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BROOKHAVEN HIGHLIGHTS

July 1972 - June 1974

MASTER

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BROOKHAVEN NATIONAL LABORATORY
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MASTER

Frontispiece

On November 11, 1974, Brookhaven National Laboratory and the Massachusetts Institute of Technology jointly announced the discovery of a new particle, designated the J particle by Prof. Samuel C.C. Ting of MIT, who led the experimental team. The particle had a mass of 3.1 GeV (about $3\frac{1}{2}$ times the mass of the proton), it was neutral, it was observed to decay into an electron and a positron, and its lifetime was of the order of 10^{-20} seconds, some thousand times longer than the lifetime associated with normal resonances that decay by strong interactions. The discovery was announced simultaneously by a group at the Stanford Linear Accelerator Center, and promptly confirmed by a group at Frascati (Rome).

The spectacular impact of this discovery on high-energy physicists is due to its totally unpredicted appearance, coupled with its unusual properties. At Brookhaven the 30-GeV proton beam was extracted from the machine and struck a beryllium target. In the photograph this target is out of view at the bottom. The photograph shows the two 70-ft-long arms of an extremely sophisticated double-arm spectrometer system that measures the energy of the electron and positron from the J -particle decay. Each spectrometer arm has three magnets, Čerenkov counters, and position detectors to allow precise identification of the electrons and positrons and measure their energies. During operation the equipment shown in the photograph is surrounded by nearly 10,000 tons of steel and concrete shielding.

The group at SLAC has shown that the J particle decays into hadrons as well as leptons. The significance of this discovery, and its place in the overall picture

of particles, has not yet been clarified. Experiments continue at Brookhaven, SLAC, and practically every high-energy accelerator in the world.

The MIT-BNL experiment was approved in May 1972, and construction started shortly thereafter. Data-taking commenced in April 1974.

Introduction

In the period under review in this issue of *Brookhaven Highlights*, from July 1, 1972, through June 30, 1974, the downward trend in Laboratory population, which had been so obvious in previous years, was checked and in fact a gain was achieved.

In accordance with our principal original purpose – to make unique facilities available to qualified scientists – the high-energy physics program centered on the Alternating Gradient Synchrotron has flourished. In addition, a design for a new major facility, an intersecting storage accelerator using superconducting magnets, designated ISABELLE, has been developed and brought to the stage of a construction proposal. The nuclear physics programs based on the Double Tandem Van de Graaff and the various research efforts at the High Flux Beam Reactor have produced important results.

Although the high-energy program accounts for the largest single part of the budget, basic research in solid state physics, chemistry, and the life sciences scored significant gains. In line with the trend in national policy, there has been a considerable shift in emphasis toward applied research, much of it supported by agencies other than the Atomic Energy Commission.

In view of the increasing awareness of energy problems in the nation, and in fact the world, and in anticipation of the splitting of the AEC into a nuclear energy regulatory body and an energy research and development agency, most of the newer programs are energy related. They range from socioeconomic studies of energy systems, to studies of the factors that influence the selection of offshore sites for power reactors, to construction of a demonstration section of superconducting transmission line. We look forward to increased support of energy-related programs, both for those in progress and for new ones yet to be established.

Naturally, it would be impossible to describe even briefly the entire research program of the Laboratory in a report of manageable size. Here we have attempted to give an overall view, concentrating on the highlights. More details are available from the Department Chairmen.

MAJOR

FACILITIES

ACCELERATOR DEPARTMENT

THE operation, maintenance, and improvement of the Alternating Gradient Synchrotron (AGS) constitute the chief responsibility of the Accelerator Department. Other major departmental functions are the design, fabrication, and operation of equipment required for the experimental program, including detectors such as bubble chambers. The Department is also responsible for a large computer complex used in the experimental program, the On-Line Data Facility (OLDF). In addition, research on new accelerator designs and their development are important aspects of the Department's activities.

Figure 1. Aerial view of the AGS.

Figure 2. Image of beam spot on beryllium oxide screen viewed by a remote TV monitor at the production target position. A grid of 0.25-mm-diam tungsten wires with 1-mm spacing adjacent to the screen provides the scale.

AGS DIVISION

Over the past ten years the AGS has been continuously improved and gradually transformed into a high-intensity proton facility with two fast external beam systems and a slow beam extraction system that supplies protons to three or more external targets simultaneously. A peak beam intensity of 9.7×10^{12} protons/pulse has now been obtained and the accelerator runs routinely with beam intensities of $\approx 6 \times 10^{12}$ protons/pulse. The facility is capable of handling, simultaneously, a large number of high-energy physics experiments. The use of on-line computers is rapidly being implemented for more sophisticated and efficient operation.

LINEAR ACCELERATOR INJECTOR

The 200-MeV proton linear accelerator (linac) performs as an injector for the AGS and as an isotope production facility. Modifications were made to further improve performance parameters, and the linac now operates well within the design specifications with regard to beam emittance and momentum spread. Extensive beam diagnostic monitors in the 750-keV beam line, the linac, and its 200-MeV end are interfaced with the linac control satellite computer. Completely unattended operation of the 200-MeV linac was achieved recently by interfacing all linac control and monitoring systems via the local PDP-8 computer to the

Figure 3. Pulsed output of a current transformer in the external beam channel of the North Experimental Area for full-extraction mode of the bunched AGS beam. Horizontal sweep speed = $0.5 \mu\text{sec/div}$.

central operational computer. A computer program now monitors all linac component parameters every ten minutes and notifies the operator if any errors are detected. Ion source developments for the linear accelerator are continuing and are directed toward the development of an operational, high-intensity H^- ion source to explore charge-exchange injection in the AGS.

In addition to serving as an injector for the AGS, the linac serves three satellite programs using the Brookhaven Linac Isotope Producer and the Chemistry Linac Irradiation Facility. Neutron-rich isotopes are being studied with use of both primary proton and secondary neutron bombardment schemes. Nose cone targets have continued to be irradiated for a contractor to the U.S. Air Force. Radioisotopes are produced on a regular weekly basis for use in clinical studies in various research hospitals.

ACCELERATOR MODIFICATIONS

Beam matching in the 200-MeV transfer system to the AGS was improved significantly by completion of automatic beam emittance measurement equipment and the associated data link to the central control computer. This greatly improved the optimum beam "stacking" adjustment for the AGS. In conjunction with the development and implementation of a low-field orbit correction program, the use of the operational computer has made possible exploration of the combined mode of vertical-horizontal multiturn stacking.

During the latter part of 1972 ten new rf accelerating cavities were installed in the synchrotron. This completed the installation of a totally new rf system designed to handle the higher beam intensities at the increased pulse rates. The new accelerating stations supply more rf power from fewer accelerating cavities and are designed to be more resistant to radiation damage.

With high AGS beam intensities, various beam instabilities were observed. These were studied in detail and the rf system was modified to compensate for the effects of beam loading. Simple damping networks were incorporated in the AGS vacuum envelope to eliminate spurious electrical resonances.

EXTERNAL BEAMS

Recently a new fast beam extraction system developed at BNL has been commissioned, together with its associated external beam channel. Since November 1973 it has been utilized for neutrino physics experiments with the 7-ft bubble chamber and counter-spark-chamber arrays in the new North Experimental Area complex. Extraction is accomplished by deflecting the AGS beam rapidly across a thin (0.25 mm) septum magnet, which in turn deflects the "shaved" beam fraction into the aperture of a thin (2.25 mm) septum ejection magnet. Rapid beam displacement at the azimuth of the thin septum is accomplished by a new, full-aperture, ferrite kicker magnet that has a peak current capacity of 8000 A and a 0.5- μ sec rise time.

The extraction system was operated in the full-extraction mode for neutrino experiments with an observed extraction efficiency of $\approx 95\%$ and an extraction duration of $\approx 3 \mu\text{sec}$. In addition to high efficiency, the other design criteria for the beam, i.e., small spot size at the neutrino production target and low losses in the 285-m-long, 10-cm-diam transport system from the AGS to the target, were achieved. A beam spot ≈ 1 mm in diameter was observed on a scintillating screen at the position of the production target. Beam losses in the transport system, which give rise to objectionable background events, were reduced to $< 1\%$ by using a system of correction magnets to provide optimum alignment and deployment of extensive instrumentation in the beam line.

The instrumentation consists of scintillating screens, current transformers, beam position monitors, beam profile monitors, and ionization chambers. The electronic instrumentation is read out by remote multiplex switching of signals into ana-

logue-to-digital converters, with subsequent digital transmission of data to a PDP-8E peripheral computer interfaced to the AGS PDP-10 computer. The beam diagnostic information is displayed graphically and numerically in the main control room of the AGS.

The new extraction system was also tested successfully for extraction of a fraction of the internal beam at a downstream straight section to serve the 80-in. bubble chamber.

Development work on the slow extracted beam (SEB) was directed at improved utilization of the facility for the experimental program. A beam-splitting system for simultaneous bombardment of targets at stations B and C was commissioned and successfully operated. The system consists of a 0.5-mm copper septum splitter magnet followed by a conventional C magnet septum. A system utilizing similar components is under test to provide an additional split between station C and a new target station A and thus permit simultaneous irradiation of three external targets.

The internal SEB extraction septa were modified to extend the duty cycle and duration of the spill. An increase in septum thickness of the F10 ejection magnet from 0.95 to 1.3 cm has made possible improved cooling and hence a longer duty cycle for this component. A spill duration of 1.7 sec was achieved. Bunched extraction (instead of the usual debunched extraction mode) of the SEB with 1-sec spill duration was also accomplished to meet the requirements of a future time-of-flight experiment.

COMPUTER CONTROL OF THE AGS

In expanding the use of the PDP-10 time-shared computer for control of AGS operations to include the fast extracted beam to the North Area, a modular system of electronic components, peripheral mini-computers, and serial data links was constructed. Extension of the system now requires duplication of existing system components rather than development of new designs. The system is capable of controlling devices ranging from individual power supplies to major subsystems of the accelerator.

Software development has continued under the manufacturer's time-sharing system, which proved to be a significant aid in the development of application programs and control systems. The ability to develop and test programs while other AGS operations continue makes a qualitative difference in the organization of the system. In the data acquisi-

tion and control system, the role of the PDP-8's was reduced to synchronization with the AGS pulse and control of the actual input/output operation. Selection by the PDP-10 of operations and the time at which they are to be performed has restored to the time-sharing operation in the PDP-10 the activities previously predetermined by inaccessible system coding in the PDP-8. Efforts are now concentrated on development of high-level procedures to operate areas of the machine collectively. This is a development of existing techniques but will be systematized via a file-oriented scheme to make initiation of subsystem operations possible for accelerator specialists and operators. The objectives are to provide rapid and predictable adjustment of machine conditions, including start-up and shutdown, and convenient diagnosis of machine operation.

HIGH-INTENSITY NEGATIVE ION BEAMS

The interest in production of intense negative hydrogen beams arose from possible applications in high-energy accelerators and fusion reactors. For accelerators and storage rings negative ions (using the multiturn charge-exchange injection scheme) offer an alternative to the present proton injection scheme that could result in a higher phase-space density of the injected beam. The required beam currents would be several tens of milliamperes. For some fusion devices, e.g., toroidal Tokamaks, intense negative beams may be used for neutral beam production and subsequent plasma heating. This may require beam currents as high as several tens of amperes.

Early in 1973 a program was started at BNL for development of an operating source of negative hydrogen ions to replace the present proton source in the AGS preinjector. Some time later a grant was received to begin work on high-intensity sources for applications in fusion devices. Prototypes of two different sources were built - a hollow discharge duoplasmatron and a magnetron source. Best results were obtained when sources were operated with a mixture of hydrogen gas and cesium vapor. Currents up to 20 mA were obtained from the duoplasmatron source and above 100 mA from the magnetron source. While an improved version of the duoplasmatron will satisfy the requirements for injection into the AGS, the emphasis will be on the further development of magnetron sources, which are more likely to yield beam currents of negative ions adequate for fusion applications.

EXPERIMENTAL PLANNING AND SUPPORT DIVISION

The experimental planning involved in operating a high-energy physics program at the AGS requires an efficient program for bringing the accelerated protons to a number of primary beam targets. The secondary particles produced therein by high-energy collisions must then be transported to the various experimental setups in such a way as to satisfy simultaneously the requirements of a large number of experiments. The diversity of these requirements is reflected in the different types of secondary beams delivered to experimenters. These include charged-particle and uncharged (neutral) beams, high-resolution beams in which the momentum is precisely established, and "separated" or, more accurately, "purified" beams in which one type of secondary particle normally present in relatively small numbers is made to predominate. In addition, the time duration of the delivery of secondary particles to the experimenter can vary from microseconds for experiments in which data are taken photographically in a limited sensitive time (e.g., bubble-chamber and optical spark-chamber experiments) to one second for experiments that detect particles by electronic means. The latter experiments generally operate most efficiently when the events to be studied occur at a uniform rate close to the minimum time resolution of the detectors, typically scintillation counters, spark chambers, or multiwire proportional chambers.

As experiments are concluded and new ones proposed, the configuration of beams and experiments is a dynamic one and the floor plan is continuously changing.

The support given experiments involves construction and operation of the components of the beam transport, experimental targets (frequently liquid hydrogen and deuterium), and provision of analyzing magnets, modular electronic logic, and floor space, including house trailers for operation of the required electronics. Services include survey, electrical power, cooling water, vacuum, and installation of large components of the experiment requiring professional rigging.

EXPERIMENTAL AREA LAYOUT

Two years ago experiments were carried out simultaneously from the internal target in the AGS aperture, in either the A or the C branch of the

slow extracted external proton beam (SEB) and in the 80-in. bubble chamber.

At that time the B target station and a beam splitter to permit simultaneous transport of protons to the B and C targets were under construction. Since then the first experiments have been completed in the high-energy charged beam and the neutral beam installed at the B station. A medium-energy separated beam has also been constructed, and experiments are under way in both branches. A large, solid-angle multiparticle

spectrometer is being set up in the B2 branch for use by experimenters (see Figure 4).

In addition, the SEB was split again and a new A target station was constructed that can operate at the same time as the B and C branches, the internal target, and the beam to the 80-in. bubble chamber. A D branch of the extracted beam, which will alternate with the A line, is under construction. Initially the A and D branches will serve two experiments utilizing primary protons rather than secondary particles.

The neutrino physics area was put into operation in 1974. Protons extracted from the AGS for several microseconds during each AGS cycle are focused on a production target in the North Experimental Area. Neutrinos resulting from the decay of pions produced in the target are then studied through their interactions in the 7-ft bubble

Figure 4. Experimental area at the AGS. The multiparticle spectrometer (MPS) is at the upper left. The electromagnetic lens system guides a beam of particles from a production source (below bottom of photograph) to the detectors. Beams to other experiments go off to the right. The trailer on the left contains fast electronics for the MPS.

chamber and in the optical spark chambers of an experiment located behind the bubble chamber. The small probability ($\approx 10^{-15}$) that a neutrino will interact while passing through the several tons of matter of the experimental detectors permits this tandem operation. A pair of superconducting bending magnets is incorporated in the primary proton transport to the production target. They are the first large-scale magnets of this type to transport charged-particle beams of about 6×10^{12} particles/pulse, and their performance bodes well for the future of this new, energy-saving technology in high-energy physics. A more detailed description of the magnets, their performance, and significance is given below.

The floor plan of the AGS complex with the various beam lines is displayed in Figure 5.

