possible the discoveries of the K^0 meson and the first vector meson. It was also the first accelerator to produce heavy unstable particles, some of which were formerly called "V" particles, and this led directly to the experimental confirmation of the theory of associated production of strange particles.

But even as the Cosmotron's

protons began speeding towards success, Brookhaven physicists were asking, "What could we do differently to build a bigger and better Cosmotron?" That was a difficult question to answer, since a proton accelerator ten times more powerful than the Cosmotron would require 100 times as much magnet — approximately 200,000 tons of steel.

This changed, however, with the BNL discovery of the "alternating gradient" or "strong focusing" principle, which permitted the use of smaller but stronger magnets that could bring an accelerator to new energy plateaus, without increasing its size.

Alternating Gradient Synchrotron

That's just what happened with the Alternating Gradient Synchrotron (AGS), which, with the help of magnets weighing a total of less than 3,700 tons, first reached its design energy of 33 GeV on July 29, 1960. With the success of the AGS, the Cosmotron gradually lost its status as a prominent research tool and was shut down on December 31, 1966.

An aerial view of the Alternating Gradient Synchrotron (AGS), which has accelerated protons since 1960. The linac (upper left) is the injector for the AGS ring. The large building in front of the ring houses the AGS Department offices and the control room. Other structures in the area are used to service the accelerator and for experiments. The excavated area at upper right contains the tunnel that would house Brookhaven's proposed Relativistic Heavy Ion Collider.

Two discoveries made at the AGS — CP violation and the J particle — captured the Nobel Prize in physics. Other important particles found there include the muon-neutrino, the Omega-minus and the charmed baryon.

Until 1968, the AGS was the highest energy accelerator in the world (33 GeV), slightly higher than its sister machine, the Proton Synchrotron (28 GeV) at CERN, the European laboratory for high energy physics. Despite the fact that today's newest accelerators can reach energies in the trillion electron volt region, the AGS remains a vital and productive machine, thanks to a continuing series of improvement programs:

- Originally, protons were injected into the AGS ring (one-half mile in circumference) at

50 million electron volts (MeV), following a journey down a 100-foot-long linear accelerator, or linac; in 1972, a 537-foot, 200-MeV linac began operation. While this linac greatly increases the AGS's efficiency, it is also the direct source of particles for experiments by BNL's Medical, Chemistry and Nuclear Energy Departments.

- In the beginning, the AGS's peak intensity (the number of protons in the beam) stood at 3×10^{11} (300 billion) protons per pulse, up by a factor of 30 from the original design intensity; by 1986 intensity had been increased more than 1,800 times over the design specifications, as the AGS reached a record intensity of 1.9×10^{13} (19

trillion) protons per pulse.

- The AGS began operation with one method of extracting beam for experimentation, the slowly extracted beam mode, in which particles come out of the AGS with uniform intensity, over a relatively long period of time — typically one second out of a three-second cycle. Today, the AGS beam is provided to users in three modes. In the fast extracted beam mode, which was added in 1973, particles come out of the AGS in 12 short bunches spread over 2.75 microseconds, with a 1.5 second cycle. The last mode, which came on in 1983, is single bunch extraction, which is like fast extraction with one of the 12 bunches extracted to a different area.
- While most physicists still do research under the original proton program, in July 1984, the AGS began providing researchers with polarized protons, protons whose spins have been aligned in the same direction, at the highest energy ever for polarized protons — 16.5 GeV. Since then, beam energy has been increased to 22 GeV. Researchers use the

beam to test quantum chromodynamics, the present theory of the nature of strong interactions, and, in general, to investigate the effect of spin on particles produced in collisions at various angles.

- In November 1986, physicists also began experimenting with heavy ions in the AGS, the culmination of a program begun in 1984 to build and commission a transfer line connecting the Tandem Van de Graaff Accelerator, a source of low energy heavy ions, with the high energy AGS. As highly charged atomic nuclei are accelerated to high energies in the AGS, scientists can study the results of collisions between heavy ions and target nuclei to see what happens when nuclear matter is compressed to extreme states of temperature and density. While the heavy ion program is

During a shutdown at the Alternating Gradient Synchrotron, John Post (left) and Robert Gottschalk perform routine maintenance on one of the 240 main magnets that help guide protons around the accelerator. Robert Dryden uses a bicycle to shorten his journey around the one-half-mile ring.

Detectors

The subatomic particles produced in an accelerator are so minute that they cannot be seen. But physicists can still "look" at them and learn about their properties — by causing collisions to occur within a detector that can capture these events in some understandable way.

At the Cosmotron, for instance, collisions took place in cloud chambers that were filled with gases. Particles darting through the cloud collided and interacted with gas atoms, leaving a trail of small, clearly visible droplets on the ions in the cloud. These trails were photographed and analyzed.

To see more events than were possible in a cloud chamber, researchers considered using liquid targets in which bubbles would form along the paths of charged particles. The bubble chamber, invented in 1952, eventually made cloud chambers obsolete. At Brookhaven, two small bubble chambers were completed in 1959 for use at the Cosmotron.

In the same year, design work began for a much larger bubble

chamber, about 80 inches long, 27 inches wide and 26 inches deep, for use at the Alternating Gradient Synchrotron (AGS). When the first photograph of particle interactions was made on June 2, 1963, the 80-Inch was the world's largest operating bubble chamber. The most famous discovery made there was the Omega-minus particle, in 1964.

By the time the 80-Inch was decommissioned in 1974, the 7-Foot Bubble Chamber was going strong at the AGS. It was the first such detector in which the chamber was surrounded by a superconducting magnet. In 1975, the charmed baryon was discovered there.

Five years later, the 7-Foot Bubble Chamber was shut down, itself a victim of new technology. This time it was electronic wire chamber arrays that could sense the passage of particles and provide researchers with the ability to record only events that met specified conditions, eliminating all those that were obviously of little interest. Very fast and relatively inexpensive, these have evolved into huge, highly sensitive detectors like the Multiparticle Spectrometer (MPS) at the AGS. Out of 2,000,000 particles per second created in collisions in the MPS, its computers can select the 20 to 50 that might be significant, for further study.

The 80-Inch Bubble Chamber, which operated from 1963 to 1974, was housed in a building on the north side of the Alternating Gradient Synchrotron (AGS). Particle beams were guided with magnets from the AGS ring into the liquid hydrogen-filled chamber, where the tracks of the resulting high energy interactions were photographed through the four small apertures in the right lower gallery. The large, central aperture was for the illumination source. Below that gallery was a hydraulic ram, which moved the entire chamber assembly along a track, to whatever position was necessary for a particular experiment.

exciting in its own right, the completion of the AGS Booster Synchrotron, on which construction began in 1986, will open new opportunities for research in both high energy and heavy ion physics. The Booster will increase proton beam intensities by an additional factor of five, polarized proton intensities by a factor of 20, and allow for the acceleration of ions as heavy as gold.

Further, with the Booster, the AGS will be in an excellent position to serve as the injector for the Relativistic Heavy Ion Collider (RHIC), proposed as Brookhaven's next major accelerator. When completed, RHIC will probe a hitherto unexplored energy regime by providing two colliding beams of the heaviest ion species, e.g. gold, at energies of 100 GeV per nucleon, or 40 trillion electron volts at the center of mass energy.

Tandem Van de Graaff Accelerator

Brookhaven is in a strong position to build RHIC because we already have a dependable and versatile source of heavy ions — the Tandem Van de Graaff Accelerator. Completed in 1970, the Tandem was for many years the world's largest electrostatic accelerator facility. It can provide researchers with beams of more than 40 different types of ions — atoms that have been stripped of their electrons, leaving only highly charged nuclei. Available are ions ranging from hydrogen to uranium.

As its name indicates, the facility consists of two high-pressure generator tanks, each about 24 meters long, aligned in tandem. These may be used independently, or one machine may be used as the injector for the other.

Two accelerators are aligned to form the Tandem Van de Graaff, which has provided researchers with low energy heavy ions since 1970. In 1986, the Tandem began a new career, as the injector for the Alternating Gradient Synchrotron, permitting scientists to do research with high energy heavy ions at BNL.

Until recently, the Tandem was used principally by nuclear physicists to study nuclear reaction mechanisms and the structure of compound nuclei. In 1984, however, it was decided to shift these efforts to the study of heavy ion collisions at much higher energies.

For this purpose, a 700-meter-long tunnel and beam transport system were designed and constructed, to deliver heavy ions to the AGS for further acceleration — to energies as high as 14.6 GeV per nucleon. This energy, which is about 2,000 times larger than previously available at the Tandem, opens an entirely new area of research.

Normally, Tandem-type accelerators operate with low-intensity, direct current beams. But to make the heavy ion transfer line possible required the development of a totally new, high-intensity pulsed

mode of operation, which was commissioned at the end of 1986. The pulsed intensities are about 50 to 100 times greater than the normal direct currents, and such intense pulsed beams had never been obtained before with tandem accelerators.

The production of beams for the relativistic heavy ion program is now the Tandem's first priority. During the remaining time, new and interesting applications are being found for the large variety of different beams and energies available. One such application is the testing of integrated circuit chips under heavy ion bombardment. By so simulating the effects of radiation both in space and on the ground, scientists and engineers from several other laboratories and companies aim to improve the reliability of computers.

Other Van de Graaffs

The Cosmotron's dismantling was completed in 1967, but one component remained on active duty until 1980: the four-million-volt (4-MV) Van de Graaff accelerator, formerly used to inject protons into the Cosmotron.

In its new incarnation, the 4-MV Van de Graaff became the Radio-logical Research Accelerator Facility (RARAF). RARAF was a source of charged particles and mono-energetic neutrons, with energies ranging from about 0.1 to 15 million electron volts. These particles were used for basic and applied investigations of radiation effects on living systems.

The 4-MV instrument had several relatives at Brookhaven. The "big brother" is the Tandem, but there are also a couple of smaller members of BNL's Van de Graaff family:

- The 2-MV Chemistry Van de Graaff is regarded as Brookhaven's oldest operating accelerator, having come on line in early 1948. It produces electrons in a precise beam for research on radiation damage and radiation effects on chemical systems.
- The 3.5-MV Research Van de Graaff was installed only slightly later in 1948. Until 1970, when the Tandem started up, the 3.5-MV machine was the major accelerator used in BNL's low energy nuclear physics program. Now it is a valuable tool for experiments in materials and biomedical sciences, as well as a major component of the Laboratory's Regional Center in the Geosciences.

The machines that make Brookhaven a world center for materials science research are an important part of the BNL landscape: The striking white building in the foreground contains the two rings of the National Synchrotron Light Source (NSLS); the domed building behind the NSLS at left contains the High Flux Beam Reactor.

National Synchrotron Light Source

While particle accelerators require the removal of electrons from atoms to form ions that can then be accelerated and guided in electrical magnetic fields, the electrons themselves are the important players in Brookhaven's National Synchrotron Light Source (NSLS). The NSLS is one of the world's most powerful and versatile sources of synchrotron radiation, providing intense beams of x-rays and vacuum ultraviolet (VUV) light for research in physics, chemistry, biology and various technologies. In addition, the combination of the NSLS and the HFBR has made Brookhaven a world center for materials science research.

Electrons are charged particles that, when moving rapidly in a curved path, give off electromagnetic radiation, which is carried by discrete units of light called photons.

Because it was first seen when electrons were accelerated in a synchrotron, this radiation is called synchrotron radiation. The photons emitted span the spectrum from very low energy radiation (long wavelengths, such as infrared light) to extremely high energies (short wavelengths, such as x-rays) and can thus be used to probe a very broad range of scientific phenomena.

Recognizing this, in 1977, Congress approved BNL's proposal for a facility to provide intense beams of photons to be used by scientists from all over the country. Construction began in 1978. When it came on line in 1982, the NSLS was one of the first electron synchrotrons to be dedicated solely to photon generation.

In its role as a national facility, the NSLS accommodates over 900 users from 70 separate institutions, providing both a VUV and an x-ray ring for experimentation. Both rings are

fully operational, and each is the brightest source of its kind in the world.

To make these bright beams available to as many researchers as possible, BNL introduced the concept of Participating Research Teams (PRT). PRTs may include BNL's own scientists, or 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 a percentage of its beam line's time. General users, who usually have a less continuing need for a beam line, are scheduled for the remaining time, as well as for lines built specifically for use by the general community.

From the VUV ring, which operates at an electron energy of 750 MeV, 25 beam lines emanate from 16 ports. The experimental program at the VUV ring got under way in

At the Exxon beam line at the x-ray ring of the National Synchrotron Light Source, William Thomlinson adjusts the photon beam transport system, which includes mirrors and monochromators for separating out the desired wavelength of light from the spectrum available.

STRAIN MAP AROUND NIOBIUM HYDRIDE PRECIP IN NIOBIUM CRYSTAL

At beam line X-14 of the National Synchrotron Light Source (NSLS), a collaboration of users from Oak Ridge National Laboratory and the Georgia Institute of Technology studies single crystals of niobium to determine how strain is distributed around the area of a crystal containing a niobium hydride precipitate — an area of the crystal to which hydrogen has migrated. Made in 1985, this map — the first of its kind — shows, quantitatively, the strain distribution near the precipitate. It was created by placing the crystal sample in the NSLS's x-ray beam and measuring the scattering intensity as a function of position and orientation. The tremendous intensity of the x-ray beam allows the researchers to work with a very small beam and to map out large regions of a crystal in a reasonable time. This work can lead to a better understanding of everyday materials such as steels, in which such precipitates are common.

1983, and among the experiments for which scientists have collected data are:

- **X-Ray Microscopy** — A team of researchers from the NSLS and the State University of New York at Stony Brook is developing a soft x-ray scanning microscope using the soft x-rays (ultraviolet light in the 15- to 45-angstrom range) available at the VUV ring. The microscope has already produced unprecedented pictures of the internal structure of living cells in aqueous solutions, as well as micrographs of human skull tissue, showing areas rich or poor in calcium.
- **Lithography** — With a view towards producing integrated circuits, scientists from the IBM Corporation use VUV light to expose circuit patterns on photosensitive materials. Features as small as 0.25 microns have been replicated with high aspect ratios.

From the x-ray ring, which operates at 2.5 GeV, 31 beam lines with a wide variety of capabilities currently occupy 18 of 28 available ports. Researchers began taking data on the x-ray ring in 1985. Some of the experiments there involve:

- **Diffraction/Scattering** — Many scientists at the x-ray ring use these techniques to determine the various properties of materials, such as structure or phys-

ical state, by monitoring the way in which photons are scattered. One such user is the Exxon Corporation, whose researchers are attempting to improve the efficiency of catalytic processes, in which complex organic molecules are broken down into smaller constituents, which are then used in making such products as heating oil and gasoline.

- **Crystallography** — A team from BNL's Biology Department uses scattering and diffraction techniques to define long-range crystalline structures of protein molecules, mostly enzymes involved in gene expression and other life processes.

The NSLS has attracted so many users that, in 1983, Brookhaven received Congressional approval for Phase II, a four-year project to expand the experimental floor and office areas and to develop five highly advanced experimental beam lines. Four of these beam lines were designed to take advantage of magnetic devices called "wigglers" and "undulators," which emit extremely bright x-ray beams. One of these magnets, a superconducting wiggler, will help scientists from Brookhaven and Stanford University develop a safe technique for coronary angiography — a method for imaging human coronary arteries. This device will be installed in the x-ray ring at the end of 1987.

Scanning Transmission Electron Microscope

Electrons are also the particles behind the Scanning Transmission Electron Microscope (STEM). STEM was constructed by researchers in BNL's Biology Department to image specimens and measure the masses of proteins, nucleic acids and complexes of the two. STEM, which went into operation in 1975, is one of only three such microscopes in the world.