EXPERIMENTAL PROGRAM

The neutrino experiments in progress are scheduled to use the entire AGS proton beam in order

to maximize the occurrence of the relatively rare neutrino events. Present interest in the description of weak interactions in terms of neutral, as well as charged, leptonic currents* has resulted in an intensive search for neutral current events, i.e., those in which there is no change in leptonic charge. For example,

$$\nu p \rightarrow \text{hadrons} + \nu,$$

as opposed to charged current events such as

$$\nu p \rightarrow \text{hadrons} + \mu^-.$$

Several thousand charged current events have been identified to date in the current AGS experiments.

Electronic experiments conducted in the past two years are listed in Table 1 to indicate the scope of the high-energy physics program at the AGS. In addition to the experiments listed, two test beams, 6B and 7A, were available to experimenters for testing and calibration of detectors.

*Weakly interacting particles such as muons ($\pm$), electrons ($\pm$), and neutrinos are called leptons. Particles that can interact through the strong nuclear forces (protons, pions, hyperons, etc.) are referred to as hadrons.

Figure 5. Experimental area layout at the AGS during the first half of calendar 1974.

Table 1

High-Energy Physics Experiments at the AGS, July 1972 - June 1974

<u>Internal Target at G10</u>	
Beam 5, 1 to 3-GeV/c Electrostatically Separated Beam Rutgers BNL-Rutgers-Indiana MIT-Brown-Bari Yale-BNL Yale-BNL-CMU	Boson resonances, 2.8 to 4.3 GeV/c. Search for structure in A_2 and ρ regions. $\bar{p}p$ annihilations into neutral nonstrange mesons. Asymmetry and differential cross sections in K^+p backward elastic scattering from a polarized proton target. Spin-dependent effects in $\pi^- + p \rightarrow \pi^+ + \pi^- + n$ in ρ region.
Beam 6, Neutral Beam Columbia-CERN-NYU Columbia-CERN-NYU Columbia-CERN-NYU Columbia-CERN-BNL Rochester-BNL Rochester-BNL*	CP violation parameters in K^0 decay. $K_L \rightarrow \mu^+ \mu^-$ branching ratio. Charge asymmetry in $K_L \rightarrow \pi/\nu$. $K_L \rightarrow \mu^+ \mu^-$ branching ratio. $K^*(890)$ production. K_L radiative decays.
Beam 7, Neutral Beam BNL-Yale	Charge asymmetry in K_L^0 decays.
A1, High-Energy Charged Beam BNL-CCNY Rochester-CMU	Strange and nonstrange bosons decaying into $K\bar{K}$ and $K\pi$. Diffractive and Coulomb dissociation of $p \rightarrow p + \pi^0$.
A2, High-Energy Proton Beam BNL-VPI Princeton- <i>travia</i>	Multiparticle production in pp collisions. Isobar production and decay in the 1200 to 2350-MeV/c ² region in pp collisions.
<u>External Targets in the Slow Extracted Beam</u>	
A, Primary Proton Beam MIT	$\pi^+\pi^-$, K^+K^- , e^+e^- , $\bar{p}p$ mass spectra in the 1.5 to 5-GeV/c ² region.
D, Primary Proton Beam Channel Stanford-NYU*	Measurement of Lamb shift in $\pi\mu$ atoms.
<u>B Target Station</u>	
B1, High-Energy Charged Beam U. Penn. U. Penn.	Momentum spectra in high-energy collisions. Cross sections in projectile fragmentation region.
B2/B4, Medium-Energy Separated Beam, 2 to 6-GeV/c K , 2 to 9-GeV/c $\bar{p}$ Multiparticle spectrometer facility BNL-CCNY* Carleton-NRC-McGill-BNL*	Production and decay of boson resonances. Missing mass measurement of strange meson spectrum in the mass range 1 to 2 GeV/c ² .
B5, Neutral Beam Princeton-Mass.	Branching ratio for $K_L^0 \rightarrow \mu^+ \mu^-$.
<u>C Target Station</u>	
6-GeV/c Muon Beam Columbia-Rochester-Harvard-Rockefeller-NAL Rochester Columbia-Rochester-Harvard-Rockefeller-NAL Columbia-Rockefeller-NAL-Rochester-Harvard	μp scattering at large momentum transfer. Missing mass search for heavy muons. Deep inelastic muon nuclear scattering. Inelastic muon scattering in deuterium.
C3, Hyperon Beam, 23-GeV/c Σ^- , Ξ^- , Ω^- Yale-BNL-NAL Yale-NAL-BNL Yale-NAL-BNL Pitt.-BNL-Mass.*	Production and decay of Σ^- , Ξ^- , Ω^- , X^- ; Σ^- and Ξ^- leptonic decays, weak form factors. Production of Ω^- and Υ^{*-} . Σ^-p , Ξ^-p differential cross collisions. Υ^{*-} resonances in Σ^-p collisions.
C2/C4, Low-Energy Separated Beam, 0.5 to 1.1 GeV/c VPI-CMU-W&M-BNL-NYU BNL Columbia-Yale VPI-W&M-Wyoming-CMU* Princeton*	X-ray spectra from K^- and $\bar{p}$ stopping in matter; Σ^- and $\bar{p}$ magnetic moments; K^- , Σ^- , and $\bar{p}$ interaction with nuclei. Total cross sections in $K^\pm$, $\pi^\pm$, and $\bar{p}$ collisions with protons and deuterons. X rays from K^- and $\bar{p}$ stopping in matter; $\bar{p}$ and Σ^- magnetic moment; K^- nuclear interaction; K^-p mass. X rays from exotic atoms: K^- , Σ^- , and $\bar{p}$ masses; Σ^- and $\bar{p}$ magnetic moments; interaction with nuclei. $\Sigma^\pm$ beta decay, weak form factor; test of $\Delta S = \Delta Q$ rule.

*Experiment still in progress as of June 30, 1974.

Figure 6. 8° Superconducting bending magnet in North Experimental Area.

The radiofrequency separated beam and the 80-in. bubble chamber were also operated for a series of experiments.

COMPUTER CONTROL

Computer control of the AGS secondary beam line magnets is proceeding on schedule. At present, of the 180 or more power supplies in use, $\approx 20\%$ have been changed from the cumbersome manual control system to the computerized system. The software for the PDP-11 computer has been written and tested, with on-line operation to begin at target station B during July 1974. The system has been successfully used with some elements in the fast extracted beam (FEB) in the North Experimental Area. On-line operation for the FEB, requiring some new hardware, is now being investigated.

In addition, work is proceeding on computer control of the 8° superconducting magnet as well as the superconducting dipoles and quadrupoles of the high-energy unseparated beam (HEUB).

Table 2

Magnet Parameters (4° Module)

Aperture (i.d., warm vacuum pipe)	7.3 cm
Magnetic field intensity	40 kG
Ampere-turns (dipole coil)	408,000
Ampere-turns (sextupole coil)	18,000
Current (dipole coil)	1200 A
Current (sextupole coil)	300 A
Current density (dipole coil conductor)	3.05×10^4 A/cm ²
Current density (sextupole coil conductor)	3.0×10^4 A/cm ²
Stored energy	150 kJ per unit
Inductance (dipole coil)	0.2 H per unit

SUPERCONDUCTIVITY

The work on superconductive technology is being done in close collaboration with the Department of Applied Science and the Physics Department.

The HEUB to the multiparticle spectrometer is being designed using superconducting dipoles and quadrupoles. Magnet and Dewar design has been started and procurement of cryogenic equipment is under way.

A large, superconducting bending magnet system (see Figure 6) is in operation in the new beam from the AGS to the 7-ft bubble chamber. Two dipole modules excited to 37 kG, with a total magnetic length of 4 m, bend 30-GeV primary protons by 8°. The system has operated routinely for several months, traversed in 3 μ sec by 6×10^{12} protons with a beam power of 30 kJ. The system is designed for on-line operation and computer monitoring of parameters with closed-loop helium refrigeration. The magnets have been operated to 44 kG with both modules identical to computed field predictions within an accuracy of $\approx 1 \times 10^{-4}$ over the useful aperture. These are the first superconducting magnets to be used in a primary proton beam.

The two magnets employ a rectangular "window-frame" iron core surrounding a rectangular cross-section dipole coil package. Their overall dimensions are 37.8 cm high $\times$ 43.5 cm wide. The iron core, which is closely coupled around the coil, reduces the ampere-turns required for magnetic fields below saturation by a factor > 2 .

The magnet parameters for the 8° dipole, which consists of two 4° modules, are given in Table 2.

The 8° refrigeration system utilizes a 74-W helium refrigerator separated from the magnet by

≈ 10 m of earth shielding and connected to the magnet Dewars by 40 m of liquid-nitrogen-shielded transfer lines. The magnet Dewars and refrigerator comprise a closed-loop system to which auxiliary equipment has been added for the recovery and storage of the helium gas. The magnet, refrigeration, and recovery systems are instrumented for automatic operation.

Later versions of the 8° magnets have been designed in which the field uniformity can be improved substantially without affecting the construction techniques for the magnet. Thus, second-generation magnets of this type should have both high mechanical precision and very uniform fields. This design has also evolved toward higher fields, with present calculations describing a very high-quality magnet capable of excitation to 60 kG.

The 8° magnet system has also been used as the basis for detailed studies of larger superconducting beam transport systems requiring ≈ 10 times the refrigeration capacity. Such larger systems would be cost effective in terms of capital expenditure and would permit significant savings in power. The 8° magnets were designed as dc devices but are also applicable to pulsed applications when provided with laminated cores.

A cryogenic facility has been established to support the superconducting magnet program and other work at low temperatures. This facility has been used extensively during the past six months to perform both magnetic and long-term pulsing tests on the ISABELLE model superconducting magnets. Assembly, leak testing, and magnetic measurements of the HEUB superconducting magnets will be performed early in 1975. This facility has been used since the summer of 1973 to store and purify the dirty helium gas collected from the closed-loop recovery systems in both the cryogenic facility and the 8° superconducting magnet system in the North Experimental Area. The purified helium gas is liquefied and made available for use wherever needed in the Laboratory; this considerably reduces procurement costs.

PARTICLE DETECTOR DIVISION

ENERGY-RELATED RESEARCH

The expertise required in the development of large experimental equipment for high-energy physics research is, in general, directly applicable to solving problems in energy-related research. In particular, techniques developed for the design,

fabrication, and operation of large superconducting magnets, such as the 7-ft bubble-chamber magnet, are directly applicable to the design of large superconducting magnets for fusion power reactors. A group has been established that is currently investigating the safety aspects of large fusion reactor magnets. Funds have been requested for further detailed design studies of fusion magnets and related equipment. With adequate funding, activities in this area will be expanded.

Work is also in progress on the safety analysis of high-temperature graphite reactors. In particular, criteria are being established for conducting studies on seismic loading effects on the reactor core. Again, the experience gained in the design of structures to withstand large cyclic loads (for example, the 7-ft bubble chamber) is extremely valuable in conducting this program.

80-IN. BUBBLE CHAMBER

Shortly after the end of this report period, Brookhaven reluctantly terminated the 80-in. bubble chamber program, despite a continuing demand

Figure 7. The 80-in. bubble chamber. The technician on the upper platform is checking the vacuum system, and the one on the lower platform is changing a film magazine.

Figure 8. Layout of the multiparticle spectrometer. The 700-ton C magnet, which will contain the target area assembly and main detectors, is at the center, with the beam entering from the left and additional detectors to the right.

for pictures. This decision was forced by the substantial reduction in real purchasing power of the Laboratory's budget for fiscal 1975.

The chamber was conceived about 15 years ago by Ralph Shutt (now Deputy Chairman of the Physics Department) and members of the Cloud Chamber Group, and design on it began just as the 20-in. bubble chamber came into operation. In May 1963 the 80-in. bubble chamber was first "cooled down" and filled with liquid hydrogen. Expansion tests followed, and on June 2, 1963, the first bubble tracks of charged particles from the AGS were photographed in the chamber. On December 14 the first experiment, looking at the interactions of 5-GeV K^- mesons with protons in the liquid hydrogen, was begun. It was performed by members of the Shutt group, led by Nicholas P. Samios. By the end of January 1964 they had taken 133,000 photographs, and about a week later they made a momentous discovery. This was a new particle, the omega minus (Ω^-) hyperon, whose existence had been predicted by a relatively new theory of Gell-Mann and Ne'eman, who were trying to make organizational sense out of the numerous hyperons and mesons discovered up to that time.

In its working lifetime the 80-in. chamber took a total of almost 12 million pictures, of which 27% were used by BNL research groups and 73% by universities. These pictures were spread over 71 separate experiments performed by staff members of 37 United States universities and 6 foreign universities, in addition to Brookhaven's own research groups. The fruits of these experiments have been displayed in about 250 papers in various journals and a similar number of talks presented at meetings of the American Physical Society and at other conferences, mostly international. In addition, 29

doctoral theses have been based on work done in the 80-in. bubble chamber.

MULTIPARTICLE SPECTROMETER

The multiparticle spectrometer (MPS), Brookhaven's major spectrometer facility, is nearing completion in its initial configuration. It can be used for a large class of counter-spark-chamber experiments at the AGS. The system test will begin during the summer of 1974 and the physics program is scheduled to start in the fall. The unique characteristics of the MPS are (1) a very large aperture magnet that provides a large acceptance solid angle to detect the reaction products; (2) good momentum and angular resolution, obtained by use of low-mass, high-resolution wire spark chambers and a large magnetic field integral; and (3) the high data-handling capacity inherent in the electronic detectors used. The availability of enriched K^- and $\bar{p}$ beams from the medium-energy separated beam (MESB) provides exceptional possibilities for excellent experiments with this spectrometer. The MPS is a joint project of the Particle Detector Division of the Accelerator Department and a research group in the Physics Department. There also has been strong backing and participation in the construction of the facility by potential users.

The layout of the MPS, which is located in the northwest corner of the AGS East Experimental Building Addition, is shown in Figure 8. The 700-ton C magnet has a pole 1.8 m wide by 4.6 m long and a gap of 1.2 m. The maximum operating field is 10 kG at the center (Figure 9). Three completely open sides and 12 slots in the top pole give easy access to the field volume for particle detection (Figure 10). The target and target area detector assemblies can be placed either in the magnet, as shown, or upstream of the magnet. In either case, close to 4 π solid-angle coverage for the particles emerging

Figure 9. Side view of the MPS main magnet. The magnet pole is 1.8 m wide $\times$ 4.6 m long, and the gap height is 1.2 m. The maximum operating field is 10 kG at the center. The large field volume of this magnet, the large openings on three sides, and the large magnetic field integral available are some of the unique features of the MPS.

Figure 10. The MPS setup early in its test period, showing MX spark-chamber modules, which are inserted from the top of the magnet, and MY spark-chamber modules, which are inserted from the left side. These modules are the main detectors for the MPS.

from the target can be achieved while maintaining good resolution in the measurement. The arrangement of detectors in the target area will be changed according to the requirements of each experiment. At present two kinds of assemblies are in preparation. One is a three-sided box made of wire spark chambers that partially surround the target. A unique electronic trigger scheme, which utilizes three multiwire proportional chambers, gives an excellent selection of the kinds of events to be studied. The other is a set of cylindrical spark chambers that encircle the target and thus give complete detector coverage around it. The main detectors, MX's and MY's, occupy the middle section and detect mainly the forward-going particles. They are low-mass, high-resolution wire spark chambers with magnetostrictive readout. The number of modules will be changed to meet the requirements of each experiment. Spark-chamber modules and scintillation-counter hodoscopes downstream of the magnet detect high-momentum forward particles with improved momentum resolution, while Čerenkov-counter hodoscopes provide particle identification. The beam will provide $K\pi$ separation up to ≈ 6 GeV/c and $\bar{p}\pi$ separation up to ≈ 9 GeV/c. From the HEUB, which is planned for the summer of 1975, particles up to ≈ 30 GeV/c will also be available. To accommodate these two beams, which come from different

directions, the MPS magnet can be rotated through 30° on its hydraulic bearings.

At present, four experiments (1200 hours) have been approved for the first period of running and there are six requests for experiments with time totaling 3200 hours. The MPS is expected to provide many users of the AGS with an excellent and unique tool for investigations of the physics of strong, weak, and electromagnetic interactions. It is also anticipated that the MPS will evolve, with appropriate additions and modifications, and provide users with state-of-the-art detectors.

7-FT BUBBLE CHAMBER

The 7-ft bubble chamber is now complete and is located in the H10 area neutrino beam. The first test of the modified chamber, completed in June 1973, had as its purpose the trial of the modified hydrogen chamber, the hydrogen refrigerator, the chamber temperature control systems, and the hydraulic expansion system. Overall, the test was successful; the chamber showed little boiling, uniform sensitivity, very low distortions, and great flexibility under varying operating conditions.

Following installation of the superconducting magnet, the complete system was tested in November 1973. During December 37,000 triad pictures for experimental use were taken in the neutrino beam, with hydrogen as the chamber fluid.

Figure 11. (a) Photograph and (b) diagram of a "standard" 3-prong neutrino event. The neutrino (ν) interacts with a proton, becoming a μ^- meson and producing a proton (p) and a π^+ meson. Note that the weakly interacting μ^- meson goes right through all four stainless steel plates. A strongly interacting π meson or proton will almost always interact in the plates (as the p does here), which allows a distinction to be made between a μ^- and a π^- . This will be the primary means of distinguishing between an "ordinary" neutrino event like $\nu + p \rightarrow \mu^- + p + \pi^+$ and a "neutral current" event like $\nu + p \rightarrow \pi^+ + p + \nu + \pi^-$.

During January and February 1974 the chamber was open for inspection and for installation of four 5-cm-thick stainless steel plates, positioned to allow photographs to be taken, with two of the three cameras, in the chamber volume between them. These plates serve as a π -meson/ μ -meson discriminator; i.e., particles can be identified on the basis of their interaction or noninteraction with the material in the plates.

In March, the chamber was run again in the neutrino beam, with hydrogen as the chamber fluid. About 100,000 triad pictures were taken. Figure 11 shows a neutrino event taken during this run. The chamber was cooled again at the end of April and filled with deuterium. Only 27,000 pictures had been taken when the run was interrupted by a leak into the insulating vacuum. It is planned to run the chamber for neutrino physics about 12 weeks per year, divided into separate runs of about 3 weeks each.

ON-LINE DATA FACILITY

The On-Line Data Facility (OLDF) has continued to play an important role in providing AGS users with the advanced on-line computer support that is vital to their counter-spark-chamber experiments. The recent trend in high-energy particle physics experiments requires increasingly complex experimental setups and high accuracy of measurement. To ensure that this complex setup is functioning properly and that the experiment is progressing as planned, the experimenters increasingly rely upon real-time analysis of the data by an on-line computer. During the last two years 16 major experiments have received this real-time support from OLDF. In addition, eight experiments have used OLDF support in an off-line mode to improve utilization of the AGS beam time.

To provide this support, two PDP-10 computers are used, both operating in the time-shared mode using the basic DEC multiprogramming monitor software so that the facility can accommodate the needs of several users simultaneously. At present, 208,000 words of core memory are available with the two computers. Additional memory locations are provided by a fixed head disk or a disk pack system attached to each computer operating in the swapping mode. As many as five users can connect their data acquisition devices to the computer, on line, via a real-time data link. The data thus sent to the computer are analyzed by a program written by users for their particular experiments. The

results either are stored in the form of histograms for later use after certain statistics have been accumulated, or are sent back to the user in the form of an oscilloscope display or a Teletype output for immediate use. Off-line use of the computer is generally for program preparation and quick turn-around analysis of the data to prepare for the subsequent run. A conversational mode of operation available with the PDP-10 system is a useful tool for program preparation and for quick analysis of data if frequent changes in the program and/or parameters are needed.

The major improvements in the OLDF computer system in the past two years are (1) replacement of the old PDP-6 processor with a more modern and efficient PDP-10 processor, (2) addition of a 5-million-word disk pack system to one of the PDP-10's, (3) expansion of an alphanumeric display system, and (4) continuing improvement in programs for improved efficiency of operation of the system.

ADVANCED ACCELERATOR DEVELOPMENT DIVISION

ADVANCED ACCELERATOR DEVELOPMENT

The Accelerator Department supports a long-range program of substantial improvement of the AGS and the addition of new facilities. In particular, design studies for a proton accelerator of very high energy have been in progress for some years. These studies are coordinated with a continuing research effort in superconductivity to overcome the economic and technical limitations of conventional accelerator designs. During 1970-72, these efforts focused on colliding beam accelerators in the energy range 100 to 300 GeV and culminated in a preliminary design for a 200-GeV colliding beam facility using superconducting magnets, termed the Intersecting Storage Accelerator (ISA), or ISABELLE. Colliding beam machines can generate high center-of-mass energies with relatively modest laboratory energies. They do not produce secondary beams effectively but they do provide an unparalleled opportunity for studying the reactions of primary particles at the highest possible energies. Two colliding proton beams, each at 200 GeV, would yield a center-of-mass energy of 400 GeV, equivalent to protons of 86,000 GeV striking protons at rest.

In the past two years substantial advances have been made in the field of superconducting magnet

technology, and the ISA design has reached the stage where the principal machine parameters are well defined and detailed engineering has been initiated. This accelerator would extend the present center-of-mass energy range by almost a factor of ten and, equally significant, provide luminosities* two orders of magnitude higher than those currently available. A number of challenging problems have emerged from recent theoretical and experimental investigations in this country and abroad. Theories unifying forces underlying the weak interaction (responsible for radioactive decay and neutrino interactions) and the classical electromagnetic interaction postulate the existence of a particle known as the intermediate vector boson, with a rest mass well within the ISA energy range. Moreover, the unexpectedly copious production of π mesons with high transverse momentum, seen in recent experiments, may signify a point structure inside the proton. Other crucial questions that the ISA could explore concern the rise in total proton-proton cross section at the highest presently available energies, again at variance with current theories, and the prediction of heavy new particles such as quarks, magnetic monopoles, and massive photons. These problems are at the very forefront of basic science, and their elucidation may deeply affect our understanding of nature.

200-GeV INTERSECTING STORAGE ACCELERATORS

As a consequence of continuing collaboration between Brookhaven staff members and university colleagues, the preliminary ISA design has been revised, most of the important machine parameters have been better defined, and considerable detailed engineering work has been carried out. This work has resulted in the submission of a construction proposal to the AEC.

The ISA design is based on separate superconducting bending and focusing magnets distributed around two ring structures, one above the other, in a fourfold symmetric pattern. Its configuration is that of a circle expanded by four 250-m-long experimental straight sections, where the two proton beams intersect, and four 110-m-long service sections for injection, acceleration systems, etc. The rings have a circumference of 2690 m ($3\frac{1}{2}$ times that of the AGS) and are electrically and magnetically separate to permit operation with unequal

proton energies and to accommodate future optional proton-antiproton experiments. The maximum circulating current is expected to be about 10 A. This value and various other accelerator parameters (such as tolerable beam-beam tune shifts and AGS emittance) determine the design luminosity of $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$.

A number of experiments have been designed conceptually and constraints on the experimental insertions established, with flexibility achieved by incorporating certain variable parameters in the basic machine design. Most experiments can be performed in four identical general-purpose experimental straight sections of modest betatron amplitude function (beta) and with adjustable optical parameters. Later, more specialized experimental insertions can be introduced as needed; for example, insertions of very low beta to achieve the highest possible luminosity.

The method of transferring protons from the AGS to the ISA is the same as that used at the CERN ISR: successive pulses of 28.5-GeV protons will be captured, decelerated, and debunched in each ring. This cycle is repeated about 250 times for each ring until 10 A of circulating current is attained; the stacked beams are then rebunched and slowly accelerated to full energy over a 2-min interval. Peak rf accelerating voltage is 40 kV, and the energy gain per revolution, 12.5 keV.

The long acceleration cycle and "flat top" associated with this machine make it attractive for superconducting magnet applications. During the past few years superconducting magnet technology has advanced to the point where the performance of magnets can be predicted with considerable confidence. The Department's extensive superconducting magnet development program has culminated in magnets exhibiting excellent stability and having a configuration that meets the severe ISA requirements on field precision, reproducibility, and reliability. Experience gained with superconducting beam transport magnets has shown that radiation damage to magnet components is not as serious as had been thought. The refrigeration system for the ISA consists of a central compressor station and eight refrigerator cold boxes, one for each octant of the machine. Systems of the required capacity (20 kW) have demonstrated reliable operation in commercial use.

The ISA 40-kG magnet design is based on commercially available, multifilamentary, NbTi superconducting wire. Prospects for commercial quan-

*Luminosity determines the rate at which a particular reaction takes place, the rate being the product of luminosity and the cross section for the reaction in question.

tities of filamentary conductors of new and superior materials, particularly Nb_3Sn and V_3Ga , are very encouraging, as a result of research efforts at BNL (Department of Applied Science) and elsewhere. These materials would permit operation at considerably higher temperatures (8 to 9 K, in contrast to 4 to 5 K for Nb-Ti) with greatly reduced power consumption, and peak fields of 60 kG or higher. Final decision on the type of conductor to be used will have little effect on the magnet design and can be delayed for some time after approval of the project.

Several future options that would enhance the versatility of the ISA facility are possible. Acceleration of electrons in a separate ring inside or outside the ISA tunnel, or possibly in one of the two main rings, would permit electron-proton experiments. The addition of a modest bypass to one ring would allow proton-antiproton experiments to be carried out. Moreover, acceleration of deuterons in one or both rings would be relatively straightforward; this suggests the possibility of neutron-proton and neutron-neutron scattering.

ISA PROTOTYPE MAGNETS

The superconducting accelerator magnet development program, for which the main initial impetus was provided by the availability of intrinsically stable low-loss superconductors in 1968, has proceeded in several overlapping stages, culminating in the construction of a series of large ISA prototype dipoles during 1973-1974. Originally the program concentrated on the development of suitable high-current conductors in the form of fully transposed braids containing several hundred multifilamentary Nb-Ti composite wires. Methods for "potting" or impregnating them in magnet coils were also studied, since even magnets wound from intrinsically stable wire can suffer "degradation"* and "training"† if the coils are allowed to move under the influence of Lorentz forces. An important advance made in 1969 was the discovery of the exceptionally stable magnet performance realized by bonding the individual twisted multifilamentary wires in a braid or cable with a secondary

matrix of a soft metal, such as indium, in a series of metallurgical steps.

As the development of a satisfactory conductor progressed, construction was initiated of a series of small, 35-cm-long, pulsed model dipoles, designed to produce 40 kG over a 5-cm aperture. Eight of these, incorporating either insulated or metal-impregnated conductors, were assembled to explore various approaches to potting. They were of the $\cos\theta$ or sector type, consisting of a single layer of wide braided conductors distributed on a circle in discrete groups and graded into a current distribution varying azimuthally as the cosine of the angle from the median plane. This was done by interleaving a spacer braid of stainless steel wires. In these magnets, a closely coupled concentric iron shield contributes about 40% to the field, reduces the external field, and, if properly positioned, acts as a mechanical constraint against the magnetic forces. The wide transposed ribbon conductor ensures efficient cooling in the helium bath. Moreover, since the "inert" spacer turns are extended around the magnet ends, the current density is graded axially as well as azimuthally, which minimizes the final end-shaping necessary to eliminate unwanted axial field harmonics. This approach is thought to be well suited for accelerator dipoles and quadrupoles, since it can be readily adapted, with a high degree of accuracy, to mass production techniques. The design is also easily extended to several conductor layers for dipoles of substantially higher field.

Storage ring magnets differ from rapidly cycling synchrotron magnets in that their power losses are relatively unimportant, but tolerances on field uniformity are much more severe because of the long lifetimes of the stored beams. During 1973-1974 two larger "identical" model magnets, designed specifically to meet the requirements of the ISA, have been completed and tested. Termed ISA I and ISA II, these dipoles are 90 cm long, have an 8-cm-diam bore, and are designed to produce a central field of 40 kG. (The ISA currently calls for 4.25-m magnets with an aperture of 12 cm.) They were intended to verify the expected field precision and to examine the reproducibility from magnet to magnet. By subjecting them to continuous pulsing in a common cryostat for an extended interval, their long-term reliability could be determined and cryogenic experience gained with a closed-cycle refrigeration system. The coil configuration is of the $\cos\theta$ type outlined above. It con-

*Failure to reach the current or field expected from tests on short samples of the conductor.

†Diminishing degradation (or improvement in characteristics) after each successive transition to the normal or "quench" state. A quench occurs when the temperature of the superconductor exceeds the critical value and the material exhibits a normal resistance. In this case the energy stored in the magnetic field must be dissipated safely or severe damage will occur.

sists of 24 conductor blocks containing 2-cm-wide braid, positioned so as to minimize the lowest Fourier harmonics in the field distribution and assembled in a precision mold by a technique readily adapted to mass production. The coils are mounted in a laminated iron shield by a method ensuring that they are clamped firmly at all temperatures. The conductor is braided from 186 twisted composite wires, each 0.2 mm in diameter and containing 400 Nb-Ti filaments of 7- μ size, and is filled with an In-Tl alloy to ensure the highest degree of stability. Small correction windings are incorporated in the design to correct for undesirable sextupole and decapole harmonics introduced by superconductor magnetization at low fields and iron saturation effects at high fields.

Preliminary tests were made on each magnet mounted in an open vertical Dewar. The performance of both magnets exceeded expectations in that they reached the design current (3500 A) with no difficulty and exhibited remarkably little training. At this current the overall current density in the windings is 30 kA/cm². Extensive harmonic field measurements were carried out over the full field range during dc and pulsed operation, with use of a set of measuring coils designed to detect specific Fourier components. At low rates of field change these measurements are in good agreement with calculated field distributions; (the calculations take into account both superconductor magnetization and iron saturation effects) and consistent with estimated constructional tolerances. At faster field changes the harmonics are altered somewhat by currents induced between the wires in the metal-stabilized braid.

After completion of these measurements, the two dipoles were mounted in series electrically in a common horizontal cryostat for extensive magnetic and thermal cycling. The bore was at room temperature to allow for more precise field comparisons, using a pair of computer-controlled harmonic coils and a nuclear magnetic resonance system. The field distributions appear to be identical to within a few parts in 10⁵. The dipoles then underwent a 3-month test program during which they were subjected to ≈ 5500 pulses, each current pulse of rise and fall duration characteristic of the ISA but with a very short "flat top." This simulated the expected lifetime of a storage accelerator in a fairly short time. During this sequence, field measurements were repeated periodically, and the magnets were also cycled to room temperature and were

deliberately quenched a number of times. These procedures produced no significant change in magnet performance, nor could any change in the field distributions be detected within the accuracy of the measurements (about 10⁻⁵/cm² in the case of the sextupole field component).

A third 90-cm-long model dipole (ISA III) is ready for testing and a fourth (ISA IV) is being assembled. In ISA III a conductor braided from organically insulated wire is used, and in ISA IV the wires are insulated by a surface layer of copper-nickel. The main purpose of these magnets is to eliminate the dynamic effects associated with the conductor used in ISA I and II without impairing its excellent stability. In addition, design has been completed for four dipoles and four quadrupoles, of the same sector type but with 20-cm warm bore aperture, for the projected HEUB. Finally, construction has been initiated of a 1-m-long dipole with a conductor braided from multifilamentary Nb₃Sn developed at BNL. This magnet should be available in 1975.