A conventional electron microscope works much like a light microscope, illuminating the specimen with electrons instead of light and using lenses to form a magnified image. Although many electron microscopes can operate at a resolution of two angstroms ($2 \text{ \AA}$), their resolution with biological samples is usually at least ten times poorer, because of damage by the imaging electrons. Thus, much of the fine structure of biological systems cannot be seen with the electron

microscope.

With a scanning transmission electron microscope, however, the problem of radiation damage is minimized. To start with, a specimen is cooled to liquid nitrogen temperature and scanned, rather than being irradiated all at once. While passing through the specimen, some of the electrons interact with it, losing energy to whatever they hit or changing their course. Detectors count every transmitted electron, and each electron contributes to a final picture. As a result, fewer electrons are needed to record an image than with other electron microscopes, so radiation damage to the sample is minimized.

The process permits scientists to scrutinize biological specimens at a resolution of $2.5 \text{ \AA}$. STEM can also determine molecular weight and mass distribution within single macromolecules and complexes.

In 1985, Brookhaven became home to another of the world's three electron microscopes capable of easily imaging single heavy atoms. The second STEM is on long-term loan from Johns Hopkins University. Though not as powerful as the BNL instrument, the new STEM will be particularly useful for gathering chemical information about a specimen, using a technique called electron-energy-loss spectroscopy.

Shortly after the 1975 commissioning of the Scanning Transmission Electron Microscope, John Bittner (left) views the microscope itself, as Joseph Wall observes the image it transmitted to the TV monitor.

Positron Emission Transaxial Tomography

The electron's antiparticle — the positron — is critical to another Brookhaven instrument: PETT VI. The name is an acronym for the technique the machine makes possible — positron emission transaxial tomography. The technique relies on a positron emission tomograph, such as PETT VI, which measures the concentration of a positron-emitting radionuclide that is present in a specific area of the body.

BNL's involvement with this kind of research dates back to 1961, before the technique had been named or the instrument invented. Brookhaven scientists were tackling the problem of detecting and accurately locating small brain tumors,

by analyzing the decay of radioactive material injected into the bloodstream and preferentially absorbed by the tumor. The Laboratory's Instrumentation Division first built an array of detectors on a spherical surface, but soon abandoned that concept in favor of arranging the detectors in a cylinder.

Since a circular device would provide many individual data points on one thin slice of the area of interest, the question arose as to how to reconstruct that information in a useful image. The answer eluded mathematicians until the early 1970's, when unique algorithms (procedures for solving mathematical problems), including one important BNL contribution, were developed. This breakthrough allowed researchers to build a practical device for imaging areas of the

brain, leading to today's PETT machines.

The original circular device built at Brookhaven is still in use at the Montreal Neurological Institute, for studies of brain blood flow. Today, circular detector arrays are a primary feature of all PETT machines, although the technology has advanced in every other aspect.

Brookhaven, meanwhile, has continued to pursue research with the technique, using the latest technology available in PETT devices. From 1977 to 1981, a machine called PETT III gave BNL scientists a look inside the human brain. Now the faster, more sensitive PETT VI is being used for studies of brain tumors and of mental disorders such as schizophrenia, and also Alzheimer's and Parkinson's diseases.

Facilities for Radioactive Material

In addition to its reactors and accelerators, Brookhaven has always had special facilities for research with radioactive materials.

For example, the 60-Inch Cyclotron, completed in 1950, was one of the Laboratory's original facilities for producing radioisotopes (radioactive species of atoms), for such purposes as nuclear reaction studies, chemical effects of nuclear transformations, and irradiation of biological systems. In 1981, a smaller cyclotron was brought to BNL to produce large amounts of positron-emitting radioisotopes for biomedical research and clinical studies. They are incorporated into radiotracers given to subjects

involved with PETT VI studies.

As the injector for the Alternating Gradient Synchrotron, the linac transports so many particles that there are more than enough to divert some to the Brookhaven Linac Isotope Producer (BLIP). Since 1973, radioisotopes have been made at BLIP for medical users and industry. Some particles go to the Chemistry Linac Irradiation Facility (CLIF), which has produced radioactive species for research since the early 70's, and to MEIN, the Medium Energy Intense Neutron facility, where neutron-rich radionuclides have been produced for study since 1974. Other particles go to the Radiation Effects Facility, commissioned in 1986 under the Strategic Defense Initiative, where materials are studied for their response to the radiation associated with high

energy particles.

Thousands of curies of radioactive material can be handled in the Hot Laboratory, using a variety of different enclosures, or cells, containing equipment that can be operated inside the cells by remote control from the outside. The radioactive products of BLIP are processed in the Hot Lab, which opened in 1951.

Two hot cells were the main feature of the High Intensity Radiation Development Laboratory (HIRDL), which operated at BNL from 1960 to the mid-1970's and served as a focal point for radiation research and development in the U.S. One cell was designed for experimental irradiations of food and other materials; the other, for processing various types of radioactive sources for experimental use.

Alfred Wolf lies with his head positioned within the circular array of PETT VI, which has operated at BNL since 1981. He awaits the start of a set of brain scans, while Barry Bittman, State University of New York at Stony Brook, makes a final check. Wolf, who heads Brookhaven's research on the brain using PETT VI, was the subject of this experiment, designed to test hypotheses about which areas of the brain are activated when a patient reads music, or reads and listens to music simultaneously. This was a prelude to studies planned on aphasia, a condition marked by abnormalities in the sensory-neural apparatus, which causes difficulties in transmitting or receiving ideas through written or spoken language.

Users and Visitors

All these facilities would be only so much window dressing without one essential ingredient: users. From the very beginning, Brookhaven's machines, large and small, have attracted the best of the world's scientific community.

Many BNL users come from the Laboratory's own scientific staff, which, at the end of 1986, numbered about 650. At any given time, that number is supplemented by about 1,800 guests, collaborators and users, who come to do theoretical and experimental work among their peers or to use a BNL facility. In 1986, for example, research at the NSLS was conducted by about 900 scientists from some 70 institutions; 700 researchers representing 93 institutions were involved with AGS experiments; and more than 200 scientists from institutions all over the world performed experiments at the HFBR.

Two notable experiments at the AGS were led by visiting scientists, who later won Nobel Prizes in physics for their efforts. Samuel C.C. Ting of the Massachusetts Institute of Technology (MIT) shared the 1976 prize for his 1974 discovery of the J particle. In 1980, James Cronin, University of Chicago, and Val Fitch, Princeton University, won the award for their 1963 discovery of CP violation, when they were both on the Princeton faculty.

While these visitors were involved with long-term experiments, other scientists may be able to spend only a few months away from their home institutions. To accommodate these researchers, Brookhaven devised its summer visitors program. Though summer visitors came to BNL from the start, the program became formalized in July of 1950. That initial group included 67 scientists representing 34 universities and colleges from coast to coast, as well as two AEC laboratories. Some were senior faculty members participating in research projects directly related to

their university work; others were graduate students seeking experience in atomic energy fields.

The summer visitors program yielded a Nobel Prize in physics for T.D. Lee of Columbia University and C.N. Yang, then of the Institute for Advanced Study. Working at Brookhaven as guest scientists in the summer of 1956, Lee and Yang were intrigued by results of experiments at the Cosmotron that showed that the lifetimes and scattering behavior of two particles — the tau (τ) and the theta (θ) — were identical. Their masses were also identical. But the τ would decay into three pions and the θ into two pions. Because their decay modes were different, theory required that they had opposite parity and must be two different particles, despite their overwhelming similarities.

This doodle pad was used by T.D. Lee during talks with C.N. Yang, while both were visiting scientists at Brookhaven in the summer of 1956. These discussions led to their questioning the conservation of parity in weak interactions and resulted in their being awarded the 1957 Nobel Prize in physics. Though the line of thought of a theoretical development can rarely be illustrated, in this case, the doodle pad presents to the initiated a rather artistic arrangement of Lee and Yang's principal points.

The rule of parity conservation, long considered absolute, means that the mirror image of a reaction is equally probable. After a crucial examination of the experimental evidence, Lee and Yang concluded that parity conservation might be violated in the weak interaction involving radioactive decay and suggested experiments to verify their conclusion. This would solve the τ - θ puzzle and show that the τ and the θ could indeed be the same particle.

The suggested experiments were soon carried out at the National Bureau of Standards and the Columbia University Nevis Cyclotron Laboratories and beautifully verified Lee and Yang's radical conclusions. In 1957, they were awarded a Nobel Prize in physics for their summer's work.

Each summer, about 65 future scientists work alongside BNL and guest scientists. These are juniors and seniors in college who participate in Brookhaven's summer student program. Laboratory Director Nicholas Samios is an alumnus of the program's first year, 1952.

A separate summer program provides 10-20 qualified graduate students with a thorough understanding of the practical aspects of health physics. And among Brookhaven's many other educational programs, twelve MIT graduate students in chemical engineering come to BNL periodically to gain work experience in solving engineering problems, while about 15 undergraduates from Southampton College are given appointments as technical collaborators throughout the school year, to gain practical experience in scientific research.

Although specific research programs lure many visitors to Brookhaven, there are other reasons why guests come through our gate. One of those reasons is to attend conferences. In August 1949, 138 visitors attended Brookhaven's first full-scale scientific conference on "Short Pulse Techniques and High Speed

One of the earliest meetings held at Brookhaven was an October 1947 Biology and Medicine Conference attended by over 400 people. Here, some of the attendees crowd the gymnasium, to view a display of radiation detection instruments.

Gus Prince (kneeling) and Benjamin Magurno (center, rear) explain a model of the Brookhaven Graphite Research Reactor to a group of students who visited the Laboratory in 1969.

Counters." Since then, the Laboratory has been the site of hundreds of important meetings. A sampling includes:

- 1950 — The first of a continuing series of important Biology Symposia.
- 1959 — An AEC-sponsored meeting to discuss long-range plans for high energy accelerators and the experimental programs associated with these machines.
- 1963 — The first scientific meeting sponsored in the U.S. by the International Atomic Energy Agency, on the biological effects of neutron irradiations.
- 1973 — In-service institute for high school science teachers on "The Forms and Uses of Energy."
- 1986 — An international conference on "Short-Term Health Effects of Reactor Accidents: Chernobyl."

Other visitors come to Brookhaven simply to see what we are all

about. A Laboratory boasting over 3,000 employees and a host of exotic machines is sure to attract the curiosity of the surrounding communities. Brookhaven has always tried to be a good neighbor and, in 1949, began reaching out to Long Island with a traveling exhibit on the basic scientific principles of nuclear energy. In April 1950, the Laboratory began opening its doors to the general public and students with annual visitors' days. Approximately 1,500 people joined that first tour.

As the program has continued and evolved through the decades, many thousands more have joined the ranks of BNL visitors. In 1986, Brookhaven hosted about 4,500 members of the general public, during the "Summer Sunday" tour program. Another 12,000 participated in special tours of the Laboratory held year-round for groups including college, high school and elementary school students, community organizations and representatives of industry.

Visitors to Brookhaven in 1958 and 1959 enjoyed playing with a video tennis game (see arrow) designed as an exhibit by William Higinbotham. Since then, this game has been widely accepted as the very first video game, the forerunner of all those Pac-men.

**Marking the Milestones
In Basic Research**

For the neutral K-meson experiment that led to their Nobel Prize-winning discovery of CP violation, James Cronin, Val Fitch, James Christenson and Rene Turlay used this spectrometer array. Here, a scientist checks the complex electronic equipment of the triggering system.

Marking the Milestones in Basic Research

Throughout the centuries, scientists have sought to understand the universe. A written representation of this pursuit of knowledge would look like an imperative sentence — a series of strong, precise words followed by an exclamation point. Copernicus's realization that the earth revolves around the sun, Newton's discovery of the laws of gravitation, and Einstein's formulation of the theory of relativity are some of the bolder exclamation points. But all grew out of the strong, precise efforts of other scientists.

The quest to advance scientific knowledge is called basic research, and it is practiced at Brookhaven in many fields, including the physical, materials and life sciences. As in the examples cited above, most of what has been learned has come in small steps, punctuated by great leaps forward — the exclamation points described here.

Nobel Prize: CP Violation

Even among exclamation points, some stand out, and they are awarded the highest scientific honor contemporary society can bestow: the Nobel Prize. Two physics discoveries made at the Alternating Gradient Synchrotron (AGS), Brookhaven's 33-billion-electron-volt (GeV) accelerator, have captured the Nobel Prize. Interactions between the AGS's beam of high energy protons and stationary targets produced these extraordinary insights into the behavior and makeup of the subatomic particles that are the basis of all matter in our universe.

The first discovery, CP violation, called into question the strongly held belief in a fundamental symmetry principle. According to this principle, the laws of physics would be the same if all particles were replaced by their antiparticles (charge conjugation, or C), while all their motions were replaced by their mirror images (parity, or P). A simpler sounding consequence: Physics would be the same if time were to flow backwards.

In 1963, Princeton physicists James Cronin (now of the University of Chicago) and Val Fitch set out to place even more stringent limits on the validity of the CP symmetry principle. The research team also included James Christenson, a graduate student of Cronin's for whom the experiment was actually a doctoral thesis, and Rene Turlay, a visiting researcher from Saclay, France.

The team's first step was to submit a proposal to BNL's High Energy Advisory Committee, in April 1963. Though this double-spaced, mimeographed proposal was extremely short by today's standards — only a page and a half — it was obviously convincing: A month later, the committee approved 200 hours of beam time at the AGS.

Cronin had done a previous experiment at the Cosmotron, so the team enlisted his experimental apparatus. Located inside the AGS magnet ring, in an area dubbed Inner Mongolia, the experiment used the neutral K mesons selected from the profusion of particles that the accelerator produces when its proton beam collides with a metal

Inside the trailer "where it all happened" at the Alternating Gradient Synchrotron are the members of the experimental team that discovered the J particle. Samuel Ting, who headed the Nobel Prize-winning effort, stands behind a graphic representation of the J-particle event, which shows up clearly as the large peak of data. Also shown are (standing, from left) Gary Krey, Y.Y. Lee, Peter Biggs, Paul Goldhagen, Bruce Bailey, (seated in foreground, from left) Ingrid Schultz, Joseph Leong and Sau Lan Wu.

cisely, they had observed a violation of CP invariance and thus had shown that the direction of time does influence the laws of physics.

The experiment was submitted to *Physical Review Letters* on July 10, 1964, and it was published in the issue of July 27 — just over one year following the data collection. Since then, a great deal of experimentation and theoretical thinking has been done by other physicists. But there is still no satisfactory theoretical explanation for the origin of CP violation. For finding this flaw in one tiny corner of the subatomic world and for their profound observation that the universe is not completely symmetrical, Cronin and Fitch were awarded the 1980 Nobel Prize in physics.

Nobel Prize: J Particle

The second Nobel Prize-winning discovery was made in 1974 by a team headed by Samuel C.C. Ting of the Massachusetts Institute of Technology (MIT). The group was searching for new unstable particles, or resonances, formed in collisions

target. There are two kinds of neutral K mesons, the long-lived K_L^0 and the short-lived K_S^0 . Previous experiments had shown that the K_S^0 decays to two particles called pi mesons. If the widely accepted CP symmetry principle were correct, physicists reasoned that K_L^0 could not decay to two pi mesons.

Set up time was minimal. The team was taking data on June 10 and started the CP part of the experiment on June 22. In all, the experiment progressed with remarkable

speed. By late October, when the research team had finished their measurements, they were left with what Fitch once called "a suspicious-looking hump, for which we waited to go away."

The hump in the data never went away, for it represented CP violation. The team had discovered that, occasionally, the K_L^0 meson does indeed decay to two pi mesons. They observed 45 two-pi events out of 23,000 decays. Instead of defining the symmetry principle more pre-

between a proton beam and a stationary target.

Particularly important to this search was the ability to provide continuous detection of events over a broad range of mass values. Ting's group achieved this by combining an elegant experimental technique with the unique capabilities of the AGS. The AGS was the ideal accelerator for this experiment because of its new high-intensity proton beams, the result of a recent improvement program.