NEW SUPERCONDUCTOR DEVELOPMENT

Modern high-field superconducting magnets utilize intrinsically stable conductors in the form of fine twisted superconducting filaments in a high-conductivity normal metal matrix. These conductors, which offer excellent stability and low losses under pulsed conditions, have been commercially available in increasingly sophisticated form for the past few years. At present the superconductor is restricted to the ductile alloy Nb-Ti. Various brittle materials classified as A-15 compounds, particularly Nb₃Sn and V₃Ga, have higher critical temperatures, magnetic fields, and current densities but, because of their lack of ductility, are difficult to manufacture in multifilamentary form. However, recent developments at BNL and elsewhere now point to the feasibility of producing filamentary A-15 wires. The low ductility is circumvented by delaying the formation of the superconducting compound until all extrusion and drawing steps have been completed. Billets of pure niobium or vanadium rods embedded in a copper-tin or copper-gallium bronze matrix are drawn down in much the same way as conventional Nb-Ti in a copper billet. After drawing to final size the wire is axially twisted and then heat-treated; during treatment tin or gallium from the bronze matrix diffuses into the core material to form filaments of Nb₃Sn or V₃Ga. One difficulty encountered is that the rapid

work hardening of these bronzes necessitates frequent annealing during the drawing process. In a new process developed at BNL to overcome this problem, niobium or vanadium is first drawn down in a pure copper matrix; this composite wire is coated with a layer of tin or gallium by a dipping technique, and then is heat-treated in several steps to form the bronze matrix and compound, respectively, by diffusion.

A-15 composite samples have been produced with critical current densities comparable with or superior to those of commercial tape conductors. This work, which has clear ramifications for controlled thermal reactor programs and possibly for the projected ISA facility, has now advanced to the point where sufficient Nb_3Sn conductor, in a fully transposed braid configuration, should be available shortly for construction of a 1-m-long model dipole magnet.

The work on superconductors has involved close collaboration with the Department of Applied Science.

ULTRAHIGH VACUUM SYSTEMS FOR STORAGE ACCELERATORS

To achieve and maintain the required circulating current in storage rings, a vacuum system operating in the 10^{-10} Torr range (3×10^6 molecules, cm^3) in the curved quadrants of the rings and 10^{-11} Torr in the experimental regions is required.

The most serious current limitation comes from the beam-induced pressure rise caused by ionized gas molecules being driven electrostatically into the vacuum chamber walls. These liberate adsorbed molecules in a process that can eventually lead to avalanche-like beam destruction. The high desorption coefficients expected from a vacuum chamber operating at liquid helium temperature have indicated the desirability of a room-temperature chamber. This type of vacuum system requires very clean, baked surfaces and high gas conductance and pumping speeds. The present ISA vacuum system design calls for an all-welded aluminum chamber with superinsulation and with pumping provided by a combination of Ti-sublimation and ion-sputter pumps. It is, however, based on several assumptions and extrapolations whose justifications are being scrutinized in experiments intended to yield information on cryosorption, the use of aluminum in high vacuum systems, and gas desorption rates. A commercial molecular sieve is used to measure adsorption and

pumping speeds of helium and hydrogen below 10^{-11} Torr and between 3 and 5 K. These measurements are also made in the presence of an AOS external beam. Spectrometric studies of outgassing in potential vacuum chamber materials are conducted as a function of surface preparation, including polishing, bake-out, outgassing, and cleaning.

An experiment is in progress in which ionized molecules from an isotope separator are used to bombard surfaces subjected to various treatments and the resulting gas desorption is measured by a rapid scanning mass spectrometer.

UNDERGROUND POWER TRANSMISSION BY SUPERCONDUCTING CABLES

Initial funding from the National Science Foundation for this project commenced in 1972. Additional funds were made available the following year from the newly created Division of Applied Technology within the Atomic Energy Commission, although the major portion of the support through 1974 has continued to come from the National Science Foundation.

The approach taken is to apply superconducting technology to an extension of the conventional high-pressure oil-filled (HPOF) practice, in the form of flexible superconducting cables pulled through a thermally insulated low-temperature envelope, with helium gas replacing the oil. Because of the high cost of conversion equipment, direct current cables have advantages only over long distances. It appears that the initial superconducting application will be to alternating current systems for relatively short runs and where cables are required to be underground, with the load exceeding the conventional capability.

Primary emphasis has been placed on developing a conductor with acceptable losses at power frequencies. Previous work has shown that niobium conductors have low losses, although their low critical temperature results in poor efficiency. The BNL design favors a flexible coaxial cable of Nb_3Sn tape because of its superior critical temperature and critical current density. The very high losses observed in many commercial samples of Nb_3Sn now appear to be due to losses arising in the solder and cladding used in manufacturing these tapes, which mask the intrinsic superconductor loss. Once these effects are removed and certain conditions are imposed on grain size and surface quality, the losses in Nb_3Sn can be reduced sub-

stantially. A method has been developed for producing a conductor exhibiting losses lower than those associated with the best commercially available tapes. At present there is some sacrifice in current-carrying capacity. The theory of losses, based on simple models, has been extended to include temperature dependence and is in good agreement with measurements.

An extensive program is under way to investigate mechanical and electrical properties of various insulating tape materials at low temperatures. A high-voltage test facility is also available. Of all the components in a superconducting transmission line the cryostat appears to be much the most expensive. Studies have been carried out of several suitable flexible Dewars, with the aid of a supercritical helium refrigerator, and of conceptual large-capacity refrigeration systems. In this connection a subcontract has been awarded to the National Bureau of Standards for studying modes of instability in supercritical helium.

A complete systems engineering analysis has been carried out jointly by BNL and the Long Island Lighting Company. A cost analysis of a 65-km, 4800-MVA transmission circuit for LILCO appears encouraging. It indicates that superconducting designs are significantly less expensive than a conventional HPOF underground system and, in the best case, are only a factor of two more expensive than a 345-kV overhead system. Longer (15-m) model cryostats and cables are in preparation, with the final goal an 800-m-long three-phase cable incorporated in the power feeder system at the Laboratory.

RF SUPERCONDUCTING CAVITIES

This program is directed at developing superconducting microwave cavities that have low surface losses and are capable of sustaining high

magnetic and electric fields. Superconducting cavities are essential to the construction of long-pulse rf beam separators in electronic-counter physics experiments; they could be used in linear accelerators and have a number of other applications in telecommunication systems or measuring equipment. Superconducting cavities derive their advantage from their high quality factors, or low surface losses, which are better by a factor of five than those of room-temperature copper cavities. The full potential of superconducting cavities can be realized only through specialized fabrication techniques and careful surface treatments, and much effort has been spent on developing these techniques.

The techniques developed at BNL have been applied to the construction of a model of an X-band (8.7 GHz) deflecting cavity for the Fermi National Accelerator Laboratory (FNAL). The results of tests performed on this model cavity were encouraging and indicated that deflecting fields of up to 7 MV/m are obtainable. This work has been used as the basis for a realistic design study of a separated beam at FNAL in the 100-GeV/ c momentum region.

Studies are in progress on the nature of the peak field limitations and methods to increase the obtainable field levels. A coaxial cavity with the center conductor designed as a removable sample has been constructed for evaluation of metallurgical factors influencing breakdown fields. The roles of solute oxygen and nitrogen in premature breakdown and residual losses have also been investigated by exposing several niobium cavities to these gases, at pressures up to 10^{-5} Torr, during high-temperature heat treatments. It was found that oxygen exposure increases the residual losses and, in high bulk concentration, reduces the breakdown field substantially.

* * * * *

REACTOR DIVISION

Among the Laboratory's major facilities are the High Flux Beam Reactor, designed to make available large quantities of slow neutrons, and the Brookhaven Medical Research Reactor, which is particularly useful for irradiating large animals. In this section the operation of these reactors, the

operational difficulties encountered, and the improvements made are discussed. The research and experimentation done by the scientific departments is described in the appropriate sections of this report.

HIGH FLUX BEAM REACTOR

The High Flux Beam Reactor (HFBR) was operated routinely during the past two years with a

minimum of unscheduled reactor shutdowns. Repairs to the primary system pipes, discussed in the previous report, were completed early in the period. In July 1973 the HFBR experienced its most extended period of unscheduled downtime, 7 days and 15 hr, when two bars of the anticritical grid broke. Previously, in February 1973, the reactor had been shut down for 2½ days for investigation of reactivity effects and unexpected boiling in an irradiation thimble. In January 1974, five days were required to grind the galled walls of the H-9 shutter cavity, a strictly mechanical operation in a high radiation field. The failure of a thermocouple well caused a delay of 2½ days in April 1974. The remainder of the unscheduled

delays ranged from 18 min to 2¾ hr on five occasions.

For economic considerations, scheduled shutdowns took place during certain holiday periods involving long weekends and for a single extended period during August 1973. The operating and shutdown times of the HFBR are summarized below.

Operation at full power, % of total time	73.6
Unscheduled downtime, hr	493
Scheduled downtime for economic reasons, hr	1883

A total of 280 fuel elements were charged into the reactor to provide fuel for 18 operating cycles. The experience with fuel elements continues to be

Table 1

Distribution of HFBR Support From Scientific Programs

	Use charges, fiscal 1974		Use charges, fiscal 1973	
	Amount, \$	% of usage	Amount, \$	% of usage
Physics Department				
Neutron Physics	357,480	27	364,800	30
Solid State Physics	476,640	36	437,760	36
Biology Department				
Biological Research	158,880	12	109,440	9
Chemistry Department				
Nuclear, Structural, and Inorganic Chemistry	331,000	25	304,000	25
Total	1,324,000	100	1,216,000	100

Table 2
Irradiations

	HFBR, Fiscal		BMRR, Fiscal	
	1974	1973	1974	1973
BROOKHAVEN				
Accelerator Department	-	-	9	1
Department of Applied Science	20	21	42	86
Biology Department	-	-	8	-
Chemistry Department	132	177	56	115
Health Physics and Safety Division	-	-	18	16
Instrumentation Division	1	-	1	2
Medical Department	13	19	47	64
Physics Department	8	13	36	20
Reactor Division	4	7	10	4
HFBR material surveillance program	22	24	-	-
OUTSIDE ORGANIZATIONS	40	39	27	21
Total	240	300	254	329

excellent. A total of 18 spent fuel shipments comprising 252 fuel elements were completed on schedule and without incident and were sent to the AEC's Savannah River Plant for reprocessing. Plans are under way to modify the shipping casks in compliance with the more stringent shipping regulations issued recently by various government agencies.

The tritium concentration of the primary cooling heavy water system has increased from ≈ 3 to 4 Ci/liter during this period because of neutron interaction with the deuterium. To keep possible tritium releases at as low a level as practical, plans have been formulated and approved for a program of annual D_2O replacement that will result in an average tritium concentration of ≈ 1.4 Ci/liter.

As part of the continuing material surveillance program, in February 1974, after five full-power years of reactor operation, one main control-rod blade was discharged from the reactor and replaced with a spare. Following an extended period of decay, this highly radioactive rod will be metallurgically examined.

TECHNICAL SPECIFICATIONS

The Reactor Division prepared a document, High Flux Beam Reactor Technical Specifications, dated December 1973, which has been ap-

proved by the AEC. These technical specifications supersede the previous AEC operating limits and define in detail the boundaries for safe operation of the reactor.

REACTOR IMPROVEMENTS

A study of the HFBR plant protection system (PPS) was made in accordance with RDT Standard C16-1T, Supplementary Criteria and Requirements for RDT Reactor Plant Protection Systems. Although the study revealed no serious deficiencies, it uncovered a number of areas in which modifications would result in increased levels of confidence. Modifications initiated to improve the plant protection systems are outlined below.

1. Analyze and improve PPS wiring (in progress).
2. Improve syphon break valve monitoring for position and helium supply (completed).
3. Isolate PPS and non-PPS systems power (modification review in progress).
4. Separate primary cover gas pressure control from cover gas pressure safety channel (completed).
5. Modify manual trip No. 1 to provide additional method for breaking rod clutch current (completed).
6. Replace core inlet temperature channels to improve readout and trip point accuracy (completed).
7. Revise setback system to provide manual reset of core inlet temperature and fuel cladding failure systems (completed).
8. Modify primary flow scram channels to monitor pump motor current (completed).
9. Replace two core ΔP channels with improved detectors and readout equipment (completed).

OPERATING SUPPORT

Except for minor income from service irradiations for external organizations, the support of the reactor is derived from the scientific departments. Table 1 indicates the source and distribution of these funds, which are adjusted to meet the direct operating costs of the reactor. An increase in the cost of electrical power was a major factor in increasing costs in the past six months and is expected to be a significant problem in the future.

BROOKHAVEN MEDICAL RESEARCH REACTOR

The Brookhaven Medical Research Reactor (BMRR) continues to be run on a demand basis

for short periods each week. During the period, 396 start-ups were completed on 217 operating days and 919.99 MWh of energy were accumulated. The total energy accumulated since initial start-up is 9808.777 MWh.

No significant changes were made in the reactor during the past two years.

This reactor continues to be a convenient and inexpensive source of sample irradiations wherever fluxes in the range of 10^{13} or less are required for short periods of time. Table 2 summarizes the irradiations made in 1973 and 1974 at both the HFBR and the BMRR for Brookhaven departments and outside organizations.

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TANDEM VAN DE GRAAFF FACILITY

The central questions of nuclear physics put strict requirements on the experimental facilities that serve it. Not only must intense particle beams of many species of nuclei be produced, but they must be produced with excellent energy definition and with a capability for easy and quick changes in both beam species and energy. Such range and versatility requirements are met by electrostatic machines known as Tandem Van de Graaff accelerators.

Brookhaven's Tandem Van de Graaff Facility is built around two of the largest such accelerators yet put into operation, the so-called Emperor or MP machines. They are aligned, as shown in Figure 1, so that nuclei accelerated by the first machine can be injected into the second for further acceleration to much higher energies. In this way the species and energy variability and the energy resolution are retained, while the energy range is

Figure 1. General view of the 300-ft-long accelerator room from the high-energy end of the second accelerator, MP-7 (foreground). The first accelerator, MP-6 (distant background), is installed in line with the second so that particles can be injected into the second machine from the first in a three-stage mode of operation. The cage-like structure between the two accelerators contains ion

sources and power supplies that are used for two-stage operation of MP-7. The large pressure vessel is filled with a mixture of N_2 , CO_2 , and SF_6 at 225 psi, or 15 atmospheres, to provide suitable insulation for voltages inside the machine as high as 12 MV. The steel walls in the central portion of the machine are 2 in. thick.

Figure 2. View from inside the high-energy end of the accelerator, looking toward the high-voltage terminal, which operates at voltages as high as 12 MV. Under inspection are the parallel bar region (rear), which is the actual high-voltage terminal region, and the circular ring section, the region of the support column that contains the accelerator tubes inside the ring structure. The entire column structure, 80 ft long, is supported from both ends of the machine; support in the central region is impossible because the only known material that can withstand the 12 MV in the terminal region is the high-pressure insulating gas used inside the machine when it is in operation.

Figure 3. View similar to that of Figure 2, but photographed outside the accelerator pressure vessel through a high-pressure window during operation. Because of a malfunction, the high voltage is not under control but is breaking down to the outer walls of the pressure vessel through the high-pressure insulating gas, as evidenced by the lightning bolts. These high-voltage discharges consist of short current pulses in the million-ampere range which can cause various kinds of damage to the internal components of the accelerator.

greatly extended. When the highest energies are not required the two machines can be operated independently so that two experiments can go on simultaneously.

Since completion of the facility in 1970, a many-faceted research program based on these capabilities has been developed. The laboratory is operated as a user facility and outside users have equal shares of the available research time. In order to match the increasing requirements of the combined inside- and outside-research programs, the accelerators themselves, the auxiliary facilities, and the operations are constantly undergoing improvement.

One of the most obvious needs is that of increasing the electrostatic potential or voltage on the high-voltage terminals of the accelerators. Higher voltage will directly increase the energy of accelerated nuclei or ions. To undergo a nuclear reaction with a target nucleus, an accelerated particle must have sufficient energy to penetrate the repulsive Coulomb interaction, which is higher for heavier nuclear species. Consequently, extending the voltage capability of the accelerators extends the range of nuclear species that can be studied.

The insulated ring structure inside the accelerator pressure vessel, shown in Figure 2, encloses the main insulated support structure and the acceleration tubes, which are the heart of the machines. Figure 3 is a similar view, showing several typical lightning-bolt discharges inside the machine. The acceleration tubes provide the vacuum housing in which the beams move, uniformly distribute the millions of volts between the high-voltage terminal and ground, and withstand the voltage breakdowns and surges. The energy dissipated in the high-voltage discharges (Figure 3) gradually results in glass insulator failure in the acceleration tubes.

The acceleration tubes first provided by the manufacturer did not permit reliable operation much above 9 MV after two years of operation. At this time the manufacturer developed a new design of acceleration tube comparable in physical size to the original set, but with a differently configured internal structure and metal parts of stainless steel instead of aluminum. These new tubes, along with improvements in other components and in insulating gas characteristics, formed a so-called upgrade kit that was guaranteed to provide reliable operation of the accelerator at 13 MV. Unfortunately, funds for these new tubes were not available.

To meet the research requirement of reliable operation above 10 MV at a cost considerably lower than that of the upgrade kit, an ingenious solution was devised. A much smaller research tandem accelerator, called an EN tandem, uses a stainless steel acceleration tube only 8 in. in diameter, in contrast to the 13-in.-diam aluminum tubes used in the MP machines at Brookhaven. These smaller tubes seem to have the internal structure to satisfy most of the operating characteristics of the larger tubes offered in the upgrade kit. Their cost is only about half that of the larger tubes, and discussions with the manufacturer indicated that they could be used in place of the larger ones; however, performance guaranties would not be comparable with those offered with the large tubes. The internal structures of the upgrade kit tubes and the alternative EN tubes were examined. After computer analysis of how these internal structures suppress electrons and perturb the beam particles as they are accelerated through the tubes, an improved arrangement of the internal electrodes was specified for the design of the new, smaller tubes for the Brookhaven accelerator.

Figure 4. Three-stage dual stripper operation of the Tandem Van de Graaff Facility.

These new tubes have provided reliable operation above 10 MV and, in fact, an appreciable amount of operation at voltages as high as 12 MV. They are currently being operated at about 11.5 MV. In principle, the smaller tubes should allow as high an operating voltage as the larger tubes; however, comparable performance has not been obtained because of the insulator damage that develops inside the smaller tube. The "ideal" tube has not yet been found, but these new small tubes have kept the BNL research program at the forefront.

The energy gained by an ion under acceleration is increased if its net charge is increased; this means that it is desirable to strip away more electrons. This is especially true for heavy ions, which form the greatest part of Brookhaven's nuclear physics research program. Therefore, to enlarge the heavy ion capability an additional foil-stripper system was designed and installed downstream from the stripper system in the high-voltage terminal.

Figure 4 is a diagram showing how the negative ions of ^{32}S are accelerated into the high-voltage terminal, where they are stripped to a moderately high charge state such as 8^+ or 9^+ and then are accelerated out of the high-energy terminal of the machine. Further on in the accelerator, the sulfur ions encounter a second foil stripper. At this point the ions have increased in energy to about 25 or 30 MeV, and because of their higher velocity are stripped to higher charge states such as 13^+ or 14^+ . Ions with higher charge states can then take better

advantage of the remaining voltage difference and consequently reach higher energies than would otherwise be possible. This additional stripper has proved very effective and is now part of the routine operation of the facility. It provides ≈ 10 MeV more energy for a given current or intensity of particles from the machine, or, at a given energy, 10 times as high an intensity of particles. In practice, the effect of the second stripper is to increase the performance of the machine as though the high-voltage terminal had been increased in voltage by 1 to 2 MV, equivalent to the effect of using a new kind of upgraded acceleration tube.

A major factor in providing more species of heavy ion beams more easily was the installation in September 1973 of a commercial version of a new cesium sputter-ion source invented by Professor Roy Middleton at the University of Pennsylvania. The present performance of this ion source has completely changed the capability and perspective of the heavy ion research program at the facility. To date, more than 30 different elements have been accelerated through the machine for research and calibration purposes. In most cases, the species of ion can be changed in a few minutes, in contrast to the many hours required with other kinds of ion sources, and in many cases negative ions of many different atomic species that cannot be practically made by the older ion sources are routinely provided.

Some of the research performed with this facility is described in the Physics Department section of this report.

RESEARCH

HIGHLIGHTS

APPLIED MATHEMATICS DEPARTMENT

The overall research program at Brookhaven National Laboratory embraces a broad spectrum of activities with varied mathematical and computational requirements; hence the environment at BNL is well suited to research in mathematics and computer science. Furthermore, because of the close relationship between these and other scientific disciplines, the work done has an impact on many other research activities. Thus, while the research in mathematics and computer science is directed toward the advancement of these two fields, it is also concerned with the needs of scientific research in general.

MATHEMATICAL SCIENCE RESEARCH

The main thrust of the mathematical science research is the development of mathematical approaches, methods, and techniques for the analysis, formulation, and solution of problems arising in scientific fields. Particular attention is given to the development of mathematical methods for the application of advanced computing systems to the solution of such problems. Aspects of many areas of mathematics are involved and the work bears on a broad spectrum of scientific research. Examples of the research done are given below.

RECONSTRUCTION OF THREE-DIMENSIONAL STRUCTURES FROM THEIR PROJECTIONS

In many areas of experimental science, the available data on the internal density distribution of an object in three-dimensional space consist of a limited number of two-dimensional projected images of the structure. The problem of obtaining a best estimate of the original density function from these projections, particularly in the presence of errors or noise, is a highly nontrivial one that touches on several areas of applied mathematics. During the past decade there have been numerous independent efforts to develop effective and computationally efficient algorithms for solving this problem in such diverse fields as nuclear medicine, x-ray photography, electron microscopy, holographic interferometry, radio astronomy, and plasma physics.

Mathematically, the topic is closely related to a classical result of J. Radon, who in 1917 first posed and solved the problem of determining a function on Euclidean space from its integrals over certain hyperplanes. This result was used as the starting point of some earlier work at BNL on the development of an optimal scheme for processing data from the BNL positron scanner. In a natural extension of this work, the reconstruction problem was recast in general terms as an interpolation, or sampling problem, for the Radon transform of a function in n -dimensional space. With use of polynomial approximants, this problem was solved in principle for a wide class of possible situations. An elementary sampling theorem for the Radon transform was derived which states that the restriction of any polynomial of degree M to an arbitrary fixed compact domain can be recovered from any N of its independent projections if, and only if, $M \leq N - 1$. The problem of noise propagation can also be treated in this framework and analyzed in terms of the eigenvalue spectrum for a certain self-adjoint operator, $R_X^* R_X$, where R_X is the projection mapping and R_X^* is its adjoint with respect to an inner product based on the correlation matrix of the noise present in the data. Finally, certain well-known iterative algorithms for reconstruction, developed elsewhere, were examined and shown to be essentially equivalent to special cases of standard iterative schemes for matrix inversion.

Because of the diversity of the fields in which the reconstruction problem arises and of the journals in which results have been published, consid-

erable duplication of effort has occurred. Some degree of unification across disciplinary lines therefore seemed desirable, and to this end the BNL Applied Mathematics Department, with support from a National Science Foundation grant, has organized an international interdisciplinary workshop that in July 1974 will bring together some fifty leading researchers with a common interest in the topic.

PADÉ APPROXIMANTS

The Padé approximant method is a procedure for approximate analytic continuation of a function from the knowledge of a finite number of the Taylor series coefficients. Substantial progress has been made in the convergence theory for this method. A general theorem has been proved that gives necessary and sufficient conditions on the distribution of the poles and zeros of a sequence of Padé approximants to ensure convergence. Previously there were two unanswered general questions about the convergence of diagonal sequences of Padé approximants. First, what are the necessary

and sufficient conditions on a general sequence of Padé approximants to ensure point-by-point convergence as distinguished from convergence in measure, which has been previously treated? Second, do such sequences exist? Our theorem answers the first question; the second remains. As a special case the famous disk problem was treated. Here one is given a function meromorphic in the unit disk and a sequence of Padé approximants that are free of extraneous poles or zeros. The problem is to prove that the Padé approximants converge. Over the past eight years the region of proved convergence has grown from $|z| < 0.3$ through $(\sqrt{2}-1)$ to $1/\sqrt{3}$ and now, with our result, to $|z| < 1$. The relationship of the Padé approximation to the solution of linear functional equations of the Fredholm type has also been investigated. It has been found, in very general circumstances, that if the kernel is projected into the Cini-Fubini subspaces, the inner product of the solution of this truncated problem with a fixed vector is a Padé approximant to the function given by the inner product of this same vector with the solution of the untruncated equation. With certain small restrictions we prove that at least a subsequence of Padé approximants converges if the kernel is compact. With additional restrictions, including a trace-class kernel, we prove that the numerator and denominator of the Padé approximants separately converge. We apply these general results to prove convergence of Padé approximants to a wide class of meromorphic functions. We also prove the convergence, for decent potentials, of Padé approximants to the scattering amplitudes for nonrelativistic quantum mechanical scattering.

WAVE PROPAGATION IN A WAVE GUIDE

The study of wave propagation in a wave guide with discontinuities is important in many branches of physics, such as microwave physics and acoustics. Furthermore, this problem is fundamental in the design of accelerators and microwave circuits. In research conducted at Brookhaven the effect of various kinds of wave-guide discontinuities on relevant physical quantities was examined.

Many mathematical results of a qualitative nature were obtained concerning the wave and scattering operators and the S matrix. In particular, results previously obtained here on the unitarity and meromorphic continuation of the S matrix, as well as the properties of its poles, were general-

Figure 1. Plot of the Padé approximants computed from the first few terms of the perturbation series expansion and, for comparison, the partial sums of the perturbation series. In this example, the range of convergence has been extended from $0 < x < 0.5$ to $0 < x < \infty$, and the rate increased.

ized and extended to a larger class of wave-guide discontinuities. In addition, quantitative results were obtained, in collaboration with the Accelerator Department, relevant to Brookhaven's rf particle separator. An algorithm was developed and a program written for computing dispersion curves. The results were in close agreement with experiments conducted at Brookhaven. Furthermore, the method is readily adaptable to more complicated physical structures. Such an extension of the method is now under way.

STATISTICAL MECHANICS PHASE TRANSITIONS

A mathematical investigation was made of physical systems and models of physical systems in which a large number of degrees of freedom play an essential role. It is this feature that makes these problems so challenging. Until fairly recently there has been no generally reliable way of reducing the complexity of this type of problem to a few variables, nor have efforts to develop closed form solutions been successful, except in a few special cases. Only within the last couple of years has significant analytic progress been made in developing techniques to reduce the mathematics to tractable form. The physical systems to which this work is germane include magnets, liquids and gases, and various order-disorder models. Experimentally these systems are studied adequately by neutron-scattering techniques. An important recent development is the investigation of the idea of defining on the space of Hamiltonians for spin systems, operations that have fixed point solutions. The thermodynamic behavior of the solution is to be the same as that of the original Hamiltonian being treated. This approach, called the renormalization group method, leads after several approximations to a nonlinear integral recursion relation for the spin $\frac{1}{2}$ Ising model in a space of D dimensions. A Brookhaven contribution has been to show that these approximations are exactly satisfied for a nontranslationally invariant Ising model – a spin ∞ Ising model with a hierarchy of spin groupings for which the interaction potential satisfies exactly the scaling hypothesis that group-group interactions involve only mean group spin. The calculation of the important critical exponents for this model has been done exactly. The spin-spin correlation function has been investigated, and the results obtained for systems of large but finite size show clearly the interplay between the Bragg-Williams type of classical behavior found to occur

for dimension >4 and the mode of behavior characteristic of the famous Onsager solution to the two-dimensional Ising model.

COMPUTER SCIENCE RESEARCH

Computer science research at Brookhaven is concerned with the most efficient and effective use of computers and hierarchies of computers. Prime goals are the development of concepts, approaches, techniques, methods, and procedures applicable to the translation of advanced problems into a form usable by computers, sharing of computer resources, and greater exchangeability of computer programs. Particular emphasis is placed on high-capacity computer networks and the human-to-computer interface. The development of advanced software that is not being developed by industry, new computer applications, and improved communications is also a continuing concern.

A significant part of the research has been the development of the concept of the "closely coupled" computer complex, in which many computers are integrated into a single system but retain a clearly defined separateness that makes possible more complex relationships between computers than is feasible with the network concept. Examples of the work in this and other areas in computer science are given below.

DYNAMIC SHARING OF MASS STORAGE

A major feature of the Brookhaven "close coupling" concept is the ability to dynamically share mass storage devices. The technique developed to allow such sharing in full generality with minimum overhead involves breaking each storage device into a number of individually allocated units. The master copy of the unit allocation map is kept on the storage device itself. The key to efficient access is then developing a hierarchical series of pools of allocation units in each computer in more and more readily accessible locations. A set of three such pools in each machine has been determined to be sufficient. The highest level is the map recorded on the device. The next level is a large pool held in central memory and managed by a module that controls the size of this pool by moving allocation units both upward and downward in the hierarchy. The third and lowest pool in the hierarchy is directly accessed by the modules responsible for disk input-output. In a normal production environment, overhead was so low as to be diffi-

cult to measure, typically ranging from 1 to 2% degradation.

INTERMACHINE COMMUNICATION

Another component of close coupling of computers is the nature of the communications between them. Work in this area resulted in the design and implementation of a generalized computer-to-computer communication facility. This facility provides for load balancing between two computers and access to catalog files resident on nonshared devices. It has also been used to control the routing of jobs requiring special facilities present on only one machine. Thus a computer user can regard the entire complex of computers as a single entity. Even if he uses specialized facilities actually present on only one computer, he can submit his job without regard to the computer system being used for job input. The load balancing facilities have reduced by $\approx 38\%$ the mean turn-around time for jobs run.

CATALOG FILING SYSTEM

A third component of close coupling is a filing system that is equally accessible from all computers in the complex but does not depend for its operation on the functioning of any one computer. Such a system was developed with use of the facilities for dynamic sharing of mass storage. However, since the amount of data to be stored in such a system greatly exceeds the available mass storage, another design criterion was the ability to use private mass storage as well as magnetic tape as extensions of the total storage facility. The system developed uses a single master catalog (which resides on shared mass storage) and also uses the shared mass storage as the preferred storage device for these files. This results in negligible overhead for access to files held on shared mass storage devices. The use of magnetic tape as an integral part of this system allows the creation of tape images of these files and their automatic loading to mass storage if they are not currently resident; this requires no special action by the user. An important aspect of this work is the development of algorithms for file migration and tape imaging. For example, whenever a particular type of disk (e.g., removable pack, private device, shared device) has little or no storage free, then files that have an existing tape image but have not been recently referenced are evicted from the disk storage to make more storage available. Upon the next attachment of

these files they are automatically reloaded to mass storage before use. If files resident on a private device on one computer are accessed from another computer, they are transmitted via the intermachine communication facilities to the requesting computer.