The MIT/BNL experiment was the first in which electrons and positrons produced in beam/target interactions were detected simultaneously, in pairs, in a double-arm spectrometer, which could determine the energy of each particle very precisely.

The experiment was one of the most complex to be set up on the AGS floor at that time. It required special magnets, large detectors called Cherenkov counters to weed out signals from less interesting reaction products, special lead glass detectors to identify electrons and positrons, and wire chambers to precisely detect and reconstruct the particles' trajectories in the spectrometer. Because of the radiation produced by protons bombarding the target, the equipment was shielded by 10,000 tons of concrete and steel, and 20,000 pounds of soap (borax) were used to shield against neutrons.

Completed in April 1974, the experimental setup went through routine tune-ups until the end of July. Actual data collection began in August.

As the data came in, they were dominated by a sharp peak in the newly produced mass of electrons and positrons at an energy of approximately 3.1 GeV. Before Ting and his team had time to investigate the nature of the peak, however, their scheduled time at the AGS ran out. When they were able to resume the experiment, in October, the peak came right back.

This peak indicated that each electron-positron pair was originating from a single parent particle with a mass of 3.1 GeV, about three times the mass of the proton. For such a heavy particle, however, this newly discovered resonance was also very stable and surprisingly long-lived, with a lifetime about 1,000 times longer than that observed with other such massive particles.

The group dubbed this new resonance the J particle, because J is the symbol used to denote electromagnetic current and internal rotations, or spins, in nuclear physics. Coincidentally, the letter J is almost identical to the Chinese character for Ting. On November 10, 1974, Ting announced the discovery of the J particle.

Meanwhile, at the SPEAR storage ring at the Stanford Linear Accelerator Center, a group led by Burton Richter had found a new particle they called the psi, using a different technique. When the researchers compared notes, it was obvious that they had discovered the same particle, now called the J/psi.

The physics community was intrigued by this unexpected new particle. Particles were thought to be made of two or three fundamental building blocks called quarks, but the J/psi's lifetime was much longer than expected from any combination of the known quarks.

Ultimately, the J/psi was confirmed to be a particle composed of a new, so-called "charmed" quark bound to its antiquark. This was the first clear indication of the existence of the charmed quark, which had been hypothesized as being necessary to complete a second family of fundamental particles. The discovery of this family made it clear that quarks are real entities, not just mathematical inventions. In 1976, Ting and Richter were jointly awarded the Nobel Prize in physics for this important finding.

Associated Production

The discoveries of CP violation and the J particle were not made in isolation. Previous research paved the way by refining the technology and experimental techniques and by raising the questions these experiments sought to answer; subsequent work helped confirm their significance.

At Brookhaven, the first "high energy" physics research was conducted with the Cosmotron. Commissioned in 1952, its unprecedented energy of 3.3 GeV enabled scientists to provide experimental confirmation of the theory of associated production of strange particles.

The associated production hypothesis, which was proposed in 1952, grew out of cosmic ray studies in England. In these early experiments, interactions took place in cloud chambers, devices filled with gases in which fast-moving particles left distinctive tracks. Such research had uncovered two amazingly long-lived, neutral particles, which often decayed into two charged particles whose tracks formed a "V". To explain the particles' long lifetime, theorists postulated that they are produced only in association with each other, and that they carry a characteristic called strangeness, which is related to the strong interaction, the force that keeps quarks bound together.

Some early evidence for associated production came from the photo on the left, taken during a particle interaction at the cloud chamber in the Cosmotron during an experiment by William Fowler, Ralph Shutt, Alan Thorndike and William Whittemore. The line drawing on the right corresponds to the photographed events and indicates what particles caused the various tracks. The K^0 (K meson) and the Λ^0 (lambda) are the "V" particles produced in associated production. Their trajectories are indicated by dashed lines, since neutral particles leave no tracks in a cloud chamber. The V particles are identified by the other particles into which they decay.

With the Cosmotron, V particles could be produced artificially. The first definite evidence to support the theory of associated production came from a 1953 BNL experiment, using a high-pressure, hydrogen-filled, diffusion cloud chamber. In photographs of the events, decay products could be identified and, thus, the masses of the parent particles could be calculated with accuracy. The results were consistent with the associated production process. The next experiment identified the two V particles as a lambda and a K meson. Further work at the Cosmotron indicated that V particles are produced *only* in associated production and provided strong verification of the existence of strangeness, which is now fundamental to an understanding of particle physics.

New Elementary Particles

The Cosmotron also made possible the discovery of a host of new elementary particles, perhaps the most important of which was the K_L^0 meson, the same K_L^0 that later led

researchers to CP violation. The 1956 discovery of the K_L^0 by a BNL/Columbia group satisfied theoretical predictions for such a particle.

Other particles discovered at the Cosmotron include the first vector meson (the rho) and the neutral sigma and negative sigma baryons.

In 1960, the AGS began operations, accelerating protons to energies more than ten times those of the Cosmotron. From the decay of beams of high energy mesons produced by the AGS, came beams of those elusive particles known as neutrinos, intense enough for high energy study of the weak interaction, the force responsible for radioactivity and nuclear decay.

In 1963, with the postulation of the "up" and "down" quarks, the "first family" of four fundamental particles was proclaimed, the others being the electron, known since 1897, and the first neutrino, discovered in 1962. With earlier discoveries of the muon and a particle attribute called "strangeness," evidence had begun to mount for a second family of four fundamental

A 1964 BNL/Rochester/Syracuse experiment, led by Nicholas Samios, produced the photo on the left — the first ever taken of the Omega-minus (Ω^-) particle. The sketch on the right shows which events in the picture point to the Ω^- . At the bottom of the drawing, an incoming K^- meson interacts with a proton in the liquid hydrogen of the 80-inch bubble chamber. This produces an Ω^- , a K^0 and a K^+ meson. The Ω^- subsequently decays into a cascade of other particles. Neutral particles, which produce no tracks in the chamber, are shown by dashed lines and are identified by their decay products.

Shown at left is the photograph of the event in the 7-Foot Bubble Chamber that led a Brookhaven group, headed by Nicholas Samios, to the discovery of the charmed baryon. The sketch at right is labeled with the particles involved in the event. Neutral particles, which leave no tracks in the chamber, are shown by dashed lines.

particles. In 1962, a Columbia/BNL experiment at the AGS uncovered the muon-neutrino, which accounted for the third member of this family. The later discovery of the J particle helped reveal the fourth member, the "charmed" quark.

Another theory was confirmed at the AGS in 1964, when a BNL/Rochester/Syracuse group conducted the first AGS experiment using the new 80-inch bubble chamber, a device in which particles interact in liquid hydrogen, leaving tracks that can be photographed and analyzed. Some 133,000 photos and less than two weeks later, a new particle was revealed: the Omega-minus (Ω^-). A particle with a strangeness of -3 had been predicted by a theory called SU(3). The Ω^- was found to have the predicted properties, establishing the theory as correct and forming a solid foundation for the development of quark theory.

Another bubble chamber, the 7-foot, was first used for neutrino experimentation in 1974. A BNL group took nearly 62,000 pictures in this bubble chamber, which were

analyzed in the spring of 1975. One event stood out. It was the first observation of a single "charmed" particle — the charmed baryon, a particle made up of three quarks, one a "charmed" quark. This finding reinforced the interpretation of the J particle and was another important step in establishing that there was a new member of the quark family.

Other important discoveries at the AGS include: the phi vector meson (1962); the antiparticles anti-Xi-minus (1962) and anti-Xi-zero (1962); and the highly exotic pionium atom (1976). A host of nuclear particles known as baryon resonances were also found at the AGS, including three Xi* (1969) and several N* and Δ resonances. The discovery of these baryon resonances has been crucial in completing our understanding of the theoretical hadron spectroscopy framework. In 1983, a collaboration of researchers from BNL and the City College of New York announced that they had collected direct evidence for the glueballs that theory predicts should result from the strong interaction.

Gathered around a quarter-scale model of the Cosmotron magnet are the scientists who co-discovered strong focusing at BNL: (from left) Ernest Courant, M. Stanley Livingston and Hartland Snyder. Livingston is holding a cardboard cutout of a quarter-scale strong focusing magnet to illustrate the great reduction in size possible with strong focusing. At right is John Blewett, who, shortly after the discovery, extended the principle to linear accelerators. In 1986, Courant and Livingston were each honored with an Enrico Fermi Award from the Department of Energy for this discovery.

Strong Focusing

All told, Brookhaven and visiting physicists have performed on the order of a thousand experiments at the Cosmotron and the AGS. But without the strong focusing principle, the AGS experiments would never have been done — because it would have been too expensive to build the AGS.

The "alternating gradient" or "strong focusing" principle was a sorely needed breakthrough in accelerator design. Even as the Cosmotron went into operation, the next machine was a primary concern. But calculations showed that to build a proton accelerator perhaps ten times more powerful than the 3.3-GeV Cosmotron would require 100 times as much steel — approximately 200,000 tons.

Physicists at BNL attempted to solve this dilemma. In ring-shaped accelerators like the Cosmotron, particles travel through a magnetic field, which keeps them on their circular course by bending their trajectories and weakly focusing them, horizontally and vertically. Since the bending power available for the magnetic field is limited, increasing the energy of the particles requires that they travel in larger diameter circles.

In the Cosmotron, all the magnets were C-shaped, with the open side facing outward. Would alternating these magnets, so some of their field gradients faced outward and some inward, focus the beam and thus allow higher energies at an affordable cost?

The answer was "yes." Calculations showed that both vertical and

horizontal motion focusing could be made strong at the same time. When the magnetic field gradients were made stronger, we saw there was no theoretical limit — provided the alternations were made more frequent as the field gradients went up. It also seemed that magnet apertures could be as small as one or two inches in diameter, as opposed to 8 by 24 inches in the Cosmotron, or perhaps 20 by 60 inches for a machine as powerful as the AGS. As it turned out, this idea had been proposed earlier, in Greece, but the results had not been published.

The strong focusing principle revolutionized accelerator design. The principle's practicality was demonstrated in 1954, when Cornell's 1.3-GeV electron accelerator began operation. Then the new

technology was applied to larger machines. In 1959, the 25-GeV Proton Synchrotron went into operation at CERN, the European high energy physics laboratory, and in 1960, the 33-GeV AGS was commissioned. These alternating gradient synchrotrons were constructed using only twice the amount of steel — 4,000 tons — needed to construct the weak-focusing, 3.3-GeV Cosmotron. Since then, strong focusing has been one of the guiding principles behind every new accelerator in the world, right up to the 20-trillion-electron-volt Superconducting Super Collider that has been proposed as the next accelerator to be built in the U.S. for high energy physics research.

Two Views of Neutrinos

Though neutrinos have been around as long as the universe, they were directly detected only about 30 years ago. Since that time, these elusive particles have been a favorite object of study for Brookhaven scientists. As neutrinos are difficult to observe directly, most information about them has come by observing how a process or interaction involving neutrinos affects other atoms or particles. Two neutrino experiments done by BNL scientists used such indirect observations to obtain extremely important results.

The first of these studies took two weeks in 1958. Its aim was to determine the neutrino's helicity. At that time, it was known that the neutrino rotates as it moves forward, like a screwball in baseball. But it was not known whether its spin was in the same direction as its momentum or opposite to it. If the spin were opposite to the momentum, the neutrino would have a negative helicity or be "left-handed"; if the spin were in the same direction as the momentum, the neutrino would be "right-handed."

The neutrino interactions in Brookhaven's famous solar neutrino experiment took place in this tank, one mile underground in the Homestake Gold Mine in Lead, South Dakota. The results of this long-term experiment, led by Raymond Davis, indicate that either ideas of the sun's history and composition are wrong or understanding of neutrino properties is incomplete.

Neutrinos are emitted during the decay of some radioactive atomic nuclei. Determining the neutrino's right- or left-handedness was important to understanding what happens when an atomic nucleus decays. The results of earlier experiments had been contradictory. This experiment was meant to decide the issue.

By studying the decay of the radioactive isotope europium-152m into the stable isotope samarium-152, BNL researchers concluded that the neutrino is left-handed. This settled the question, providing important confirmation of what is known as the V-A theory describing weak interactions. Today it is known that left-handedness is a property of all particles involved in weak interactions.

For the neutrino helicity experiment, neutrinos were generated and detected on a tabletop in an old bar-rack at BNL. For a solar neutrino experiment, which Brookhaven ran from 1967 to 1985, the scale was much larger. The sun was the neutrino generator, and the detector was located nearly a mile beneath the earth's surface, at the bottom of the Homestake Gold Mine in Lead, South Dakota.

The radiant energy from the sun is produced in the center of the sun and diffuses via many interactions. The only direct "window" into the solar interior and its dynamics is furnished by the neutrinos created in the solar energy-producing process. Neutrinos, since they interact weakly, provide the best hope of a "first-hand" observation of the very heart of the solar furnace. By observing solar neutrinos, scientists could test theories of how the sun generates energy and how neutrinos behave in their long flight paths from the sun.

The presence of a solar neutrino can only be observed by the effect it has when it collides with an atom on earth. Brookhaven's detector was a place where such collisions could happen. It was located far below

ground to eliminate interference from cosmic rays and other particles. The detector consisted of a 100,000-gallon tank of perchloroethylene, a common dry-cleaning solvent that is 85 percent chlorine. A neutrino that struck a chlorine-37 atom in the tank would convert that atom into one of argon-37. A count of the argon atoms determined the neutrino capture rate.

The results threw the field of astrophysics into an uproar. The Brookhaven experiment found that the number of energetic neutrinos from the sun was far lower than predicted by theories. The actual neutrino capture rate in the detector was less than 0.4 neutrinos per day, which was a factor of three or four below the theoretical prediction.

To date, new measurements of nuclear cross sections and improved solar model calculations have failed to account for this discrepancy. Physicists and astronomers have been forced to rethink some basic assumptions underlying the whole theoretical framework of stellar evolution.

To help resolve the problem, BNL scientists, over the past ten years, developed a new neutrino detection scheme using gallium as the interaction medium. Beginning in 1987, BNL will participate in a European-based experiment, which will use this system to seek an explanation for the disagreement between theory and the chlorine results. So far the explanation remains as elusive as the neutrino.

Pioneering Work With Computers

If there are about 500 atoms in a crystal lattice and each atom can move in three ways, the equation describing the lattice's motion would have to account for some 1,500 combinations of movement, or degrees of freedom. Since it's not likely such a complex equation could be solved on a blackboard, what can be done?

That's the dilemma that faced theoretical physicists at Brookhaven in 1957, when they wanted to calculate the number of defects produced in a crystal lattice by radiation damage. And that's when the Laboratory pioneered the use of computers to study systems with many degrees of freedom.

A lattice is a regular arrangement of objects or points over an area or in space. In a crystal lattice those points are atoms, ions or molecules. The question was, what happens when radiation interacts with a crystal and produces defects by moving atoms off their proper sites? For an answer, BNL scientists "taught" a computer to solve the equations governing the motions of atoms, taking into account the interactions between them.

The original calculations were done on the IBM 704 at New York University, a primitive machine by today's standards. But it was modern enough to do what had never been done before, and the results were published in 1960. Thus, Brookhaven became the first laboratory to apply high-speed computers to realistic studies of problems such

as defects caused by radiation damage.

A moving picture of the results provided a more dramatic display of what was happening in the computations. Though this film was never entered at Cannes, it generated so much demand that a film supplier was enlisted to sell prints at a nominal cost. The film is occasionally still ordered today.

Similarly, Brookhaven researchers were the first to use computers and moving pictures to study the system of spins in a model of a magnet. In a magnet such as a piece of iron, the atoms themselves are little magnets with distinct spins. When a bar of iron is magnetized, the atomic magnets are parallel to each other, or nearly so. But if the iron is made hot enough, the atoms misalign and there is no overall magnetization. From 1965 to 1975, scientists at BNL used computers to determine what happens to the spins during mis-

alignment and found that even in disordered magnets, waves called "spin waves" move through the lattices.