DIGITAL DESIGN AUTOMATION

Work in design automation produced computer codes capable of generating, analyzing, and documenting digital circuit designs with minimal computer intervention. The system is centered around a circuit description data base formulated in a special language called *MODEL*. A synthesis task generates *MODEL* circuit descriptions from another language, called *LIXDA*, which specifies behavior. Output may consist of a circuit description, a set of oscillograph traces, and/or a logic diagram, depending on the specific problem and the tasks invoked.

Generalizations of these automated design techniques to the areas of software, linear systems, and beyond are being developed with use of the formalism and theoretical basis of categorical algebra.

DIGITAL COMMUNICATIONS NETWORK — Brooknet

The fourth phase of development of *BROOKNET* was completed. The *BROOKNET* system already had data rates 100 times as great as those of any commercially available communication system. However, Brookhaven's projected research requirements require even higher sustained data transmission rates, exceeding those available from mass storage devices on large-scale computer systems. A technique was devised and implemented to allow direct transmission of data from an executing program in one computing system to an executing program in another. This scheme allows sustained data rates close to the burst data rate capacity of *BROOKNET*, which is 12 million bits/sec. The scheme has already been put to use in support of the flying image digitizer in the bubble-chamber research program.

CENTRAL SCIENTIFIC COMPUTING FACILITY

The Central Scientific Computing Facility (CSCF) of the Laboratory is operated by the Applied Mathematics Department and is housed in a specially designed computer wing. The facility provides large-scale, general-purpose computational support to the Laboratory's research pro-

Figure 2. The Central Scientific Computing Facility, early in 1974.

gram and performs the bulk of BNL's scientific data processing. Universities and other outside organizations engaged in federally supported research also utilize the CSCF.

CURRENT HARDWARE CONFIGURATION

The CSCF is currently equipped with two Control Data Corporation (CDC) 6600 computers, which share a million words of extended core storage, and a CDC 3200 computer. The CDC 6600's provide general-purpose batch processing, and the CDC 3200 is used in an interactive file manipulation and remote job entry system called focus, which is accessed from remote keyboard terminals over the dial telephone system. Focus enables users to remotely (a) set up and submit jobs to the 6600's, (b) debug programs on line, (c) enter and permanently store programs and data files for use in 6600 processing, (d) edit and modify permanent files, (e) store input and output files for subsequent processing, and (f) receive results of 6600 processing.

BROOKNET, a 12-million-bit/sec digital communication system, interconnects 17 remote on-site computers to the CDC 6600's. This computer-to-computer digital communications network en-

ables the remotely located satellite computers, which handle data acquisition, graphical display, preprocessing, and other functions, to utilize on line the greater computational capability of the CSCF computers. This system also allows remote computers access to the central data storage system and to the central input-output job queues.

The OX (operator extension) subsystem, using a PDP-8 computer and six Teletypes, automates various operator communication and logging procedures. It allows posting of tape mounting requests in the magnetic tape area and acceptance of tape drive assignments from this area, as well as logging certain error conditions. It also allows user inquiries concerning the status of a job, backlog of work to be done, availability of library routines, etc.

FUTURE HARDWARE SYSTEM

In the fall of 1974, a very large-scale CDC 7600 system will be added to the CSCF configuration. The two CDC 6600's and the CDC 7600 will then be integrated into a system in which the 6600 computers will not only perform independent processing but will handle the input/output oper-

ations for the speedier, more computationally capable CDC 7600. The new equipment is expected to increase the overall throughput capability of the CSCF by at least a factor of 3. With the 7600 will come a new remote batch job entry capability utilizing remote on-site batch processing terminals operating over dedicated lines and the ability to handle this type of terminal over the dial telephone system. Off-site users will then be

able to access the CSCF with such terminals. In addition, on-site and off-site interactive processing via keyboard terminals will be provided over the dial telephone system; the FOCUS system will be phased out when the interactive work load has moved over to the new, more capable interactive system. BROOKNET will be continued as before, and the OX system will be upgraded to include the 7600.

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DEPARTMENT OF APPLIED SCIENCE

The programs of the Department of Applied Science span a wide variety of topics involving applications of science and engineering and having as a common basic goal the identification, understanding, and solution of technical problems of vital concern to man for which the unique facilities of the Laboratory or the special talents of its staff are particularly well suited. Most of the work is multidisciplinary, involving collaboration between groups both within and outside the Department and combining disciplines as disparate as chemistry, medicine, meteorology, and computer science. Most of the problems studied relate to energy and/or the environment, while the remainder are too varied or complex to be categorized simply. Space permits description of only a few representative areas.

ENERGY

The Department's efforts to develop improved sources of energy fall generally into five categories: the production and storage of hydrogen, the development and characterization of superconducting materials, the engineering aspects of fusion reactors, the ultimate storage of radioactive wastes from nuclear reactors, and the evaluation and analysis not only of specific types of reactors but of entire regional and national energy systems.

HYDROGEN UTILIZATION

Devices that can store electric energy are of great interest to the electric utility companies because of the cyclic nature of the electric load that results from variations in the demand for electrical energy with time of day and season of the year.

The need for storage devices will grow as more nuclear reactors are used to generate electricity, since nuclear systems function best at constant load.

The production and storage of hydrogen and its reconversion to electricity during periods of peak demand are being examined. The hydrogen would be produced electrolytically from off-peak electricity and stored as an iron titanium hydride, FeTiH_2 .

Hydrogen can be retrieved from the storage system by adding waste heat, to decompose the hydride. It can be reconverted to electricity in a fuel cell or high-temperature turbine, or used for many direct combustion applications. Hydrogen storage has been proposed for use in a hydrogen-gas-electricity conversion system that would ultimately link electric and gas utilities. An artist's concept of such a system is shown in Figure 1.

The largest hydride bed (or hydrogen reservoir) built thus far is shown in Figure 2. The tubes (foreground) extend into the bed in the shape of a U and carry water for cooling it during hydride formation (charging) or for heating it during hydride decomposition (discharging). An advantage of using FeTiH_2 is that readily available water temperatures can be used, e.g., 16 to 21°C (60 to 70°F) during charging or 38 to 49°C (100 to 120°F) during hydrogen recovery. A nominal discharge rate of hydrogen of 2.5 lb/hr can be achieved with a water flow rate of 5 gal/min. This reservoir (Figure 2) was built for the Public Service Electric and Gas Company of New Jersey for use in a small-scale experimental facility of the type shown in Figure 1.

SUPERCONDUCTING MATERIALS

Applications of superconducting materials to energy conversion and transmission and to high-

Figure 1. Artist's conception of a system to "store" electricity by storing hydrogen. Electricity is used in the electrolyzers to produce hydrogen, which is stored in the hydride beds and reconverted to electricity in the fuel cells.

Figure 2. Compact hydrogen reservoir. The hydride bed (horizontal cylinder in center) can store 13 lb of hydrogen, an amount equivalent to that in the 13 high-pressure cylinders flanking the reservoir. The 6.5-ft-long vessel is made from 12-in. pipe and contains 894 lb of granular FeTiH_2 , retained by a group of porous-metal filter tubes connected to the gas line at the far end of the vessel.

energy particle accelerators are being seriously considered. Prototypes of magnets using niobium-titanium (Nb-Ti) alloys have been successfully made, and pure niobium has been used in a prototype transmission line. However, realization of the full potential of superconducting materials in these applications appears to depend on the successful development of conductors such as niobium-tin (Nb_3Sn) and vanadium-gallium (V_3Ga) compounds, which have critical properties superior to those of Nb or Nb-Ti. Unfortunately, these superconductors are brittle and difficult to prepare in a useful form.

By a processing method recently developed in collaboration with the Accelerator Department, these brittle compounds can be formed into tapes and fine multifilamentary composites with filaments only a few micrometers in diameter; several hundred of them constitute a 0.25-mm wire composite. This process takes advantage of the fact that a compound such as Nb_3Sn can be formed at the interface between Nb and a copper-tin alloy. Thus a composite consisting of Nb in a Cu-Sn alloy matrix can be cold-worked into a desired conductor configuration before heat-treating to form the brittle compound.

Notable recent developments include the successful fabrication of Nb_3Sn multifilamentary composite conductors capable of carrying extremely high current densities (J_c) and of Nb_3Sn composite tapes having extremely low losses at 60 Hz, the frequency usually used in ac power transmission. J_c is the maximum current density that a superconductor can carry without detectable resistivity, and the measured value of J_c for the most recently prepared wire was $\approx 2 \times 10^6$ A/cm² (at 40 kG applied magnetic field), twice that of any commercial superconductor. This increase in J_c means that a given magnetic field can be produced with less superconducting material and at lower cost. Moreover, since the ac loss of a superconductor is one of the most important properties determining the feasibility of using the material in ac power transmission lines, it now seems reasonable to assume that an economical superconducting transmission line can be made with a low-loss material such as the Nb_3Sn composite tape.

A possible energy source for the future is the controlled thermonuclear reactor (CTR), in which high-energy neutrons are generated in the fusion reaction. Because of the high operating temperatures of this reaction the reacting plasma must be contained by very strong magnetic fields. In most

CTR designs these fields will be produced by superconducting magnets surrounding the plasma. The magnets will be subjected to a radiation environment, and the effects of this environment on the superconducting properties of the magnet material must be determined.

Nb_3Sn , Nb_3Ga , Nb_3Al , and V_3Ga , the superconducting materials most commonly used for producing very high magnetic fields (100 to 150 kG), have the A-15 type of crystal structure. To determine the effects of high-energy neutrons on their superconducting properties, these materials have been subjected to high-energy ($E > 1$ MeV) neutron fluences up to 5×10^{19} n/cm².

In all cases studied, irradiation greatly depresses the critical* temperature, T_c , critical fields, H_c , and critical currents, I_c . T_c is reduced by as much as 85% of the unirradiated values, and drastic reductions in H_c and I_c are also observed for high exposures. The superconducting properties may be restored by annealing at elevated temperatures (750°C) for various periods of time.

These large depressions in superconducting properties are produced by the disorder induced in the crystal lattice through atomic displacement collisions caused by the incident high-energy neutrons. This disorder causes rearrangement of the atoms in the unit cell, which weakens the superconducting mechanisms.

By measuring the positions of the atoms in the unit cell, one can determine quantitatively how this disorder is correlated with the superconductivity of these materials. In fact, neutron-induced disorder has proved to be a powerful tool in studying the origins of superconductivity in the technologically important materials.

The data generated in this research will be useful to the designers of the CTR magnets that will contain the plasma. Knowing the exposures that cause serious damage, the designers will be able to incorporate sufficient neutron shielding to prevent excessive irradiation.

The work on superconductivity is a close collaboration of the Physics and Accelerator Departments and the Department of Applied Science.

FUSION REACTOR TECHNOLOGY

Favorable results in recent plasma physics experiments have led to a greatly accelerated pro-

*The "critical" parameters (temperature, magnetic field, and current) represent limits that cannot be exceeded without having the material "go normal" and lose its superconductivity.

gram in fusion reactor technology in the United States, and the timetable for fusion power includes operation of several large experimental power reactors in the 1980's. A key component of a fusion reactor will be the blanket in which the kinetic energy of 14-MeV neutrons from deuterium-tritium (D-T) reactions is converted to heat and tritium is regenerated by neutron reactions with lithium. The heat is removed by a fluid and used to generate electricity by some type of power conversion cycle, while the regenerated tritium is removed and cycled to the plasma to replace that consumed in the D-T reactions.

Brookhaven has developed a new type of fusion reactor blanket with several important advantages over previous concepts. First, the lithium in the blanket is present as a solid, high-temperature compound (LiAl , LiAlO_2 , etc.), instead of liquid lithium metal or salts; second, all components of the blanket are made from material with practically zero residual radioactivity. The structural material, for example, is a high-temperature aluminum alloy. This concept eliminates corrosion problems associated with liquid lithium and allows the use of proved high-temperature gas-cooled reactor technology. Further, residual radioactivity in the blanket can be reduced to ≈ 1000 Ci in a 1000 MW(e) reactor (about one-millionth of the activity in previous fusion reactor designs and an even smaller fraction of the activity in fission reactors). In this way waste-disposal problems are virtually eliminated and hazards and maintenance problems are greatly reduced.

Experiments at Brookhaven have demonstrated that tritium can be easily extracted from the solid lithium compound by diffusion into the blanket coolant (helium) stream, from which it can be recovered by trapping. For example, granular LiAl was irradiated with thermal neutrons to produce trace amounts of tritium ($\approx 5 \mu\text{Ci/g}$) uniformly distributed throughout the sample. The material was then exposed to flowing helium at a controlled temperature in the range 400 to 650°C, and the tritium activity in the downstream gas was constantly monitored to determine the fraction of total tritium removed as a function of time.

Fusion energy is virtually inexhaustible and unlimited in amount, barring thermal pollution restrictions. To date, it has been considered primarily for electrical generation. However, Brookhaven studies of the energy economy indicate that fusion reactors, by providing as much as 2.1 million

MW(t) and utilizing only air and water, can meet virtually all U.S. energy needs after 2000 A.D. by producing synthetic fuels such as gaseous or liquid hydrogen and methanol at costs competitive with those of fossil and fossil-derived fuels and thus eliminate the need for fossil fuel. Other materials such as ammonia, cement, iron, and aluminum could be manufactured by fusion power, with less impact on the environment than at present. Synthetic fuel production results in economies of scale through larger fusion reactor unit ratings [e.g., 10,000 instead of 1000 MW(e) for electricity production] and greatly simplifies the plasma physics aspects of fusion reactors through better plasma confinement, reduced sensitivity to plasma impurities, lower magnetic field requirements, etc.

STORAGE OF RADIOACTIVE WASTES

The estimated rapid growth of commercial nuclear power plants will impose a serious problem on radioactive waste management. The ultimate storage of high- and intermediate-level radioactive wastes from the reprocessing of fuel from various types of reactors will become increasingly complex. Protection of the environment requires control of these wastes to prevent any significant quantity from entering the biosphere.

The fixation of existing aqueous and solid radioactive wastes by incorporation into concrete or concrete-polymer composites to form monolithic blocks is being studied. Primary emphasis has been on the immobilization of aqueous 25-yr-old sodium nitrate waste. Such waste containing as much as 70 wt % NaNO_3 has been mixed with cement and the resulting solid impregnated with polystyrene. These composites have increased strength and durability and decreased leachability as compared with currently used waste forms. They can withstand ^{60}Co gamma radiation doses of 10^{10} rads without noticeable chemical or physical effects. The solidification of other waste forms such as dry nitrate waste, solid calcined waste, and reactor and laboratory wastes is also being investigated. Cooperative programs are under way with the AEC's Savannah River Laboratory and Allied-Gulf Nuclear Services for applications to their specific waste problems.

Techniques for fixation of tritiated water in stable solid forms are also being investigated. In one method, tritiated water is combined stoichiometrically with silicates and aluminates in hydraulic cement to form hydrates, and the resulting

solid is impregnated with a monomer that is subsequently polymerized in place to seal the open pore structure and thus reduce the leachability of tritium. In another technique, tritiated water is reacted with calcium carbide to form gaseous tritiated acetylene, which can be polymerized by radiation or chemical catalysts to form cuprene, an insoluble solid material that is thermally stable to 325°C.