Monte Carlo Methods

Those first calculations using computers to study systems with many degrees of freedom involved solving Newton's equations of motion, given some initial conditions and some of the forces between atoms. But there is another way to calculate probable outcomes without solving the equations of motion. It is called the Monte Carlo method. Done on large computers, this technique uses statistical sampling, strung over a three-dimensional lattice, to obtain a probabilistic approximation of a problem's solution.

One Monte Carlo project shows how BNL physicists in different disciplines — here solid state and high

energy physics — often exchange ideas, with fruitful results. It all began in the mid-1970's, when a Brookhaven solid state physicist combined Monte Carlo techniques with previously developed renormalization calculations. Dubbed the Monte Carlo renormalization group, this combination proved to be the most efficient method of analyzing critical properties of spin models.

Solid state physics is a field that deals with the physical properties of solid, tangible materials. In 1974, however, Nobel laureate Kenneth Wilson of Cornell proposed using a lattice formulation for high energy physics, a field that deals with intangible matter. His proposal called for positioning particles and their fields over a cubic lattice, with discrete points of both space and time. Then, while preserving particle size, the lattice would be shrunk, or renormalized, finally converging to ordinary time and space.

In pioneering work at Brookhaven, John Gibson, Allen Goland, Martin Milgram and George Vineyard used computers to determine the action inside a crystal lattice when radiation imparts a large impulse to one atom (near the center of the picture). Initial positions of atoms are indicated by large round dots. Trails of atoms knocked off their lattice sites are shown by small dots. For rapidly moving atoms, the dots are widely spaced. Radiation damage, consisting of misplaced atoms, is the result of the process. Later, Martin Blume, Richard Watson and Vineyard used computers to study the system of spins in a model of a magnet.

Claudio Rebbi (left) and Michael Creutz look over some of the Monte Carlo calculations they used to demonstrate aspects of the theory of quantum chromodynamics.

In 1979, Brookhaven high energy physicists, spurred by Wilson's proposal and aided by the Laboratory's previous solid state work with the Monte Carlo technique, began applying the method to relativistic quantum field theory, the primary tool of the elementary particle physicist. In concept, a field is continuous, with a value at every point of space/time, adding up to an infinite number of degrees of freedom. Though it had never been done before, it made sense to use the Monte Carlo method and describe the field on a lattice in order to do these incredibly involved computations.

In this way, we were able to demonstrate aspects of quantum chromodynamics, or QCD, the theory proposed to explain the interactions of quarks. These particles are thought to be held together in pairs or triplets by a force called the strong interaction. These Monte Carlo calculations were the first direct, if approximate, application of the fundamental theory to the most basic of strong interaction phenomena, the spectrum of particles and resonances. Today, BNL continues to develop this technique for the study of QCD, an activity which is also influencing condensed matter and nuclear physics, and having important consequences for advanced computer design.

In addition, Monte Carlo methods have been used by chemists at Brookhaven. Starting in the 1950's, nuclear chemists here were in the forefront of research looking at the way high energy protons (and later, other particles) interact with complex nuclei. Experimental work focused on yields, energy spectra and angular distributions of the particles produced in interactions. To account for those results in terms of a simple model, that work was supplemented by extensive Monte Carlo calculations of nuclear cascade and evaporation processes. Since then, these calculations have been very widely used.

Neutron Scattering

While some Brookhaven physicists used computers to describe the system of spins in a model magnet, others complemented those efforts by searching for actual data that might support the computer descriptions. One way to do this is to use thermal neutrons to probe atomic structure. The way a neutron

At the High Flux Beam Reactor, Gen Shirane (left) and Julius Hastings review data collected in a neutron scattering experiment.

beam scatters off a sample in its path can tell a lot about that substance's structure, physical state, dynamical behavior and other properties.

The best source of thermal neutrons for such experiments is a nuclear reactor. It was at our first research reactor, the Brookhaven Graphite Research Reactor (BGRR), that, over 30 years ago, scientists at BNL first observed changes in the number of neutrons scattered by a solid undergoing magnetic transitions. Subsequent experiments were done at the more powerful High Flux Beam Reactor (HFBR) in the 1960's and 70's. This continuing research has provided a large part of the experimental information on which are based today's remarkably detailed descriptions of the magnetic ordering process.

In the magnetic systems studied, correlations develop at temperatures above the ordering temperature, the point at which the atoms assume a regular order with respect to one another. The picture these data supply is of precursor effects, in the form of spin correlations, developing at temperatures well above the magnetic ordering temperature. As the system cools, the correlations become increasingly longer-ranged and longer-lived. Finally, at the ordering temperature, a stable, spin-aligned structure starts to appear.

Magnetic transitions are very different in character from the more familiar changes of state (such as the freezing of water), which occur discontinuously and without any microscopic forewarning of what is to come. In fact, magnetic phase changes form part of a group of transitions known collectively as the continuous phase transitions. What makes the magnetic systems unique is that they are accessible to detailed, microscopic study with neutrons. And what has been learned has turned out to be very helpful in reaching an equivalent understanding of other transitions of this type, most of which are exceed-

ingly difficult to explore on a microscopic scale.

Investigating the properties of magnetic systems is just one example of how scientists at Brookhaven have used the neutron scattering technique. Many of these areas of study were first explored at the BGRR, then continued at the HFBR, which, because it is a stronger source of neutrons, broadened the range of experiments possible.

Over the years, neutrons have been used to probe the static and dynamic properties of an amazing variety of solids and liquids, as well as the macromolecules that form the building blocks of living systems. Just to cite a few examples, neutrons are a prime source of information on how monatomic gas (made of one-atom molecules) films form on solid surfaces, how charge density is distributed in crystalline solids to create the bonds that hold atoms together, how hydrogen atoms diffuse into certain metals and how

metal atoms are integrated into the structure of organic molecules.

In early 1968, pioneering experiments at the HFBR proved that neutron diffraction and scattering techniques could be used with equal success in the life sciences, to determine such things as the structures of membranes, ribosomes and proteins, to locate the positions of hydrogen atoms in proteins such as myoglobin and trypsin, and to pinpoint those hydrogen atoms involved in catalysis mediated by trypsin-like enzymes.

Detector Development

Studies with protons and heavy ions at the AGS, neutron scattering experiments at the HFBR, and research with photons at the National Synchrotron Light Source (NSLS) require detection of these subatomic particles. To track these particles and count them at rates of several million per second, Brook-

Displayed next to a ruler for size comparison are a silicon pad detector (lower right) and a ceramic overlay board (lower left). In the completely assembled unit at top, 400 very fine signal lines fan out from the pads, via the overlay board, to the fiber-glass motherboard that links the detector to the low-noise preamplifiers.

haven develops and builds particle detectors.

Many experiments require position-sensitive detectors — ones that can either track the direction or locate the position of radiation. For new applications in high energy physics, such detectors have been built using the solid material silicon as the detecting medium. These thin-wafer silicon detectors are a few square centimeters (cm) in size. On one side, they have conducting strips, which are spaced only 25 micrometers apart. These strips collect signals from high-energy charged particles that pass through the silicon, which makes it possible to locate the particle trajectory to an accuracy of only a few micrometers.

An alternative readout system features a small conducting pad on one side of the detector wafer, each one connected to its own preamplifier via a very fine wire, thus providing two-dimensional position information. Several silicon strip and pad detectors developed at BNL are being used to locate particle trajectories in an experiment at CERN.

Technology for the silicon detectors is state-of-the-art, and, worldwide, Brookhaven is one of the few leading establishments working on these devices. Moreover, Brookhaven has developed unique gas-filled x-ray and neutron proportional chambers that are unsurpassed in their performance by similar chambers from elsewhere.

These gas-filled proportional chambers use gas as the detecting medium and can have considerably larger collecting areas than silicon detectors. As position-sensitive detectors, they are used in many high energy physics experiments, as well as in diffraction experiments using x-rays or neutrons.

For x-ray detection, a gas such as argon or xenon, which can absorb many x-rays, is used. A detector was recently constructed for use at the NSLS that can analyze as many as 100 million individual x-ray signals per second, while locating their

positions within an accuracy of one millimeter. Such a detector is used to study structural changes in large organic molecules on a time scale down to 1/1000 of a second.

Another type of x-ray detector can locate the x-ray absorption position to an accuracy of less than 100 micrometers at rates approaching one million per second.

Neutron detectors based on the gas proportional chamber design use helium-3 in the operating gas mixture, since it has a very large cross section for neutron absorption. A neutron detector with a collecting area of 50 cm X 50 cm and a position resolution of about one millimeter in each axis is now in operation at the HFBR.

Many detectors must read out and amplify very small amounts of electrical charge from a large number of closely-spaced channels. To do this, one Brookhaven researcher developed low-noise preamplifiers, packaged on hermetically sealed cards the size of a postage stamp.

Radiation Chemistry

While Brookhaven is noted for its "big machines," many of our major achievements took place in individual laboratories, using smaller research devices that were, nevertheless, appropriate to the particular scientific problems at hand. In one such laboratory, for instance, the radiation chemistry of water was studied using the 2-MV Electron Van de Graaff.

BNL scientists developed a model for what happens to the energy of ionizing radiation when it is absorbed by water. This process, called radiolysis, was studied at BNL from 1948 to the 1960's.

During radiolysis, radiation causes water to decompose into ions and free radicals, highly reactive compounds with one or more unpaired electrons. Brookhaven researchers were able to identify many of these radicals as hydroxyl radicals,

hydrated electrons, and hydrogen atoms.

These studies have bearing on radiation biology. The human body is roughly 80 percent water. In the event of exposure to radiation, then, most internal interactions would occur in water and many free radicals would be produced. The presence of free radicals has been linked to such conditions as cancer, inflammation and toxicity, as well as damage to DNA, the substance in cell nuclei that carries the genetic code.

Tritiated Thymidine

One way to study DNA was developed in another BNL laboratory in 1956, with the synthesis of tritiated thymidine. The compound thymidine is a building block of DNA. The method developed here for labeling thymidine with the radioactive isotope tritium provided a way to label DNA.

The first biological use of tritiated thymidine was an investigation of chromosomes, the carriers of double-stranded DNA. For one

experiment in 1957, tritiated thymidine was incorporated into the DNA of plant root tips. The radioactive tritium was used to produce a photographic image of where DNA synthesis had taken place, making a high-resolution autoradiograph that was used to test the then recently published Watson-Crick model of the molecular structure of DNA. The astonishing result was the first evidence that the Watson-Crick hypothesis for DNA replication operated at the level of a chromosome.

During this experiment, exchanges of DNA were observed between joined "sister" pairs of chromosome subcomponents — the chromatids — in the replicating chromosomes. This was the first microscopic identification of sister chromatid exchange, a cellular phenomenon now used extensively to study genetic damage caused by exposure to toxic substances.

Tritiated thymidine also proved useful in studies of cell migration and growth throughout the body. Following initial studies with mice, the first human clinical studies were done in 1957, showing how long it

Harold Schwarz prepares a sample for study with BNL's oldest operating accelerator, the 2-MV Electron Van de Graaff. From 1948 to the early 1960's, Gus Allen and his coworkers used this electron generator to study the radiation chemistry of water.

Richard Setlow checks a tank of fish he used in the BNL experiment studying cancer induction by ultraviolet (UV) light. When the fish were exposed to visible light before UV light, they developed many tumors. But when the fish were exposed to UV light, then visible light, no tumors developed.

UV Light and Cancer

DNA is present in the nucleus of every cell in the human body. When a cell divides, its DNA copies itself so the genetic message remains intact. Sometimes, however, the genetic message is flawed because DNA has been damaged.

One thing that can damage DNA is ultraviolet (UV) light, one of the constituents of sunlight. UV light causes several kinds of chemical changes in DNA. One of the most important is the formation of a molecular combination, called a pyrimidine dimer, on a DNA strand. Dimers are suspected of being important in UV-produced skin damage and cancer.

In 1979, Brookhaven biologists conducted experiments in which human skin cells were exposed to multiple small doses of UV, rather than one single dose, to mimic what happens to humans who receive multiple, relatively small sunlight exposures. The cells were also allowed to grow for several generations to express any mutations caused by the UV. This was the first time human cells in culture were successfully transformed from normal to a pre-malignant stage, by UV exposure.

When does a cell cross the line from normal to malignant? The first step involves the cell's ability to grow without being attached to a surface, a trait called anchorage independence. In 1984, Brookhaven reported on a new method for studying this trait in normal human cells treated with DNA from human cancer cells. This method relies on a

takes for labeled bone marrow cells to appear in the peripheral blood. Later studies focused on cell proliferation in various cancers and in the gastrointestinal tract.

Within a few months after this work was presented by Brookhaven researchers at a 1958 meeting, tritiated thymidine was in great demand all over the world. Today, it is used in many different immunological tests and has become a standard for studies in cell proliferation.

process called transfection — putting foreign DNA into recipient cells. Because DNAs from most human skin cancer do not transform the rodent cells used by most researchers, a DNA transfection system using human cells was developed.

Normal human recipient cells were transfected with human DNA from a range of sources. In all cases, when the DNA came from a tumor cell, the cells grew into an anchorage-independent colony, although the rates of growth varied with tumor type. When the DNA came from a normal cell, the recipients showed no change. This was attributed to the fact that, unlike normal DNAs, tumor DNAs have a gene that controls anchorage-independent growth — a gene that has been altered by the damage caused by sunlight or some other carcinogen.

DNA Repair

Not all cells that are exposed to sunlight or other carcinogens become malignant. In most cells, damaged DNA is repaired before any real harm is done. Two kinds of DNA

repair have been studied at Brookhaven.

Photoreactivation is one type of DNA repair. In this case, visible light reverses the effect of UV light by reversing the photoproduct, the pyrimidine dimer. Because of an enzyme activated by visible light, the chromosome returns to its original configuration. This is true, however, only for the UV damage caused by pyrimidine dimers.

An experiment completed in 1976 showed that tumors induced by UV radiation could be reversed via photoreactivation. The subjects of this study were fish called the Amazon molly — an all-female species in which the animals are identical. These fish were ideal subjects because their cells contain a lot of the photoreactive enzyme and because cells from one animal can grow in another without rejection. Fish cells were irradiated with UV, then injected in recipient fish, which developed tumors. If the UV irradiated cells were later exposed to a large dose of visible light, the fish did not develop tumors. But if the cells were exposed to visible light before the UV, or not at all, the fish did develop tumors. These data

Tradescantia

Its blue and pink flowers make the *Tradescantia*, or spiderwort, a pretty plant. But those same flowers also make the plant very useful to Brookhaven researchers. *Tradescantia* is extremely sensitive to many agents that induce mutations (mutagens), even at low doses. After exposure to radiation, chemicals or other environmental stresses, mutations are likely to occur in the buds, at the genetic locus for flower color. Each cell has one gene for blue flower color and one for pink. Since the blue gene is

dominant, normal plants will have blue flowers. But if the dominant gene is mutated, cells may express only their recessive pink gene and appear pink. The altered cells are easy to detect and count.

The thrust of Brookhaven's work, begun in 1958, was to fully develop and use *Tradescantia* as a tool to study basic mechanisms for mutagenesis and as a biological assay system for monitoring potential health hazards in the environment. Brookhaven pioneered the use of *Tradescantia* as the first major tool in cell mutation studies. The spiderwort proved very useful in

establishing accurate dose-effect curves, which are essential for explaining or predicting effects of low-level radiation on higher organisms.

From 1976 to 1983, *Tradescantia* cuttings were transported on a specially outfitted 24-foot trailer and exposed to ambient air at industrial sites all over the country. For these experiments, a special, very sensitive, hybrid plant was developed. Significant increases in mutation rates were found at several locations, particularly sites associated with petroleum refining and mixed chemical processing.

were the first to indicate that pyrimidine dimers in DNA can result in tumors.

Excision, the second type of DNA repair, works on many kinds of damages and does not need light to occur. In this instance, excision repair enzymes cut out the defective part of the DNA and put in a new one.

On occasion, however, the enzymes fail to repair the DNA and damage is perpetuated through replication. Occasionally, this repetitive cellular damage results in cancer. Some people seem more deficient than others in their ability to repair genetic damage. And severe, abnormal defects in DNA repair are associated with huge increases in cancer susceptibility — up to 10,000-fold. These observations led BNL scientists to the hypothesis that small variations in DNA repair might result in a large variation in cancer susceptibility within the apparently normal population.

Studies With T7

DNA is a long chain molecule made up of a large number of units called nucleotides. In each of its two strands, DNA has four different kinds of nucleotides. As the DNA strands wrap themselves in a double helix, these nucleotides pair up. The sequence in which these base pairs are arranged determines function and whether the DNA comes from a human, a bird or a virus.

Perhaps someday every species' DNA sequence will be a matter of record. But in 1982, this was far from the case. That's when scientists at Brookhaven finished determining the sequence of the DNA of the virus T7, the longest DNA sequence then known. In all, 39,936 base pairs were counted and identified.

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. The genetic map was correlated with T7's protein production, which led to a detailed understanding of how such viruses control their own replication. Replication occurs once the entire host cell has been converted to making new T7 viruses. A short time later, the host cell dissolves, releasing hundreds of T7 virus particles to infect other cells and repeat the process.

T7 can successfully invade a host cell because it can control which

messenger RNAs are made. Messenger RNA carries information from DNA to the ribosome, a protein factory. This kind of 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 very specific "strong" promoters already found in T7 DNA and not in the DNA of the host cell. T7 also deactivates the host polymerase.

William Studier (left) and John Dunn check the results of an analysis of protein production using the bacteriophage T7 RNA polymerase to initiate the process.

This understanding of how T7 controls RNA transcription and its translation into new proteins, coupled with the BNL discovery of strong promoters, makes it possible to mimic the way T7 works. The first step is to clone the T7 gene that produces RNA polymerase, so the polymerase can be made separately from the T7. The strong promoter is added and, next to it, the gene for the desired protein. With this, BNL scientists have successfully engineered a system to make particular proteins in large amounts. Brookhaven researchers continue genetic engineering of T7, refining the system and adding to knowledge about the fundamental processes of life.

Focus on Porphyrins

Another ongoing project focuses on compounds that play an important role in the growth of green plants, as well as in many other biological systems. These are porphyrins, organic molecules that can bind a metal. Biological roles of the porphyrins are varied, and can include: carrying oxygen in the blood; protecting against toxic substances; converting light into chemical energy in plants, algae and bacteria; generating ammonia from fertilizers; and converting carbon dioxide into methane gas. A porphyrin's role is determined by small

variations in the molecules and changes of metals, such as substitution of magnesium for iron, cobalt or nickel.

Research that began at Brookhaven in the 1970's has addressed the mechanisms by which the porphyrins fulfill their biological roles and the relationships between their structures and functions. This has involved a combination of experimental techniques: magnetic resonance, electrochemistry, flash laser spectroscopy, and neutron and x-ray diffraction, combined with theoretical calculations that predict the reactivity and properties of both model compounds and the actual biological molecules.

A significant finding of these studies is the crucial but common occurrence of porphyrin radicals, molecules that have gained or lost one electron during the course of the biological reaction. Also significant is the short time with which these radicals can be generated by light — a few picoseconds (a millionth of a millionth of a second). These mechanisms not only provide an insight into many important metabolic and photosynthetic reactions, but also offer the potential of developing practical new methods for the synthesis of novel compounds and the generation of fuels from cheap sources, such as water and carbon dioxide.

Meeting National Needs

Meeting National Needs

As a national laboratory, Brookhaven has always played a major role in this country's scientific enterprise. In particular, our multidisciplinary nature makes us well-suited to assist the Federal government in solving national problems, jobs that typically require expertise in overlapping scientific disciplines.

Such was the case in 1973, when the OPEC oil embargo triggered a national energy crisis. Soon after, Brookhaven was asked to embark on a number of energy research and development programs.

Energy Conservation

Much of the work has been in the area of energy conservation, in response to the government's emphasis on conservation as an immediate national goal. The reasoning was that energy conservation — more careful and efficient use of energy — is clean, inexpensive and easy to implement.

The first of several demonstration houses was built on site in 1976 to test better construction techniques and energy-conserving ideas. The house had larger wall studs to accommodate thicker insulation, reduced window area on the east and north sides, and electrical wiring along the floor stud plate so as not to interfere with wall insulation.

A further refinement of those ideas appeared in the Brookhaven House, which was built in 1980 as a demonstration project for builders and architects. This innovative one-family home combines the passive

use of solar energy with natural thermal storage. Although the house has some unusual features, there is no complex technology involved in its construction. Dramatic energy savings are the result of a good, basic, energy-conserving design, with main living spaces on the south side and buffering spaces to the north; a well-insulated and tightly constructed shell, which retains as much heat as possible; and a properly sized heating plant. In fact, the 2,000-square-foot home can be heated for about one-third the annual energy costs of typical modern homes.

The house did so well in its first year of monitoring that the U.S. Department of Housing and Urban Development decided to make the design generally available by distributing the blueprints at cost. Today, other Brookhaven Houses, as well as houses designed along the same

line, are built all over the country. Rightly so, the house has been recognized as one of the most influential houses ever designed.

A separate area of conservation research was the oil-fired boiler testing program, begun in 1976 to examine currently available residential heating equipment. BNL research identified units of higher performance and characterized the preferred features of heating units, in an effort to stimulate development and commercialization of more efficient heating systems. The program ended in the early 1980's, but information is still being mailed out to homeowners who call for advice.

In related work, an inexpensive and easy-to-install solar collector was developed for all temperature applications. A key factor in achieving low installation cost is the use of thin plastic films attached to a lightweight aluminum frame, a

Built in 1980, the Brookhaven House demonstrates the dramatic energy savings that result from the use of passive solar energy and thermal storage. The 2,000-square-foot home can be heated for about one-third the annual energy costs of typical modern homes.

David Hansen holds aloft a solar panel made of thin plastic films attached to a lightweight aluminum frame. This innovative design was the work of William Wilhelm.

departure from the heavy materials typically found in collectors.

As did other national labs, BNL devoted much effort to educating people about energy. From 1972-84, for example, the Laboratory sponsored Energy Institutes for high school teachers. In this popular series, which ran the course of a school year, sessions dealt with basic energy concepts, individual energy systems and conservation measures. And at the height of the energy crunch, energy expositions were organized at Brookhaven to offer homeowners ideas on how to cope with dwindling and increasingly expensive energy supplies.

ALF

Just as BNL has had strong energy-related research programs, so has the Laboratory matched that effort with in-house energy management.

BNL has reduced its energy consumption per square foot of building area by 31 percent from the time an on-site energy conservation program was begun in 1973. On top of that, the Laboratory developed a unique oil conservation system that became BNL's answer to the high cost of fuel oil. It's called ALF.

ALF, short for alternate liquid fuels, is a mixture of surplus or recycled light feedstock fuels — mostly alcohols, mineral spirits, solvents or substandard distillate fuels. It has no specific chemical formula; rather, it's the result of a carefully engineered physical blending process that yields a homogeneous fuel of predictable Btu content, viscosity and flash point. Independent fuel analyses

Nelson Tyler looks on as Ed Rogers (left) and Mark Culp check seals on tank cars full of surplus calibrating fluid obtained from an Air Force base. No longer pure enough for calibration purposes, the fluid was later blended with other surplus or recycled liquids to make ALF, a much cheaper substitute for fuel oil for the Laboratory's steam plant. Credit for developing ALF goes to M. Joseph Rose.

have shown ALF to be clean-burning.

Through the 1970's, the Laboratory's steam plant used a blend of ALF and No. 6 oil. Then in 1982, the facility was retrofitted so it could handle up to 100% ALF, and a separate storage and supply system for ALF was installed.

Now the Laboratory has complete flexibility to buy as much ALF as it can. And for good reason. Since 1973, using ALF has saved us 30 million gallons of oil, or \$6.7 million.

Metal Hydrides

Attacking the energy problem on a different front, Brookhaven has been a leader in developing a viable alternate energy source. Hydrogen, the most abundant element in the universe, is high on the list of candidates as a replacement for petroleum. A major obstacle, though, is the problem of storing it safely and compactly.

As early as 1965, the Laboratory was studying chemical compounds of hydrogen and metals, called metal hydrides, as a way to store hydrogen. A metal hydride is formed by forcing hydrogen gas into the gaps among the atoms of a particular metal. At a critical pressure, the metal becomes saturated with hydrogen and goes into the metal-hydride phase. The process can be reversed by lowering the pressure below the critical value, thus releasing the hydrogen.

Back in 1965, the known hydrides were either too stable or too expensive for practical storage applications. Deciding to investigate the reaction of hydrogen with inter-metallic compounds (two or more metals), Laboratory researchers discovered a promising hydride-forming alloy made of iron and titanium.

In the 1970's, BNL's metal hydride work was applied to various automotive systems by the European company Daimler-Benz, as well as two American companies, Ergenics and Billings Energy Research Corporation. In addition, Public Service Electric and Gas, a New Jersey utility, tested the use of metal hydrides for storing excess power generated by nuclear plants during off-peak periods.

Today, one increasing use of metal-hydrides is for convenient storage of hydrogen for laboratory purposes. Also, researchers elsewhere have been experimenting with the use of metals hydrides in heat pumps, as well as in the recovery of hydrogen from such processes as oil refining.

In a short time, novel metal hydrides have advanced from a laboratory curiosity to actual use in demonstration projects. The world supply of fossil fuels will not last forever, and alternate fuels such as hydrogen most certainly will be needed in the future.

As part of Brookhaven's work on metal hydrides, James Reilly Jr. and Richard Wiswall Jr. discovered an iron-titanium hydride that has great potential as a safe means of storing hydrogen.

Superconductivity

Another vision of the future shows levitated trains, underground power cables, super atom smashers, and medical diagnosis with magnets. What can make it all happen? Superconductivity.

Superconductivity was discovered in 1911 by the Dutch scientist Heike Kamerlingh Onnes, in the course of his research on liquid helium. It works this way: Near absolute zero on the Kelvin temperature scale, many metals and alloys lose all trace of their electrical resistance and become superconductors. The potential use for such material is enormous. Typical of the time lag between basic research and its application, however, the principle was not put to use until the 1960's, when it was applied in detector magnets for nuclear and particle physics research, and, later, in particle accelerators.

Brookhaven began working with superconductivity in the early 1960's, when scientists started studying the use of superconducting magnets in particle accelerators. Magnets made of superconducting materials have two great advantages over conventional electromagnets. They can carry much higher currents and, therefore, produce much higher field strengths, and, once started, they can run indefinitely on just the power required to maintain the refrigeration.

In 1973, when the first superconducting magnet was built for use in the experimental programs associated with the Alternating Gradient Synchrotron, it was the largest superconducting bending magnet ever constructed. Today, our scientists and engineers are working on the design of magnets for the Superconducting Super Collider (SSC) and the Relativistic Heavy Ion Collider (RHIC).

The SSC, a proton synchrotron, has been proposed by the particle physics community as a national project to extend the high energy

frontier into a realm where fundamental new phenomena are expected. As envisioned, it will be 20 times more powerful than the Tevatron in Illinois, at present the world's highest energy accelerator. Hence, the SSC magnets are critical to the machine's success.

For the SSC, the Laboratory has focused on a high-field (6.6 Tesla) magnet design that uses a niobium-titanium superconductor in a two-layer coil, held in place with a stainless steel collar and a cold iron yoke.

The RHIC magnet (3.5 Tesla) has a single-layer coil, which is very cost effective. In many ways, it is similar to the SSC magnet design, only geared to accelerating heavy ions. RHIC, which Brookhaven has proposed to build on site, will bring together nuclear and high energy physicists in the study of heavy ion collisions at ultra-high energies, for explorations of the properties of nuclear matter at temperatures and densities far more extreme than those presently existing in the universe.

The magnet research has inspired other projects here. As early as 1971, the Laboratory had a power transmission project, charged with building a demonstration line to show how large amounts of electricity could be transmitted over long distances using underground superconducting power lines. In 1982, the transmission line carried full power, 1,000 megavolt-amperes, validating the technology of superconducting power transmission. One example of what this technology can provide is this: twenty circuits of conventional cable could be replaced by two circuits of superconducting cables, to carry the 10,000 megavolt-amperes needed to power the city of New York.

Spin-offs from the power transmission work include a synthetic tape insulation for room temperature cable, which, among other advantages, can sustain a higher voltage than a conventional kraft paper cable of the same diameter; an innovative x-ray technique for

locating damaged electric power cables; and a laser device for continuous measurement of airborne particles, to monitor air quality in industrial environments such as coal mines, grain storage elevators and chemical plants.

A coil made of niobium-titanium (NbTi) conductor is at the heart of the superconducting magnet designed for the nationally-proposed, high energy particle accelerator, the Superconducting Super Collider (SSC). When cooled by helium to near absolute zero on the Kelvin scale, the conductor becomes superconducting; that is, it loses all trace of electrical resistance. Substantial innovations in superconducting magnet design, which are now being applied to the SSC and to Brookhaven's proposed Relativistic Heavy Ion Collider, are the work of Robert Palmer.

Reactor Physics

History was made in 1957 at Shippingport, Pennsylvania, when the first commercial nuclear power plant began operating. Today, there are 100 power-generating reactors in the United States, concentrated principally in the high-density, energy-consuming, eastern half of the country. With one exception, all are light-water reactors, that is, cooled and moderated by ordinary water.

The development of light-water reactors owes much to basic research at Brookhaven in the mid-50's and early 60's, when theoretical and experimental studies were done on the neutron physics of thermal neutron reactors. This research became the basis of modern understanding of how such reactors work.

Back in the 40's, light water was one of the first moderators considered for nuclear reactors, but early calculations indicated that the hydrogen in the water would absorb so many neutrons that a self-sustaining chain reaction in the uranium would

be difficult to achieve. Still, uncertainties in the analysis were large enough to warrant further study.

An early experimental program at Oak Ridge National Laboratory concluded that a slight enrichment of uranium in the isotope uranium-235 would make use of the light-water moderator feasible. Brookhaven's reactor physics program followed on that work, focusing on experiments with light water and slightly enriched uranium rods. The intent was to develop a body of data that could be compared with the results of calculations.

Work was done with a variety of rod sizes and uranium enrichments. These experiments consisted of measurements made on roughly 150 assemblies of fuel rods of varying enrichment, diameter and fuel-to-moderator ratio. Five ratios of water-to-uranium volumes were studied with three different fuel enrichments of 1.0%, 1.15% and 1.3% uranium-235.

Such research helped advance theoretical work to a point where design calculations of practical pressurized water reactor cores could be made with confidence.

As part of their analyses of structural safety, (foreground) Jose Pires, (rear, from left) Morris Reich, Charles Hofmayer and Kamal Bandyopadhyay check computer outputs evaluating the capacity of the reinforced concrete containment building of a nuclear power reactor.

Reactor Safety

Much has happened in the public arena since those early years of reactor physics studies at BNL. Public opinion of nuclear power today is often one of distrust, and the safety of nuclear reactors, in particular, has become a highly charged issue. Brookhaven does not make policy on nuclear issues; our job is to provide objective scientific information to the decision makers.

Over the last ten years, BNL has established a solid reputation in the field of reactor safety, providing vital technical support to the Nuclear Regulatory Commission (NRC), which licenses and regulates commercial power reactors. One area of research is structural response to various loads, such as an earthquake, a tornado, or an internal explosion.