EVALUATION AND ANALYSIS

Assistance to the Atomic Energy Commission was provided in the form of a series of assessments of the impacts of new technologies on the future development of the U.S. energy system. The purpose of these assessments was to guide the budgeting of funds for the five-year, \$10-billion, energy research and development plan. The Reference Energy System, shown in Figure 3, and the Brookhaven Energy System Optimization Model were employed in this effort. Studies are also under way to determine the role of intensive electrification by the use of coal in electric power plants in reducing

dependence upon imported oil. Additionally, a study of energy utilization in the New York City region was made under the sponsorship of the National Science Foundation to assist planners in evaluating the social, economic, and environmental effects of various policy options in energy use. These studies permit the assessment of cost and energy losses incurred throughout the energy network, starting from the point of resource extraction and progressing through the refining, central conversion (where applicable), and end-use steps. The environmental consequences of the various pathways are also collated.

Technical assistance was provided to the Regulatory Staff of the AEC in the matter of the safety of light water reactors, with emphasis on core physics and system transients. The first area includes calculations of the space and time distributions of power and temperature in fuel elements and coolant for both normal and perturbed states of the reactor. Specific problems considered include the rod-drop transient, the effect of fuel densification, and the determination of control-rod worths.

In the area of system transients a wide range of off-normal operating conditions were considered and the important temperatures and pressures in the nuclear steam supply system (NSSS) were monitored. One problem has been anticipated

Figure 3. Chart of Reference Energy System network (1985 base case projection), showing the various pathways taken by five forms of natural resource fuel before arriving at ten categories of end use. Flows are in 10^8 joules.

transients without scram, including transients such as that initiated by a turbine trip. The transients are calculated for specific models of the NSSS of different vendors. Here, as in the core physics work, much of the work has been directed toward the development of calculational models and computer codes needed for analysis of these safety-related problems.

TECHNICAL SUPPORT FOR AEC DIRECTORATE OF LICENSING

During fiscal 1974, BNL expanded its technical support program for AEC regulatory activities. These programs are coordinated by the newly organized BNL Office of Regulatory Assistance, which also is charged with suggesting additional services which BNL can offer to the AEC regulatory directorates.

Within this program the Thermal Reactor Safety Division conducts analytical studies on safety-related questions pertaining to light-water-

reactor commercial nuclear power stations, which must be licensed by the AEC. Particular emphasis has been placed on off-normal operating conditions that could be of safety significance. Specific power plants are modeled by computer programs, and plant responses to anticipated or hypothetical incidents are analyzed. These include such transient events as loss of electrical load by the plant and ejection of control rods. An additional study has been undertaken on the safety implications, if any, of reactor cores containing recycled plutonium fuels. The staff of this division has been increased almost threefold during fiscal 1974 (from 6 to 17 scientists).

The Fast Reactor Safety Division, created in fiscal 1974, will play a leading role in the safety evaluation of fast reactors, including the demonstration liquid-sodium-cooled fast breeder reactor (the Clinch River LMFBR), and a future gas-cooled fast breeder reactor. A staff of about 20 scientists has been assembled and the analysis program is under way.

In addition to providing direct day-to-day support to meet AEC regulatory needs, both reactor safety divisions are developing new analytical procedures for reactor safety studies under the auspices of the AEC Division of Reactor Safety Research. The goal is to provide the tools needed to evaluate future licensing applications.

Various other regulatory support activities have included stress analysis studies of steam generators and preparation of regulatory guides for the safeguarding of special nuclear materials.

Frequent conferences have been held between BNL and the AEC regulatory staff to delineate new programs through which BNL can provide a wider range of technical assistance in nuclear safety. A long-range goal of BNL is to assume a leading role in providing technical support for the Licensing, Operations, and Standards Directorates of the AEC. Many BNL programs have the potential of providing services that will be needed in the future, including advanced computing capability, creation and management of data banks, coastal meteorology, oceanography, energy systems analysis, biomedical assessments, and site environmental monitoring. BNL is in a unique position among the national laboratories to provide such assistance since it is no longer involved in any reactor development programs and hence is free of the "conflict of interest" problem that has beset the AEC regulatory functions.

Figure 4. The power in a reactor as a function of radial (R) and axial (Z) positions at different times t during a rod-drop transient. Each plot is normalized to the same total power. The rod moves along the core centerline at 5 ft/sec, which causes power peaking. An inherent negative feedback terminates the transient. After 1.0 sec, control rods move into the core to shut it down completely.

NUCLEAR MATERIAL SAFEGUARDS

Highly enriched uranium or plutonium might be stolen to fabricate a nuclear weapon; plutonium or other radioactive byproducts of nuclear energy might become targets for radiological threats to society. The Technical Support Organization at BNL has provided technical assistance to the AEC in developing improved safeguards policies and methods to combat such threats.

Continuing assignments are to assess the effectiveness of safeguards programs at AEC contractor facilities and at privately owned nuclear plants and to review the AEC's safeguards research and development contracts.

In 1971 a conceptual design for a comprehensive and balanced national safeguards system was drafted. This model system was tested through application of the criteria to private fuel-processing facilities and to AEC production facilities. In light of this experience the conceptual design was modified and extended and contributed to the formulation of new AEC regulations and requirements. This iterative, upgrading procedure continues.

A number of tasks have been performed for the AEC in support of the International Atomic Energy Agency: studies of international safeguards measures for reactors and for fabrication, reprocessing, and uranium enrichment facilities; studies of IAEA manpower requirements and costs; assistance in specifying requirements for and obtaining portable measurement instruments for IAEA inspectors, and participation in demonstrations in the U.S. of methods and techniques that the IAEA might adopt.

Brookhaven personnel, working with AEC inspectors, have instrumented two mobile inspection laboratories in order to gain firsthand knowledge of inspectors' needs and make their operations more timely and effective.

The safeguards activity requires a combination of physics, engineering, systems analysis, statistical analysis, assessment of physical security methods, and an appreciation of the relationship of nuclear material security to other areas being studied at BNL, such as reactor safety and future energy alternatives. Substantial use is made of BNL resources.

THE ENVIRONMENT

The Department's environmental study is broadly based and includes the atmosphere, the

Figure 5. View of a utility power-plant plume extending the width of Long Island, as seen from a plane making diffusion measurements.

sea, the land and its groundwaters, and the meeting place of all these phases, the estuarine marsh.

STACK PLUME BEHAVIOR

Brookhaven is a major center for study of the behavior of plumes emitted into the atmosphere from a point source, such as the tall stacks of fossil-fuel-burning or nuclear power plants. This work embraces both the chemical behavior of pollutants, primarily the oxides of sulfur and nitrogen, and the meteorological behavior of the plume as it is dispersed in the atmosphere. Studies have dealt with the rate of conversion of sulfur dioxide to higher oxides of sulfur in plumes, of particular importance in view of recent concern about the effects of these compounds on health. Experiments are carried out aloft at tall-stack oil-burning and coal-burning power plants with use of the isotope ratio tracer (IRT) and the sulfur hexafluoride (SF_6) tracer methods, both developed at Brookhaven. Effective measurements have been made at distances up to 75 km from the source. A method has been developed for the collection, separation, and characterization of the sulfuric acid and various sulfates that are constituents of the end-product aerosols. The relationship between NO and NO_2 in plumes is being studied with real-time airborne chemiluminescent monitoring methods and an IRT system based on measurement of $^{14}\text{N}/^{15}\text{N}$ ratios. In an extension of the plume chemistry studies, Brookhaven is participating in the 5-year Regional Air Pollution Study being carried out by the Environmental Protection Agency (EPA) in the St. Louis area.

Meteorological studies involve the diffusion of plumes from tall-stack sources over land and from point sources located offshore, in line with the current interest in floating nuclear power plants located off the coast. Oil-fog and SF_6 , generated on an anchored ship, are used as tracers. Observed concentrations are correlated with a broad range of meteorological measurements. Results to date have shown that turbulence levels are significantly lower over water than over land, because of lower surface roughness and the stable condition resulting from the advection of warm air over cooler water. Plumes are substantially more compact than those observed over land, although this is offset to some degree by the generally greater wind speeds over water. Indications are that the parameters used in atmospheric diffusion models will require substantial modification.

The SF_6 tracer method for following the movement of gas masses through the atmosphere over long distances has generated considerable interest here and abroad. Its capabilities were demonstrated as part of the Long-Range Transport and Diffusion Study of the National Oceanic and Atmospheric Administration, a cooperative experiment carried out at the AEC's National Reactor Testing Station at Idaho Falls. Applications are being developed in Denmark, Israel, Eire, and Japan. A technique developed in a program undertaken for the EPA permits the calibration and interlaboratory comparison of instruments used to measure ambient levels of such atmospheric trace contaminants as NO_2 at the parts-per-billion level, in periods of minutes to hours. It employs a volumetric method to determine the permeation rate through a calibrated tube. With previous gravimetric methods, weeks to months were required to complete a calibration.

AEROSOL BEHAVIOR

The chemistry and especially the mechanism of formation of aerosols in the atmosphere are being studied in an effort to understand their behavior. Atmospheric aerosols are important factors in precipitation, visibility, the global radiation balance, and the distribution and removal of many harmful airborne pollutants. Areas of study include the interrelationships among atmospheric ions, free radicals, and neutral associations vis-à-vis the formation of particulates from trace constituents of air and the concomitant processes by which gas-phase species become attached to or incorporated in already existing particles. A recently completed study involved the Junge layer, a persistent, globally distributed aerosol area in the lower stratosphere composed primarily of sulfate compounds. Correlation of sulfur concentrations and $^{32}\text{S}/^{34}\text{S}$ isotopic ratios of selected stratospheric and tropospheric aerosol samples with well-documented events of major pyroclastic volcanic eruptions during the past ten years definitely established the fact that volcanic emissions represented the principal source of perturbation of the sulfate concentration of the stratosphere.

OFFSHORE ECOLOGY

The possibility of offshore power plants has generated interest in the study of the coastal shelf. Very little work has been done on the physical, biological, or chemical characteristics of this re-

Figure 6. Diagram of the coastal boundary layer transect (COBLT) experiment. Four fixed, submerged instrument towers will be located at intervals from the south shore of Long Island to a distance of 12 km. Measurements will be made of speed and direction of the current, water temperature, and salinity at four depths on each tower, and the data will be telemetered back to shore. Supporting meteorological measurements will also be made.

gion. At the request of the AEC's Division of Biomedical and Environmental Research, a program in coastal shelf oceanography was begun, and work is in progress on coastal shelf transport and diffusion processes, in collaboration with Woods Hole Oceanographic Institute, and on fish eggs and larvae studies, with the National Maritime Fisheries Administration. A program on coastal shelf productivity will be carried out in collaboration with Brookhaven's Biology Department. To round out the project, programs are planned to study the transfer of materials across the sea-air interface and to establish valid mathematical models of all these processes.

SEWAGE RECLAMATION

The feasibility of applying sewage to land as an alternative to conventional biological or physicochemical treatment systems is being studied in two programs. One, in collaboration with the Biology and Plant Engineering Departments and sup-

ported by the Town of Brookhaven, is an investigation of the effectiveness of forests, marshes, and fields in removing contaminants from sewage and returning potable water to the underlying aquifer. This promises to be an effective low-cost treatment for waste waters in this area. The other program, supported by the U.S. Army Medical Research and Development Command, is an evaluation of the capacity of various commercially available irrigation systems to return sewage effluent to the ground with minimum aerosol formation.

BIOGENIC SULFUR

A comprehensive study is being made of the widely held hypothesis that most of the sulfur compounds entering the atmosphere on a global basis are biogenic in origin and that therefore, in terms of sulfur compounds, nature is a greater polluter of the atmosphere than man. As first steps in the study, emissions of sulfur compounds from a nearby salt marsh estuary are being measured, and a laboratory investigation of the effect of liquid-phase reactions on emissions from aqueous solutions has been started.

OTHER PROGRAMS

The Department's remaining programs are in varying degrees at least indirectly related to en-

ergy or the environment, although the main emphasis of each makes inclusion in this third category more appropriate.

MEDICAL RADIONUCLIDE DEVELOPMENT

The medical radionuclide development (MRD) program, part of the Laboratory's interdepartmental program in nuclear medicine, utilizes unique facilities to develop new and improved radioisotopes and radiopharmaceuticals for diagnosis and therapy.

One highlight of the MRD program was the attainment of routine operation of the Brookhaven Linac Isotope Producer; the first off-site shipment of a radioisotope made in the BLIP took place on October 16, 1973. Dedicated exclusively to the nuclear medicine program, this facility is used to explore the potential of the 200-MeV proton linear accelerator (linac) for preparing a wide variety of radionuclides through simultaneous irradiation of several targets in which spallation reactions are induced with the 200- to 50-MeV protons and conventional nuclear reactions are induced with the lower energy protons. This concept was successfully demonstrated with the satisfactory operation of the BLIP equipment, which involves semiautomatic irradiation of precisely assembled targets in a helium atmosphere under 32 ft of shielding water (see Figure 7).

Significant quantities of ^{52}Fe , ^{123}I , and ^{127}Xe are being prepared in the BLIP and supplied to collaborating groups within and outside the Laboratory. All three radionuclides possess nuclear properties that will increase the amount and accuracy of diagnostic information while decreasing the radiation dose to the patient as compared with the radionuclides heretofore available. Uses to be evaluated include determination of the distribution of functioning bone marrow in various diseased states (^{52}Fe), perfusion and ventilation of the lungs and cerebral and cardiac blood flow (^{127}Xe), and a wide variety of procedures with iodine-labeled radiopharmaceuticals (^{123}I).

A simple procedure involving a single inhalation of a small amount of stable normal helium gas and using inexpensive equipment was developed to detect chronic obstructive pulmonary disease at an early stage. This procedure measures what is believed to be the point in the breathing cycle at which the small airways of the lung begin to close - the so-called closing volume. ^{127}Xe , which will permit sequential imaging of the pulmonary

Figure 7. The 8-in.-diam beam pipe and the 10 target guide tubes (5 on each side) of the BLIP irradiation chamber, seen through 32 ft of shielding water. These water-filled, J-shaped tubes convey water-cooled targets clamped to continuous cables running in each tube from target-handling caves (not shown) at the operating floor level down and into the 200-MeV proton beam inside the cylindrical irradiation chamber. The pressurized helium in the beam pipe balances the hydrostatic head of the shielding water in the guide tubes; thus, water is kept out of the beam pipe, proton losses are reduced, unnecessary energy degradation is eliminated, and most of the protons are absorbed usefully in the several targets undergoing simultaneous irradiation. This equipment, combined with the high current and continuous mode of operation of the linac that provides accelerated protons to the BLIP, enables the preparation of usefully large quantities of radionuclides, hitherto available only in amounts insufficient for practical medical applications.

system, will also be used in continued development of this procedure to correlate regional lung ventilation patterns with closing volumes.

Studies are continuing on ^{99m}Tc , which was developed earlier in the MRD program and is the radionuclide most widely used today in nuclear medicine because of its optimum nuclear properties and widespread availability. With a greater understanding of its chemistry, it should be possible to increase the number of radiopharmaceuticals into which it can be incorporated. Recent achievements include the development of simple, efficient kits with which a doctor can label human

red blood cells and human serum albumin with ^{99m}Tc and thus make these materials generally available to patients.

PORPHYRINS IN BIOENERGETICS

A general study of the oxidation-reduction mechanisms of metalloporphyrins and related compounds is being carried out in a program involving theoretical and experimental physicists, chemists, and medical scientists at Brookhaven, Harvard University, and the Georgia Institute of Technology. Metalloporphyrins function as catalysts in crucial energy-converting metabolic and photosynthetic processes. This study encompasses two broad areas: (1) the electronic structure of metalloporphyrins and their radicals and, hence, their chemical properties, and (2) the biological role of porphyrin ions in metabolism and photosynthesis. For example, theoretical studies guided the synthesis of a simpler substitute for the complex chlorophyll found in photosynthetic bacteria. The properties of the model were then determined and used as guides to predict and investigate the biological system and thus identify primary steps in the conversion of light to chemical energy.