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. In the case of an earthquake, for example, the interaction of structure and ground is important. An earthquake causes shock waves to travel through the ground, and 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.

Brookhaven's work on the Diablo Canyon nuclear power plant, begun in 1982, is an example of the kinds of structural safety analyses our scientists do. Lying 2.5 miles from the Hosgri fault near San Luis Obispo, California, 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 positions that would have been correct 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.)

A three-dimensional computer technique developed by BNL was used to analyze the potential stress on the annulus produced by a 7.5 magnitude (on the Richter scale) earthquake. As a result of this and other reviews, major structural changes were made to Unit I, which now meets the design requirements

On-line graphic display from plant analyzer. This display shows one of the many consequences of component failure that can be simulated on the BNL plant analyzer. In this case, a pressure regulator failure was simulated as if the regulator failed at maximum demand. The blue curve shows the reactor pressure as a function of time (one bar is approximately one atmosphere). The white curve is the steam flow rate leaving the reactor vessel. As can be seen by following the blue line, the reactor vessel was depressurized until, at the low point, the main steam isolation valve closed automatically. The pressure recovered and then overshot until the safety and relief valves regulated the pressure at a safe level. The white line shows the discharge through the safety and release valves, which opened and closed to maintain the pressure.

Doing calculations for a probabilistic risk assessment of a nuclear power plant are (from left) Wm. Trevor Pratt, Robert Bari and Robert Hall.

for the postulated 7.5 magnitude Hosgri event.

In the U.S. today, 27 nuclear power plants are in various stages of construction, some on the verge of being licensed. On request from the NRC, we study a particular aspect of a plant, drawing on 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 study all the variables, make an assessment, and turn that information over to the NRC.

Another area of accomplishment is development of a sophisticated mathematical model of the inner workings of a nuclear power plant. Packaged in an advanced minicomputer, it's called a plant analyzer.

Work began on the plant analyzer in the early 1980's, when the Laboratory recognized a need for a fast and reliable computer system that would replace, in part, the large central computing facilities now in use. The result is a responsive, everyday work tool for people on the job, reactor operators in training, and the NRC acting in its licensing and regulating capacity.

The special purpose minicomputer used in the plant analyzer is superior to a large main frame, or super, computer because it carries out the same calculations a hundred times faster, while still producing the same answers. In fact, it can compute a process seven times faster than real time. That speed makes the plant analyzer seem like a crystal ball, allowing operators to compute in advance the consequences of their actions.

Work is also being done in a relatively new and important field called probabilistic risk assessment (PRA). PRA is a method of examining complex technical systems, like nuclear power plants, to calculate risks to public health, the environment and the economy. It's a particularly useful tool for identifying weak points in a system.

BNL analysts have been doing PRA-related studies for the NRC for the past ten years. These include comprehensive evaluations of PRAs done by nuclear utility owners for particular plants, methods development in the field, applications of PRA techniques to the regulatory process and to the resolution of outstanding safety issues, and teaching PRA-

related courses to NRC staff. More recently, PRA is proving useful in addressing specific questions about plant management. For example, it can be used to make more intelligent decisions about plant modifications and operations.

International Safeguards

Taking a world count, there are over 500 nuclear power plants operating, under construction or on order. The peaceful use of nuclear energy worldwide is monitored by the International Atomic Energy Agency (IAEA), which has played a major role since 1957 in assuring that nuclear materials and activities

are not diverted from peaceful uses to military applications such as nuclear weapons.

In 1976, Congress approved an appropriation to the U.S. State Department, which, through the U.S. Department of Energy, set up a special program of technical assistance to IAEA safeguards. Under this program, American technology and expertise are made available to upgrade international safeguards applied by the IAEA to prevent diversion of nuclear materials.

Brookhaven, through the International Safeguards Project Office, is responsible for technical management of the U.S. effort, which includes specific tasks done by var-

From left, Arthur Waligura, Ann Reisman, John Skalyo and Leon Green examine an instrument developed at BNL for verifying the deuterium enrichment in storage barrels containing heavy water. This is one tool used by International Atomic Energy Agency inspectors, who do periodic surveys of nuclear facilities as part of an international program to safeguard nuclear materials.

At the National Nuclear Data Center, William Kropp (left) and Sol Pearlstein use an interactive graphics program that displays computerized nuclear data. Pearlstein holds a light pen, which is used to make changes to the display.

ious groups at ten laboratories, BNL among them. Their activities can be divided into four broad areas: inspector training, measurement and surveillance equipment, data processing and system studies.

The U.S. also provides people to the IAEA to meet certain technical needs. BNL employees with special expertise are routinely sent on temporary assignment for periods of two to four years at the IAEA headquarters in Vienna, to transfer U.S. technology to the IAEA.

A National Center For Nuclear Data

Just as BNL takes a national lead in supporting international safeguards, so does the Laboratory provide the American link in a global network of organizations that compile, evaluate and exchange low energy nuclear data. Located at Brookhaven is the National Nuclear Data Center (NNDC), which has been handling nuclear data since the Laboratory began. It is, in fact, the inspiration for all such centers around the world.

Nuclear data are used in basic and applied research in such fields as low energy physics, nuclear reactor physics, astrophysics, space applications, fusion and nuclear medicine. The NNDC is responsible for information from the U.S. and Canada, including data on the nuclear structure and radioactive decay properties of nuclides (species of atoms, of which there are about 2,400) and data on low energy nuclear reactions. The latter are generated by experiments on the reaction of target nuclides to neutrons, protons, photons and other particles striking targets at energies below 100 million electron volts.

Information compiled and evaluated by the NNDC is distributed to scientists in the Northern Hemisphere, as well as to the data centers that service the rest of the world.

NNDC produces the Nuclear Data Sheets, a compilation of experimental and theoretical results in nuclear physics, and COMPUTOPE, a nuclide chart on microfiche. The NNDC also publishes Nuclear Wallet Cards, a pocket reference for selected nuclear properties of all known nuclides, and the book *Neutron Resonance Parameters and Thermal Cross Sections*, which contains recommended nuclear properties based on experimental data.

In recent years, the Center began moving in a new direction — toward telecommunication of data. Today, there is less emphasis on printed material because it often is out of date by the time it comes off the press. In response, on-line terminals have been set up for users both at BNL and off site so they can have direct access to NNDC's computer files.

Brooknet

Nowadays, computer-to-computer linking, called networking, is routine. Pioneering work was done at Brookhaven on a system called BROOKNET.

It was developed in the early 1970's as a flexible, high-speed, computer-to-computer communications network intended primarily as an aid for increasing the productive use of some of BNL's major experimental facilities. Small, inexpensive computers were used at experiments to collect data on-line and relay them, via the network, to the central, large-scale CDC 6600 computers, which processed the data rapidly and then sent back results for output by the small computers. The network also provided for auxiliary input-output stations, conveniently located to permit direct use of the central computer by scientific personnel at remote points within Brookhaven.

Today, a number of networks have evolved at the Laboratory to meet specific user needs for both

In the Gamma Field, experiments were conducted on the effect of radiation on plants. When personnel were working in the field, as Howie Jones did, the radioactive cobalt source stayed shielded in the pipe.

local and long distance telecommunications. Although BROOKNET has been replaced by these newer technologies, it paved the way for them all.

Early Radiation Studies

Although ionizing radiation was first discovered in 1895, there was still much to be learned about radiation effects when the Laboratory was founded half a century later. Early radiation studies at BNL included: the nature of radiation damage in metals; the properties of radiation-induced defects in crystals; and the effect of irradiating organic

substances either by an outside source or by radioactive atoms within the system.

Of particular note are biological studies done at the level of the whole plant or animal and, later, at the cellular and molecular level.

The concept of studying chronic exposure to ionizing radiation originated at Brookhaven in 1949, and the idea was first tested that year with a prototype experiment using a 16-curie cobalt-60 source. The project was relocated in 1951, when the Gamma Field was established to do basic research in plant radiobiology. Plants were exposed to radioactive sources raised remotely from a lead shield near the center of the 12.8-acre field. The sources could be lowered into the lead shield to permit researchers to enter the radiation area for planting, crop maintenance and data collection. The samples were planted directly in the soil or in pots, arranged along isodose arcs (to insure uniform dose along each arc), at varying distances (radii) from the center to vary the doses. Gamma-emitting cobalt-60 radioactive sources were used, ranging from 145 curies in 1951 to 3,900 curies in 1963.

Studies included such basic subjects as the nature of mutations, factors affecting sensitivity to radiation, tumor formation in plants, and production of useful plant varieties through somatic mutations (affecting only vegetative tissue and not reproductive cells).

Research on radiation sensitivity led to the important finding that plants having the smallest number of large chromosomes were the most sensitive to radiation. These plants were selectively stressed or killed at high radiation levels nearest the source.

Experiments with various strains of tobacco revealed that when the genetic potential exists, relatively small amounts of radiation will induce tumors in plant tissues.

An unexpected spin-off came out of an experiment with seed potatoes that were being tested for radiation tolerance. While the yield of mature potatoes from plants fell off in proportion to increasing radiation exposure, it was also found that the seed potatoes exposed to large doses of radiation failed to sprout and remained firm all season underground. This suggested that the potatoes were somehow preserved and led to the demonstration that radiation could be used to inhibit sprouting and enhance storage life for as long as 15 months.

In 1961, the Gamma Forest project was begun in a 123-acre stand of pines and oaks, to investigate changes due to various levels of ionizing radiation on natural plant communities. Unlike the Gamma Field experiments, the vegetation irradiated was part of the natural vegetation of the Laboratory.

A 9,500-curie source of cesium-137 was placed in the middle of the area. Since the radiation level decreased with distance from the source, the gross effects of radiation gradually diminished farther away from the source. More specifically, plants with a small number of large chromosomes were more sensitive to radiation, as had been found earlier in the Gamma Field studies.

The Gamma Forest project was terminated in 1979, and the affected area is slowly recovering. An important observation is that recovery from radiation occurs in a pattern similar to recovery from many other disturbances, including repeated burnings, mechanical disruptions and other toxins.

Radiation research has continued over the years. Most recently, a new facility has been built to study radiation effects on various materials — mainly electronic components. As part of the federal government's Strategic Defense Initiative, the facility is supported by the Air Force Weapons Laboratory.

Radiological Monitoring And Assessment

From 1946 to 1958, the U.S. conducted almost 70 nuclear tests in the Marshall Islands in the South Pacific. Inhabitants of the isles of Bikini and Enewetak, which were used for the tests, were relocated prior to testing. Following one test at Bikini in 1954, however, a wind change sent fallout over two other inhabited atolls — Rongelap and Utirik. Shortly after that incident, Brookhaven was asked to evaluate the radiation doses and medical effects on people exposed at Rongelap and Utirik. In 1974, the program was expanded to include the now-returned residents of Bikini, and, in 1980, Enewetak.

The main goals of this program are to provide general health care and to obtain information for dose assessments and for validation of environmental models that predict future dose. Another important aim is to determine and document exposure to radiation, as a basis for taking timely action to reduce unnecessary or excessive exposure.

An example of the latter occurred in 1978, when BNL's program revealed that the Bikinians had levels of radioactivity in their bodies higher than those projected by environmental models. If these people remained on the contaminated island for several more years, their doses would exceed the guidelines established by the U.S. government as well as guides set by international radiation protection groups. To protect them from exposure to radiation at those levels, the people were relocated to Kili island and Majuro atoll, and Congress took on the responsibility for the cleanup of Bikini.

The people of Rongelap and Utirik fall into two distinct groups. A minority on the islands in 1954 was exposed to fallout at high radiation levels. A majority, not present in

1954, has been exposed only to residual fallout at a level similar to natural radiation in a high altitude location such as Denver, Colorado.

Over the last few decades, the Marshallese exposed to low-level radiation have not shown any health effects related to that exposure, but health effects have been seen in some of those exposed in the 1954 incident. One effect is a continuing increase in cases of enlarged thyroids, as well as several instances of thyroid cancer. The types of thyroid disease observed, however, are treatable and are treated. Because of BNL's long history of caring for the health of these people, their life span remains similar to that of unexposed Marshallese.

Since 1954, teams of medical doctors and health physicists have made annual trips to the Marshall Islands to check the health of islanders accidentally exposed to radioactive fallout during a U.S. bomb test in the Pacific. Pictured during a visit is Robert Conard, examining a Marshall Islander for any thyroid abnormalities.

RAP

Twenty-four hours a day, every day of the year, a special phone number is manned at Brookhaven for radiological emergency calls. Such a call came in at 9 a.m. on March 28, 1979, because of a nuclear power plant accident at Three Mile Island (TMI) in Pennsylvania. Within hours, a BNL team of radiation experts flew to TMI by helicopter to lend their assistance.

Brookhaven is the Northeast region's headquarters for the Radiological Assistance Program (RAP). The program was established in 1958 by the Atomic Energy Commission to provide expert assistance during a radiation emergency, in order to protect people and property. RAP is now under U.S. Department of Energy jurisdiction.

At TMI, the Brookhaven team helped identify and quantify the radioactive releases by taking samples of air, soil, water, milk and grass. Measurements of radioactive isotopes of iodine were emphasized because of their persistence and their potential for reaching the general public through the food chain. It was found that very little radioactive iodine had escaped into the environment, and very low levels of radioiodine were found in milk and rainwater.

A nuclear accident halfway around the world, at the Chernobyl power plant in the Soviet Union, led to another RAP response. Shortly after the accident on April 26, 1986, RAP teams went to Kennedy International Airport to meet incoming groups returning from tours of the Soviet Union. The people and their belongings were checked for external contamination, of which there

was very little, and their thyroids were checked for radioiodine, a reliable indication of exposure to the Chernobyl plume. About one-third of the people examined by BNL health physicists did have radioiodine in their thyroids, but so little as to be medically inconsequential.

On March 28, 1979, within hours of a call for assistance because of a nuclear power plant accident at Three Mile Island, members of a RAP team assemble equipment before boarding a Coast Guard helicopter bound for Harrisburg, Pennsylvania.

**Making a Difference
In Everyday Life**

Making a Difference In Everyday Life

Over the course of Brookhaven's 40-year history, a wealth of knowledge has been gained in the scientific disciplines. Rooted within that firm foundation of basic research, numerous programs have proved to have direct benefit to mankind — to make a difference in people's everyday lives.

Nuclear Medicine

When the Atomic Energy Commission (AEC) was created after World War II, one of its missions was to develop peaceful uses for nuclear science, including medical applications. With nuclear technology came the widespread availability of certain radioisotopes generated in nuclear reactors and particle accelerators. These radioisotopes, unstable isotopes of various ele-

ments, have made possible a new frontier in medicine — nuclear medicine, which involves the use of radiation in the diagnosis and treatment of disease.

From its earliest years under the AEC, Brookhaven has had strong nuclear medicine research programs because of our unique combination of facilities and personnel. BNL's reactors and accelerators can produce a wide variety of new radioisotopes, while specialists in chemistry and pharmaceutical design can incorporate them into useful radiopharmaceuticals. Animal studies provide preliminary evaluations of an experimental radioisotope, and, later on, through collaborative programs with area hospitals, clinical evaluations are carried out in the diagnosis and study of disease in humans.

Technetium-99m

The most widely used diagnostic radioisotope in nuclear medicine is technetium-99m, which was developed at Brookhaven. In fact, out of the over 12 million nuclear medicine procedures carried out annually in the U.S., over 85 percent involve technetium-99m. Brookhaven's long-standing work on this radioisotope has significantly benefited the lives of many.

Incorporated into a variety of radiopharmaceuticals, technetium-99m can be used to image almost any organ in the body. It is commonly used for locating brain tumors, and for imaging the blood pool, thyroid, liver, spleen, heart, lungs, kidney and bone marrow. Even dynamic studies can be done. For example, the pumping action of

Walter Tucker (left) and Powell Richards are two of the scientists involved in the earliest development of technetium-99m.

the heart can be evaluated by sequential imaging during its cycles of contraction and expansion.

Several characteristics make technetium-99m ideal for clinical work. To begin with, it gives off a single 140 keV (thousand electron volt) gamma ray with no accompanying beta particle, which minimizes radiation exposure to the body. Also, the energy of its gamma is well-suited for use with scintillation cameras, which detect the tracer. Another advantage is that technetium-99m has a half-life of only six hours, again resulting in a low radiation dose to the patient.

That six-hour half-life, however, is also a disadvantage because it means the radioisotope must be used shortly after it is made, making difficult both its transportation and routine patient scheduling. The key

to technetium's widespread use is a device called a generator, which Brookhaven developed to make the radioisotope easily and routinely available.

In the 1950's, BNL scientists developing new radioisotopes were working with selected parent-daughter pairs in which, contrary to the usual situation, the daughter had a shorter half-life than its parent. As the daughter grew out of the radioactive decay of the parent, it could be "milked" periodically by a chemical separation process in a generator. Thus, the short-lived daughter could be made available with the effective half-life of the longer-lived parent.

At the time, Brookhaven had developed and marketed a generator that made 2.3-hour iodine-132 from the decay of 3.2-day tellurium-

Medical "Walkie-Talkies"

The ability to visualize internal organs from outside the body was the dream of medical practitioners at the turn of the century, soon after x-rays were discovered. Today, radioisotopes have fulfilled that dream, and their use continues to grow in the diagnosis and treatment of various diseases.

Radioisotopes are unstable isotopes of the elements. They decay into stable isotopes by emitting radiation. Because this radiation can be detected, radioisotopes can serve as invisible "walkie-talkies," signaling back to a detector, "here I am." A healthy organ can show even distribution of the radioisotope throughout, while an unhealthy one can show either more or less radioactivity in the diseased area, depending on the process by which the radioisotope concentrates in the organ.

Because of the sensitivity of this method, very subtle changes in some organs can be detected. In addition, the use of short-lived radioisotopes, with half-lives measured in minutes or even seconds, also permits the diagnostic information to be obtained quickly and without harm to the patient.

Initially, Brookhaven scientists made radioisotopes in the Brookhaven Graphite Research Reactor. During its first full year of operation, back in 1951, that reactor supplied nearly 300 different radioisotopes to 26 different research organizations.

In 1972, Brookhaven began using a new facility that, for the first time, made possible the large-scale production of a variety of radionuclides having important biomedical and industrial applications. Called BLIP, for Brookhaven Linac Isotope Producer, the facility uses excess protons from the linear accelerator

that serves as the injector to the Alternating Gradient Synchrotron, the Laboratory's largest particle accelerator. Radionuclides are produced by having the high energy protons bombard suitable stable isotopes to make the desired radioisotopes.

Technetium-99m, considered the workhorse of nuclear medicine (see main story), along with thallium-201, another radioisotope in great demand, were both developed at BNL and later transferred to industry.

The quest for new and improved radiolabeled compounds with desirable biological properties continues today. Now under production at BLIP for commercial distribution are the following radioisotopes: xenon-127, strontium-82, ruthenium-97, magnesium-28, iron-52, iodine-123, germanium-68, copper-67 and a beryllium-7 activated carbon tracer.

132. This was a simple, easy-to-use device that involved fixing the tellurium-132 on a small column of powdered aluminum oxide and washing out the iodine-132 by passing a dilute acid solution through the column.

On one occasion, in making the iodine, a trace impurity was found. It turned out to be technetium-99m. A little work revealed that the molybdenum-99/technetium-99m parent/daughter pair followed similar chemistry to the tellurium-132/iodine-132 pair, and that the aluminum oxide generator could be used with only minor modification as a source of technetium-99m. This meant that the technetium-99m with its six-hour half-life now had an effective half-life of 2.7 days (that of its parent, molybdenum-99), long enough for it to be shipped to user institutions around the world, with adequate time for use.

Even with production and distribution of the radioisotope made possible by the generator, however, the usefulness of technetium-99m was not recognized early on. In fact, in 1958, the AEC decided against preparing a patent application on the technetium-99m separation process, on the grounds that they could foresee no use for it.

Technetium-99m was used briefly at BNL in 1960 to study thyroid physiology. Then in 1961, Argonne Cancer Research Hospital ordered the first technetium-99m generator, for tracer studies in the body. After that, word about technetium-99m spread rapidly, and institutions in this country and abroad began sending in orders for generators. Finally, the demand grew so great that in 1966, the Laboratory turned generator production and distribution over to commercial suppliers.

Today, all hospitals and research centers have on the premises (or have ready access to) technetium-99m generators. They are "milked" daily to get the technetium-99m, which is then prepared with the proper compound for a particular

application.

In related work, a medical kit was developed in the 1970's to label red blood cells with technetium-99m. Such labeled cells are commonly used in clinical studies to image various organs in the body. For example, blood-pool imaging, especially as required to diagnose heart disease, is carried out routinely in hundreds of thousands of patients each year.

The kit (actually a small glass vial) contains all the necessary ingredients to make possible a number of complex reactions that ordinarily would require a chemistry lab and highly trained professionals. An improved version, developed in the 1980's, simplifies the labeling operation and improves the incorporation of technetium-99m into the cells.

L-Dopa and Parkinsonism

The successful use of L-dopa to treat Parkinson's disease evolved from a Brookhaven program in the early 1960's, in which researchers were using radioisotopes to study the role of trace elements in the body and their relationship to neurologically based diseases.

Parkinsonism is a degenerative brain disorder initially characterized by trembling lips and hands and muscular rigidity, with body tremors, a shuffling gait and possible incapacity developing later. As its victims are deficient in dopamine, L-dopa works well to relieve the symptoms because it acts as a precursor of dopamine.

The human brain is surrounded by a natural blood barrier that prevents unwanted (even if needed) material from crossing it to enter the brain. Dopamine, though badly needed, is kept from crossing this natural barrier. L-dopa, however, can cross, and once across, is converted by the brain to the needed dopamine.

Early on, Brookhaven studies showed that treatment with L-dopa resulted in striking and sustained

The use of L-dopa to treat Parkinson's disease was work originally begun at BNL by George Cotzias in the early 1960's and substantiated over years of clinical testing by a number of doctors in various hospitals throughout the country. Here, Sidney Jungreis works with a patient in a physical therapy program designed to supplement treatment with L-dopa.

improvement in moderately advanced cases and a total absence of symptoms in some mild cases of the disease. It was also found that each patient has an individual daily dose limit, which will yield the greatest improvement with the fewest side effects, if any. Also, each patient must be brought slowly to that person's most beneficial dose.

A related study on manganese poisoning, a disease with symptoms similar to Parkinson's, further verified L-dopa's success in diminishing muscular rigidity. That work was done in a cooperative research program between BNL and the Catholic University at Santiago, Chile, involving Chilean miners suffering from manganese poisoning.

By the 1970's, the successful use of L-dopa was confirmed both at BNL and elsewhere in several thousand cases, and the federal Food and Drug Administration released L-dopa for general use by physicians.

To date, there is no known cure for the disease, but with L-dopa, a great many Parkinson's disease patients have achieved sufficient benefits to become self-reliant individuals once again.

PET: A Window Into the Brain

An amazing thing about the human animal, as opposed to other species, is its awareness of its own brain. Perhaps more amazing is the human's ability to study that organ, to understand the why and how of its being. Brookhaven scientists have been studying the brain since the 1970's, perfecting a novel technique called positron emission transaxial tomography, or PET.

PET can measure the rate of glucose metabolism and other biochemical processes in the brain and other organs. BNL research has focused on the brain, using the technique to measure regional metabolic processes in normal individuals and in people with such pathologies as schizophrenia, Par-

In a laboratory, Chyng-Yann Shiue (left) and Joanna Fowler carry out the chemical synthesis required to incorporate a radionuclide into a complex radiotracer for PET research.

kinson's disease, Alzheimer's disease and cerebral malignancies.

Brookhaven has the perfect combination of resources and expertise with which to do PET research: cyclotrons in which radioisotopes are produced, expertise in the development of new methods for radionuclide production and radiotracer synthesis, and, of course, a sophisticated PET instrument, which can measure the concentration of a radionuclide that is present in the brain.

A typical study begins when the subject is injected with a short-lived radioactive tracer, fluorine-18 fluorodeoxyglucose (FDG). Because the tracer behaves essentially the same as glucose, which the brain uses for energy, it is taken up by the brain.

The subject is then positioned inside the PET instrument's circular

array of detectors. As the tracer decays, positrons are emitted. Each positron interacts immediately with an electron, annihilating each other and producing two photons that penetrate the body barrier and are detected simultaneously by the detectors. Because the photons have a fixed energy and are emitted along a straight line, in opposite directions, pairs of photons (differently oriented) permit location of the source within the body. These data are then translated by a computer into three-dimensional color pictures showing where the glucose is being actively metabolized. Such measurements can sometimes provide clues to neurological disorders.

Numerous significant achievements have been made since BNL began work in this field. High on the list is the development of FDG, which is a particularly useful tracer because, as mentioned above, it behaves essentially the same as the brain's energy source, glucose. In addition, fluorine-18 has a half-life of 110 minutes, long enough to be viable even after transport to PET facilities within a two- to three-hour travel time from BNL. Also, the energy of its positron is the smallest of the tracers now commonly used, thus allowing the maximum possible resolution with a PET scanner. Recognizing FDG's potential, BNL has developed cyclotron targets that produce high yields of fluorine-18 and has discovered new facile synthetic routes to label compounds with fluorine-18.

In addition to the work with FDG, other highlights of PET research include synthesis of a new tracer now used in clinical studies of human cerebral malignancy; the use of "suicide" inhibitors to map the activity of monoamine oxidase, an enzyme responsible for regulating the concentration of neurotransmitters in the brain; the development of compounds used to probe brain-receptor occupancy; and the automation of the production of some routinely used radiotracers.

Salt and Hypertension

The relationship between salt intake and high blood pressure is commonly accepted today. Much credit is due Brookhaven scientists, who, in research spanning over a quarter of a century, made valuable contributions to understanding the role of common table salt in hypertension.

The work began when researchers reasoned that if a low-salt diet helped relieve high blood pressure, perhaps salt was also a causative factor. To do the experiments, two strains of rats (which have blood pressure characteristics similar to humans) were bred at Brookhaven. One is resistant to induction of hypertension by salt, and the other is prone to hypertension.

In the hypertension-prone strain, if dietary salt is restricted at the time of weaning, the animals develop only mild, benign elevations. But if, instead, a high-salt diet is begun at the time of weaning, a malignant hypertension is triggered, from which most animals will be dead within three to four months. (The normal life span of these rats is about two years.) If the high-salt intake is delayed for three to six months, hypertension develops much more slowly, although ultimately, all will die from it. Finally, even a transient high-salt intake early in life will induce permanent, often fatal, hypertension in these genetically susceptible animals.

Based on later studies with rats fed a diet of processed baby food, the researchers concluded that the liberal addition of salt to these foods was potentially harmful, particularly for infants genetically prone to high blood pressure.

In general, then, the Brookhaven experiments showed that the younger the organism, the greater will be the susceptibility to hypertension from salt. As the amount and duration of salt consumption increase, the probability of hypertension will increase. In sensitive indi-

viduals, even occasional high-salt intakes may induce hypertension. And finally, the genetic constitution is a prime determinant in susceptibility to developing hypertension from salt.

Synthetic Insulin

Studies initiated at the University of Pittsburgh and continued at Brookhaven led to the synthesis of human insulin in 1964. It was the first chemical synthesis of a human protein. This work paved the way for later production of human insulin by modern recombinant DNA techniques.

In the body, insulin controls the metabolism of carbohydrates; lack of insulin is the cause of diabetes. During the years that Brookhaven undertook research in this area, diabetics were treated with injections

of insulin available only from animals. The problem with this treatment, though, is that diabetics can have allergic reactions to animal insulin after many years of use. At that time, then, there was impetus to synthesize human insulin, which would not be likely to cause immunological reactions in human beings.

The insulin molecule consists of two polypeptide chains linked together by two disulfide bridges. In doing the synthesis, the major hurdles were the synthesis of the individual chains and the combination of the chains to generate insulin. In the end, the procedure that worked was quite complicated, especially to achieve high yields, and would have been very expensive to use commercially.

But the story continues. In later years, a major pharmaceutical company, Eli Lilly, discovered how to make the polypeptide chains using

Lewis K. Dahl was a pioneer in hypertension research. Among his findings was the discovery that high-salt intake was much more dangerous in early years, and he was instrumental in alerting the medical profession and the general public to the potential danger of adding salt to processed baby foods.

Research by Panayotis G. Katsoyanis resulted in the first synthesis of human insulin in highly purified form. Pictured here is one of five different crystalline insulins made at Brookhaven.

bacteria. To do so, they made use of advancements in recombinant DNA techniques, and, originally, they also relied on Brookhaven's procedure for purifying the chains, as well as on our method for combining those chains into insulin.

Today, diabetics who cannot take animal insulin have an alternative, thanks in part to Brookhaven.

Applications Of Gamma Radiation

In 1985 and 1986, the U.S. Food and Drug Administration approved the use of gamma radiation to preserve certain foods — mainly fresh fruits and vegetables and fresh pork. This is just one example of the practical applications of radiation. Brookhaven's important contribution in this area lies in solid engineering studies done over 20 years ago.

That was in 1963, when BNL's High Intensity Radiation Develop-

ment Laboratory (HIRDL) began operating. The facility's main purpose was to obtain engineering data on a variety of radiation sources in the million-curie range and to develop more efficient techniques for handling large radiation sources. That information was essential for the design of irradiation facilities later built by industry for a wide range of applications of radiation.

For example, cobalt-60 sources, which were evaluated at HIRDL, are now used by industry for sterilizing plastic and paper medical supplies such as gloves, sutures and bandages, which cannot be sterilized by heat.

Also at HIRDL, a number of portable food irradiators were prepared for irradiation studies in such locales as South Korea, India, Iceland, Pakistan and Chile, as well as closer to home. These irradiators were used in food pasteurization and preservation studies. BNL's program came to an end in the early 1970's, after proving that food sterilization was a viable way to preserve food.

New Crops: Peppermint And Grapefruit

In the 1950's, plant breeders became interested in using radiation to improve cultivated plants. After irradiation, the number of variations can be dramatically increased, making it possible to trigger more variants in one season than might be seen in a lifetime under normal conditions.

BNL initiated a cooperative program in which dozens of organizations sent plant seeds and vegetative grafting stock to the Laboratory for irradiation by various methods, including the Gamma Field, the Graphite Research Reactor and special irradiation chambers. After the material was exposed, it was returned to

the home organization for propagation and mutation screening. The organization then tracked mutations that appeared useful.

Aside from the color and size changes that were achieved in a number of ornamental plants, an outstanding success story of this program concerns peppermint.

Some years ago, the sole source of peppermint oil in the U.S. was the Mitcham variety, until it fell to a wilt disease caused by the verticillium fungus.

Soil fumigation and crop burning were only partially successful in reducing the incidence of this disease. Attempts to produce disease-resistant varieties by cross-breeding failed because those varieties that resisted the fungus always suffered an unacceptable change in the oil flavor.

In the late 1950's, a visiting researcher from a large mint-producing company, participating in Brookhaven's cooperative program, grew a number of viable plants from irradiated stock. One of these was a disease-resistant mutant that maintained the original flavor of peppermint oil. This mutant is now in general use.

The savings achieved through its introduction amount to millions of dollars yearly. And what American child has not chewed peppermint gum!

Another practical result of the BNL irradiation program is gourmet grapefruit — Star Ruby and Rio Red.

In the late 1950's, a Texas citrus grower found a natural mutation on a Foster Pink grapefruit tree. Called Hudson Pink, the fruit was

George Woodson (left) and William Vogel do a final check of a truck-mounted, portable food irradiator about to leave Brookhaven on a scheduled nation-wide demonstration program in 1967. The first of its kind to become operational, the irradiator was developed to evaluate the irradiation of fruits, vegetables and other foods as a means of retarding spoilage while retaining fresh taste and nutritional quality. A year earlier, the Laboratory had irradiated 15 tons of bacon for the U.S. Army and Air Force, in the first large-scale field test of the application of gamma radiation in the sterilization of perishable foods. Other foods irradiated included mushrooms (shown here), strawberries, tomatoes, potatoes, onions, peaches and bananas.

sweet and red, but contained a lot of seeds.

In 1959, the Texas A&I University Citrus Center sent to BNL more than 3,000 Hudson Pink seeds for irradiation. Six seeds produced an almost seedless grapefruit with peel an orange-red color and juice the color of ripe tomatoes. From these, one was selected that consistently produced the fruit with the fewest seeds. This was the Star Ruby grapefruit — a brilliant, red grapefruit with a higher sugar and citric acid content than its predecessors.

Budwood was made available to nurseries in 1970, and Star Ruby was planted in several locales. It does not thrive in all locations, and yield is variable. Still, the trees are reported to do well in California and Israel. Although production will

always be limited, the Star Ruby does have consumer appeal as a gift fruit because of its rich red color.

Another grapefruit, however, seems destined for the mass market. In 1963, the Texas Citrus Center had BNL irradiate budwood from a planting of the popular Ruby Red grapefruit. The budwood was propagated on rootstock, and several years later, one of those trees grown from irradiated budwood produced fruit with flesh three times redder than the Ruby Red. In 1971, this particular tree was propagated and ten trees placed in a test planting. In 1976, the careful nurturing and tracking of the original budwood finally paid off. A natural mutation was discovered on a limb of one of the ten trees. This mutation, named Rio Red, pro-

duced fruit with flesh color nearly as red as Star Ruby (five times redder than Ruby Red), although the peel doesn't have such a deep blush.

Rio Red budwood was released to growers in 1984. While it's too soon to tell, Rio Red will likely become popular, both among citrus growers and consumers. Taking after Ruby Red, it is less finicky about growing conditions. Given no unexpected production problems, it will find its way onto more and more breakfast tables.

The success story of Star Ruby and Rio Red grapefruit may be appended someday. In 1986, the Texas Citrus Center sent to the Laboratory orange budwood, which was irradiated in the Medical Research Reactor. Years from now, we may see the payoff.

Insect Control

Another success story with gamma radiation involves an insect pest — the screwworm fly.

About twice the size of the common housefly, the screwworm fly has a metallic-colored body and red head and is a warm-climate insect. Although the males mate many times, the female fly mates only once during her life, laying from 250 to 3,000 eggs in the open, untreated wounds of cattle. The larvae emerging from the eggs feed on the living flesh, causing serious injury or even death.

In 1958, a project was started to eliminate the screwworm fly from the southeastern U.S., where it had been costing the livestock industry an estimated 20 million dollars of damage each year.

The project involved the release of screwworm flies made sterile by gamma irradiation. The premise was that these sterile males would mate with native flies and produce infertile eggs, thus reducing the population.

Brookhaven designed and built irradiators, each with a cobalt-60 source that would provide the correct dose of gamma radiation so that the flies were sterile but still virile.

An unused airplane hangar in Florida was converted into a factory to house six irradiators, each using 500 curies of cobalt-60. Some 50 million flies a week were reared under controlled conditions and then sterilized. Trucks transported each day's output of sterile insects to waiting airplanes, which dropped about 200–3,000 flies per square mile each week. When the Florida plant reached its full capacity, it was rearing, irradiating and releasing more than 50 million screwworm flies per week.

In less than two years, the screwworm fly was eradicated in the southeastern portion of the U.S. — the project was a complete success. Thus, an investment of about eight million dollars resulted in a savings of about 20 million dollars a year to the cattle industry of the area.

Art and Archaeology

Oil paintings, ancient gold pieces, Mayan pottery — these are some of the art objects and archaeological artifacts that have been studied at Brookhaven by a sophisticated nuclear chemistry technique called neutron activation analysis. First applied in this unusual way in the

1960's, the technique is useful for determining an object's origin, age, method of manufacture and, in some cases, its authenticity.

In neutron activation analysis, the object is exposed to a beam of thermal neutrons from either one of the Laboratory's research reactors. In the case of a painting, the various elements present in the paint pigments generate radioisotopes. An autoradiograph is made by placing a piece of photographic film over the activated painting. Because each radioisotope decays with a different half-life, the radiation emitted from the painting will be dominated in turn by radiation from different elements. Therefore, a series of autoradiographs made at different time intervals will reveal the structural distribution of elements in the painting.

A striking example of the technique's usefulness occurred in 1975, when Brookhaven was asked by New York City's Metropolitan Museum of Art to analyze a painting purported to be by Rembrandt. The museum had been offered the Rembrandt as a donation, and when an autoradiograph revealed a 19th century painting beneath the visible painting, the gift was rejected.

The following year, the Metropolitan and Brookhaven began a coop-

This hot cell is one of two at the High Intensity Radiation Development Laboratory, where researchers developed techniques for handling large-scale radiation sources. Such experience was applied by Brookhaven in the screwworm fly control project, which successfully eradicated the fly in the Southeast.

erative project to analyze 17th century Dutch paintings. Rembrandt was the principal artist studied.

One important discovery was that Rembrandt often used a pigment known as bone black to make his initial sketches on canvas. Bone black contains phosphorus, which activates with neutrons. Autoradiographs clearly showed these sketches that had been hidden for hundreds of years. This finding helped explain the apparent paucity of existing oil sketches for Rembrandt's paintings. They do exist, but under the finished canvas.

In related work, a compact counter for carbon-14 dating was developed in 1979, as an outgrowth of BNL's solar neutrino project, which required extremely low background counting. The small counter needs only about ten milligrams (about a third of a toothpick) of extracted carbon for a sample measurement. In 1982, it was first used commercially to authenticate a 7th century gold treasure being auctioned by Sotheby's of London. In 1986, the Pontifical Academy of Sciences at the Vatican announced tentative plans to allow carbon-14 dating of the Shroud of Turin. Brookhaven, because of its carbon-14 counter, was one of seven institutions chosen to participate.

From left, Edward Sayre, Garman Harbottle and Elaine Borowski examine ancient artifacts. Neutron activation analysis can be applied to such pieces to trace their origins.

In 1975, Meyer Steinberg (left), a principal in the development of polymer concrete, showed Anthony Ameruso, then Commissioner of the New York City Department of Highways, a five-by-fifteen-foot polymer impregnator. In an earlier demonstration project, Steinberg's group had successfully repaired several large holes in New York City's Major Deegan Expressway, using polymer concrete.

Polymer Concrete

The mix of art and science extends into yet another area. In 1974, the Brooklyn Museum turned to Brookhaven for help in preserving selected stone carvings from the late 1800's. The museum had heard of the Laboratory's work with polymer concrete, which combines the best characteristics of concrete and plastic to form a material with four times the tensile and compression strength of concrete and with high resistance to abrasion and corrosion. Already, BNL had used polymer concrete as well as various polymer composites (some using recycled glass as the aggregate) in a number of demonstration projects all over the country, repairing bridges and roads and installing sewer pipes.

Polymer concrete was developed at the Laboratory in the mid-1960's. In those early years, it was made by placing ordinary hardened concrete

in a vacuum to remove moisture, then impregnating it with a liquid chemical called a "monomer," such as methyl methacrylate. Next, the monomer was hardened, or polymerized, by either radiation, a combination of heat and radiation, or heat and a chemical catalyst. (The common name for methyl methacrylate after it has been polymerized is Lucite.)

Continuing work on the material has led to refinements in making it, as well as even more versatile versions of it. One example is a polymer concrete that can be cast in place. A formulation was developed for the U.S. Air Force for the rapid repair of runways. The process is simple: Fill in the hole with aggregate and pour over a mixture of monomer and polymerizer until the aggregate is saturated. The hardening time, even under wet and cold conditions, is 30 minutes.

In recent years, the basic technol-

ogy has been successfully transferred to industry, and a corporation is producing a polymer concrete that is intended to be used as a repair and replacement material in four markets: architecture, highway construction, electrical utility, and the oil and gas industry.

As for the stone carvings from the Brooklyn Museum, they were preserved by being impregnated with polymer. Thanks to that process, they have withstood very well the ravages of weather and time over the past decade and more.

Tracers

In the late 1960's, Brookhaven began studying the feasibility of using tracers to track the spread of pollution emitted to the atmosphere from fossil fuel plants. Today, tracers have been used to track flow patterns in many different substances, in places ranging from oil wells under the North Sea, to the atmosphere 3,000 kilometers over North America, to ventilation systems in commercial buildings.

In the last ten years, the tracers of choice have been perfluorocarbon compounds (PFTs), developed because they are inert and are easily detected. In all probability, the amount of tracer contained in one grain of sand could be located in a Shea Stadium filled with sand.

One of the latest projects involving PFTs is at an oil-drilling rig in the North Sea. Once the first fast flow of oil has lessened from a well, gas is usually injected into it to force more oil back to the surface. A radioactive tracer is used initially so that the gas flow can be monitored, and depending on where and when it emerges, the best flow pattern to yield the most oil can be deduced. PFTs are now being tested as an alternative to the radioactive tracers. They are doubly promising in this application because information about the quality or quantity of oil in a well can be obtained by the particular way the PFT combines with oil from that well.

AIMS

Consider these scenarios: A homeowner wants to know if window caulking has reduced air infiltration, thus lowering the family's energy bills. Another homeowner is worried that the pollution from the wood stove will affect air quality in the upstairs nursery. In both cases, air infiltration rates must be measured.

As a spin-off of the tracer technology developed at Brookhaven, the Laboratory came up with another original — AIMS, a compact tracer system to measure the rates at which air leaks into a building.

AIMS, short for Air Infiltration Measurement System, uses steadily emitted amounts of perfluorocarbon compounds to trace actual infiltration of fresh air into a house, or the mixing of air among floors as it normally occurs in an occupied house.

To use the system, source vials containing perfluorocarbon are placed along walls shared with the outside of the house. This placement allows the tracer gas to mix thoroughly with the infiltrating fresh air, ensuring uniform concentration throughout the house. Collector tubes are located along inside walls, at least ten feet from the sources, in rooms at extreme corners of the house. A typical two-

story house requires only four sample collectors, and the usual measurement period is one week.

Analysis consists of measuring the amount of tracer gas collected, which can then be related to the infiltration rate of fresh air.

In 1986, the National Association of Home Builders National Research Center chose to make AIMS available nationwide. Their program is designed to inform homeowners and builders alike of the effectiveness of weatherization techniques and materials.

Brookhaven's latest research in this area is directed at using AIMS to certify the performance of ventilation equipment in large commercial buildings.

Russell Dietz holds a tube similar to the device used to collect gas samples from an oil well in the North Sea. This is one application of perfluorocarbon tracer gases developed by Dietz for tracking flow patterns in different substances.

Looking Forward

The Brookhaven site in 1986.

Looking Forward

So much has happened in the last 40 years that it is easy to forget many accomplishments that should be remembered. It is for this reason that, in the preceding pages, we have tried to bring together the most important research performed here since this institution was named Brookhaven National Laboratory and the first contract was signed with the Atomic Energy Commission in support of this work. It is a noteworthy account.

But the quest for knowledge is not static; it is always in motion. And it is time now to look at some of our hopes and plans for the future and see where Brookhaven can continue its contributions in this country's scientific interest.

Brookhaven expects to continue as a center for "big science" and looks forward to implementing programs already proposed or on the drawing board. The "big machines" have been the base on which big science at BNL rests, and they are still the foundation for many future programs.

The venerable Alternating Gradient Synchrotron (AGS), which has served so well in the past, will continue to be productive. Together, the heavy ion transfer line between the AGS and the Tandem Van de Graaff, and the booster synchrotron now being added to the AGS complex, will enable researchers to expand their heavy ion studies. The booster will also increase proton intensities for the regular high energy physics program and will permit the AGS to operate like a "kaon factory" for new experiments in rare kaon decays.

Approval for construction of the Relativistic Heavy Ion Collider (RHIC) would allow the joining of particle physics and nuclear physics at BNL, and provide nuclear science with a unique facility of almost unparalleled potential for new discovery. RHIC would make possible the study of the fundamental properties of matter in a state where the primordial

quarks and gluons are no longer confined as constituents of ordinary particles — conditions that existed immediately after the Big Bang.

Completion of Phase II of the National Synchrotron Light Source (NSLS) construction project will enhance the capabilities of the ultraviolet and x-ray rings. Further improvements are planned for this advanced instrument, and the Laboratory expects to play a major role in the next generation of light sources. Research activity at the High Flux Beam Reactor (HFBR) is increasing and will most certainly double if the proposed Guide Hall is approved.

Other Programs

No one can predict the future and no one can confidently assume what specific projects in science and technology will be approved in the coming decades. Nevertheless, plans must be made and designs drawn for the major programs Brookhaven sees as distinct possibilities in the long term.

The Laboratory supports the Superconducting Super Collider (SSC) project and is already engaged in the design and testing of SSC magnets.

With its unique facilities and its ability to draw on the talents of a staff versed in many of the scientific disciplines, the Laboratory is in a good position to serve as a regional center in several areas.

For instance, the combination of the HFBR, the NSLS and the Scanning Transmission Electron Microscope makes BNL a logical location for a

Center for Molecular Biotechnology, an extension of the present Center for Structural Biology. Again, research groups from universities and industry would participate.

Brookhaven's PETT VI (Positron Emission Transaxial Tomography) machine, coupled with the 60-inch Cyclotron, are cornerstones of a Cyclotron-PET Center, which is already supplying radiolabeled tracers to research groups outside BNL. Plans are under way for an expansion of this nuclear medicine system that would make possible the delivery of radiotracers and radiopharmaceuticals to medical centers in the Northeast. In addition, state-of-the-art tomographs would be acquired to augment the existing PETT VI, thereby expanding the Center's image processing facilities in order to support researchers analyzing brain measurements at BNL or at other laboratories.

A broad program in basic trace element geoscience is being started. Its aim is to understand the formation mechanisms of the major geological features of the earth, based on deductions from measurements of their chemical and physical characteristics. BNL geoscientists and physicists and their counterparts at universities and industry would need and have access to the NSLS, the Tandem Van de Graaff and the 3.5-MV Van de Graaff.

These programs are just a glimpse of what the future could bring. Many other sound ideas ripe for scientific exploration are being pursued at BNL — advanced accelerators; novel magnetic structures at the NSLS leading to very bright, coherent light for advanced research; and a stretcher ring at the AGS that would

double the number of protons available for the slow extracted beam program.

Solving Problems

A complex, industrial society such as ours has many problems to solve, and Brookhaven is ready to help meet these challenges. At the Light Source, for example, several programs show promise in yielding benefits to our society.

Already, Brookhaven has taken the lead in coordinating a national effort to develop x-ray lithography. This new technique is used to transfer circuit patterns onto silicon wafers. Because microchip circuitry is becoming smaller, present-day optical production techniques for making integrated circuits are reaching the limits of resolution. To remain competitive in the international market, the U.S. semiconductor industry needs synchrotrons to produce x-rays for lithography, and these machines must be compact so several can fit in one factory.

Synchrotron radiation promises to play a vital role in another area — health care. Scientists are now studying the use of x-rays from the Light Source for angiography of the heart. This non-invasive technique will help in the early diagnosis of diseases of the coronary arteries.

Looking back, the first forty years of scientific research at Brookhaven have been marked by dramatic discoveries in all areas of science. Looking forward, the next forty should be just as exciting and productive.

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