MEMBRANE BEHAVIOR

The Danielli-Davson model of a cell membrane proposes a phospholipid bilayer (≈ 70 Å thick) sandwiched between two protein layers. In 1962, Mueller and Rudin developed a technique for synthesizing a variety of bilayer lipid membranes (BLM's), and by 1969 they could state that the characteristics of these BLM's correspond in so many ways to those of real cell membranes that they should be considered as something more than interesting models.

An important aspect of BLM studies has been the characterization of their electrical properties with the objective of quantitatively correlating ion transport, membrane structure, and voltage-current data. Recent experimental work in the Department employs a charge-pulse technique in which the membrane capacitance is charged rapidly (in < 1 μsec) to a given electric potential difference between the surfaces. This voltage then decays through the conductive mechanism of the membrane. Analysis of the time dependence of the voltage decay yields detailed information about the conductive mechanism.

Results thus far indicate that this experimental technique significantly improves the state of the

Figure 8. Comparison of the optical spectra of a natural tetrahydroporphyrin with those of a synthetic model compound. Top, the optical spectrum of a synthetic model compound, zinc tetraphenylbacteriochlorin (solid line) and the spectrum upon oxidation to its cation radical (dotted line). Bottom, the corresponding spectra of bacteriochlorophyll, the naturally occurring, light-harvesting pigment of photosynthetic bacteria, and its cation radical. In both molecules, the optical changes caused by oxidation closely resemble the spectral features of the *in vivo* system exposed to light and thus identify formation of a cation radical as the primary photosynthetic step. Inserts show the structural formulas of the compounds, and the solvent in all cases was CH_2F_2 .

Figure 9. Improvement of resolution of electron spin resonance (ESR) spectra. Top, the second-derivative ESR spectrum of the cation radical of bacteriochlorophyll, the naturally occurring, light-harvesting pigment of photosynthetic bacteria. The lower graph indicates the improvement in resolution of this spectrum made possible by a combination of new oxidation techniques and repeated computer scanning developed at Brookhaven. These data help to predict the reactivity of the radical. Insert shows the structural formula of bacteriochlorophyll.

art. Data obtained on conductance of membranes mediated by compounds known as macrotetralides complement data found in the literature and, in several cases, clarify apparent anomalies.

ELECTRONIC CONDUCTIVITY OF MOLTEN SALTS

In addition to their ionic conductivity, molten salts possess a small electronic conductivity, undetectable by ordinary means, which controls important properties, such as the efficiency of electrolysis, the self-discharge rate and open circuit voltage of batteries, and the efficiency of fuel cells, in systems containing molten salts. Under certain circumstances the corrosion rates of materials in molten salts are also controlled by the electronic conductivity.

Recently a new technique was developed in this Department to measure small electronic conductivities in the presence of large ionic conductivities. It involves measuring the current vs the applied potential in specially designed cells. Systems studied have included molten lithium chloride-potassium chloride mixtures and molten sodium chloride. In the latter case, when the melt contained more sodium than chloride, the electrons were found to obey Fermi statistics. Thus, the thermodynamic properties of dissolved sodium metal and the electronic conductivity of sodium chloride can be described quantitatively by quantum statistics. From a knowledge of the solubility of sodium in sodium chloride the mobility of quasi-

free electrons was obtained. Practically, these results should be useful in prescribing operating conditions that will foster maximum current efficiency in commercial electrolysis processes.

CONCRETE-POLYMER MATERIALS DEVELOPMENT

Concrete-polymer materials, developed at Brookhaven, are composites that are finding wide application as new construction materials. There are two major types, polymer-impregnated concrete and polymer-concrete. In polymer-impregnated concrete, the more advanced system, conventional precast concrete is impregnated with a monomer that is then polymerized in place by either gamma radiation or conventional means. Distribution of the polymer throughout the concrete results in increased (by factors of 4 to 6) compressive and tensile strengths, virtually no water absorption, and the ability to resist corrosive conditions and thousands of freeze-thaw cycles without deterioration. Information developed at Brookhaven on monomer selection, processing methods, fundamental properties, and practical applications has been made available to interested persons both here and abroad. Work in this country has emphasized highway and bridge applications, in conjunction with the Federal Highway Administration. A bridge using impregnated curbing as a less costly alternative to granite is currently under construction.

Polymer-concrete, consisting solely of an aggregate and a polymer, is finding use as a structural patching material for major arterial highways, where high traffic densities require high strength and wear resistance and fast set times. This was demonstrated on the Major Deegan Expressway in New York City, where an entire bridge deck was repaired and reopened to traffic in one 5-hr shift. Further work is being done on the Express-

Figure 10. Machine for installing polymer roofbolts in mines, which incorporates the pumpable rockbolt system developed at Brookhaven and is being designed for commercial production by the Eimco Corporation. This method of supporting mine roofs utilizes remotely installed rockbolts formed from continuous glass-fiber roving bundles bonded into a drilled hole by a polyester resin polymerized in place. The process was successfully demonstrated by the placement of 150 bolts in the White Pine Copper Company mine in Michigan by Brookhaven personnel, under normal working conditions. The machine shown mounts two bolting units of the type designed and built at Brookhaven under a three-year program with the U.S. Bureau of Mines, completed in 1973.

way, in collaboration with the New York State Department of Transportation. An active program is also under way to transfer this technology to federal and state transportation agencies. Polymer-concrete is also being investigated as a construction material for lining pipe and vessels designed to handle hot corrosive brines in the geothermal energy program. A demonstration program, sponsored by the National Science Foundation, with the city of Baltimore and an industrial concern will utilize the technology to convert glass bottles recovered from municipal solid waste to corrosion-resistant glass-polymer sewer pipe.

Fundamental studies have been aimed at modifying the brittle nature of polymer-impregnated concrete, while retaining its high strength and elastic modulus. The use of steel as aggregate or the incorporation of a small volume of steel fibers has resulted in composites having slow, controlled fracture modes.

STRESS ANALYSIS

Stress analysis has been performed recently in the following areas:

1. Liquid Metal Fuel Breeder Reactor. A paper is being prepared summarizing the evaluation of code case effects in piping systems and the application of fracture mechanics to the prediction of piping failures, and another paper will describe a finite element piping code for use in further analysis of these systems.

2. High-Temperature Graphite Reactor. Stress analysis methods dealing with the nonlinear and anisotropic graphite fuel elements and theoretical formulations for core seismic response are being used in evaluating this system.

3. Steam generator tubes. Steam generator failure is being analyzed in terms of leaking or

severed tubes over a 40-year reactor service period, and studies will be undertaken to identify the principal sources of variability or uncertainty in the service life of tubes.

4. Tailing dams. Computer methods to predict whether, and where, tailing dam failure might occur combine stress and flow calculations in a single finite element code by finding the phreatic surface, calculating from this the pressures due to flow and gravity, and using these pressures in conjunction with the Coulomb-Navier criterion.

5. High Flux Beam Reactor. The spent-fuel shipping cask was analyzed for safety according to specified criteria.

6. Superconducting power transmission lines. The stress condition in coaxial cable at very low temperatures was analyzed because of the importance of minimizing stresses on the delicate superconducting elements, and the presence of large differences in thermal expansion coefficients in various components such as copper and polyethylene.

7. Controlled Thermonuclear Reactor. Components analyzed included the blanket system, various magnets, and the magnet support system.

TRACE ELEMENT ANALYSIS

A facility was set up to determine the concentrations of elements occurring in very low quantities in samples taken in studies of environmental pollution, biological problems, and human disease. Samples of human tissue from autopsies are being examined in an attempt to correlate trace element concentrations with tissue function and/or pathological condition. Protons are used to excite characteristic x-ray fluorescence, and the facility will ultimately handle about 500 samples per week inexpensively.

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BIOLOGY DEPARTMENT

The aim in modern biology is to understand the physical and chemical basis of the myriad processes that take place in living cells and organisms. Such fundamental knowledge is essential for a rational approach in areas of common concern that relate to biology, such as human health, agriculture, and protection of the environment.

Ultimately, the determination of biological structure and function rests in the genetic material, that is, DNA. Considerable effort is therefore focused on the synthesis and reactions of DNA within cells and on the mechanisms by which DNA determines the nature of RNA and protein. The control of gene function in the development of multicellular organisms and the influence of environmental factors in this process constitute an area of increasing interest in the Department.

Structural studies of the components of living cells at various levels of organization – from peptides to protoplasts – are being carried out with use of a variety of novel techniques. These studies are basic to the understanding of processes ranging from photosynthesis in plants to blood coagulation in human beings. Communities of organisms also have structure, and the analysis of this structure and the interrelationship of component parts underlies the ecological program of the Department. Of particular practical interest are studies on the effects of environmental intrusions, such as ionizing radiation and chemical pollutants, on individual organisms and their communities.

Progress in these areas is documented in the following brief summaries of results obtained during the past two years.

GENETICS AND BIOCHEMISTRY OF VIRUS DEVELOPMENT

Bacteriophage T7 is a small virus that infects *Escherichia coli* cells. When a virus particle comes in contact with a cell, the T7 DNA is injected into the cell. The enzymes of the host cell interact with the T7 DNA and new T7 proteins begin to be made. Some of these new proteins act to turn off the synthesis of host RNAs and proteins and to convert the metabolism of the cell entirely to the production of new virus particles. The first steps in this process were studied by using mutants that delete parts of the T7 DNA. The positions of the deletions were mapped both physically and genetically, and the effect of each deletion on the synthesis of T7 RNAs and proteins was determined. In this way it was possible to physically map the T7 RNAs and proteins specified by the leftmost 20% of T7 DNA and to study the role of these T7 proteins in normal infection.

The leftmost 20% of T7 DNA is referred to as the early region because the RNAs and proteins specified by this part of the T7 DNA are the first to be made after infection. Five early messenger RNAs are made, synthesized by the host RNA polymerase enzyme. Purified *E. coli* RNA polymerase can also synthesize RNA from purified T7 DNA in the test tube, but, when this is done, long RNA molecules that cover the entire early region of T7 RNA are made instead of the five shorter RNAs observed in the cell. Another *E. coli* enzyme (RNase III) was found to cut these long RNAs at five specific sites to generate the early messenger RNAs normally observed after infection. This enzyme was purified and its properties were studied.

When T7 infects a mutant of *E. coli* that lacks RNase III, the early messenger RNAs of T7 remain uncut and the long RNAs are found. Thus, the first steps in the expression of T7 genetic information are sufficiently understood to be accurately reproduced in the test tube with purified components.

DNA UPTAKE IN GENETIC TRANSFORMATION

Pneumococcal bacteria can be genetically transformed by DNA taken up from outside the cells. A number of mutant strains that had lost the ability to be transformed were isolated. Analysis of these mutants revealed two distinct steps in the process of DNA uptake. In the first step DNA is bound to the outside of the cell surface. This step, which appears to require energy, is blocked in one class of transformation-defective mutants. The second step involves entry of bound DNA into the cell. This step is blocked in another class of transformation-defective mutants. The latter mutants bind DNA to the outside but cannot introduce the bound DNA into the cell. Such mutants lack a particular cellular enzyme, a deoxyribonuclease, that can degrade DNA.

The results support a mechanism for DNA entry in which a deoxyribonuclease sequentially degrades one strand of the incoming DNA while the complementary DNA strand is brought into the cell as a consequence of the enzymatic attack on its partner. It was previously shown that newly introduced DNA is, in fact, single stranded and that equivalent amounts of DNA fragments appear outside the cells. Thus, the deoxyribonuclease involved in DNA entry may act as a DNA translocase, an enzyme that transports DNA into the cell.

DNA CONTENT AND EVOLUTION IN PLANTS

Data on nuclear and genome volumes of more than 1000 species of higher plants were examined for possible evolutionary trends. Logarithmic frequency distributions of genome volume (i.e., nuclear volume divided by the ploidy) or DNA content per genome within higher plant families, e.g., the Gramineae, show a series of peaks that indicate an apparent sequence of doublings. Similar distributions were observed in other groups, such as fungi and bacteria. The results suggest that evolution proceeds, in general, by means of a series of doublings of DNA from a basic ancestral genome, a process called cryptopolyploidy.

Figure 1. DNA content of related plant species. Logarithmic distribution of genome volumes (*GV*) and DNA content per genome (*DNA/G*) for 76 grasses. Arrows indicate mean *GV* for species within each group.

CONTROL OF THE MITOTIC CYCLE IN PLANTS

The amount of nuclear DNA in cells of mature plant root tissue was found to be biologically determined in two ways. First, in some species the meristematic or dividing tissue is comprised of two distinct cell populations. One produces progeny destined to mature as cells arrested in their mitotic cycle prior to DNA replication and, therefore, containing a diploid complement of DNA (2C amount). Another population produces cells that differentiate with a 4C amount; that is, they are arrested in their mitotic cycle after replication. In such plant species, the 2C cells are preponderant. Second, other plant species have in addition to the two predestined populations a third group of cells that can mature with either a 2C or a 4C amount of nuclear DNA. The amount depends on a factor that originates in the cotyledon and is transported down the root to the tip where, if it is present continuously, the responsive cells eventually mature with a 4C amount of DNA. If the factor is absent, the responsive cells still mature, but with a 2C amount of DNA. The discovery of the factor from cotyledons and its biological effects in the root-tip meristem furnishes an example of how the metabolism of one organ produces substances that influence the cytology of another.

PLANT CELL GENETICS

Model systems for studying higher plant genetics at the single cell level are being developed. These systems include haploids and hybrids that are particularly suitable materials for growth in culture as somatic tissues or as single cells in suspension. Systems were obtained that are highly efficient in producing viable cell colonies, can be selected on chemically defined culture media for specific genetic variants, and are readily differentiated into whole plants. These systems are being used primarily (1) to produce plants with higher levels of specific amino acids or other altered biochemical characteristics, and (2) to study the genetic control of plant differentiation.

PHOTOPERIODISM

Many processes, and particularly reproduction, in both plants and animals are environmentally controlled through photoperiodism, a response to the timing of light and darkness. In plants, photoperiodism involves both endogenous circadian rhythmicity – the so-called biological clock – and a light-absorbing protein, phytochrome, but the nature of their interactions is unknown. In a new approach, the patterns of carbon dioxide output by photoperiodic plants under sterile conditions have been studied on schedules combining light of different wavelengths with various periods of darkness. Interactions analogous to those found in photoperiodism can be identified in such patterns. Furthermore, these interactions can be modified by compounds affecting amino acid metabolism. The purpose of this work is to obtain a more thorough understanding and control of photoperiodism in terms of its underlying biochemical components.

FINE STRUCTURE OF PLANT CELLS

The scanning electron microscope was used to study fine details of the surface morphology of a variety of biological specimens. The external surfaces of freshly isolated plant protoplasts viewed in this way either were studded with numerous small blebs extending from the plasma membrane or were relatively smooth. The character of the surface may reflect the physiological state of the particular protoplast or may be related to the cell type from which the protoplast was derived. Fragments of undigested cell wall were frequently seen adhering to the outer surface of the protoplast.

Methods were devised to view organelles of the cytoplasm in plant and animal cells with the scan-

Figure 2. Scanning electron micrograph of protoplast isolated from *Amaryllis* petal. Numerous small blebs extend from plasma membrane surface. Patch of adhering cell wall can be seen at left. (1100 $\times$.)

ning electron microscope. If two micrographs of specimens are taken at slightly different angles, the cell contents can be viewed stereoscopically to some depth within the cytoplasm.

SCANNING TRANSMISSION ELECTRON MICROSCOPY

A 100-kV scanning transmission electron microscope (STEM) with better than 2-Å resolution and high information-collecting efficiency is under construction. The STEM is superior to the conventional electron microscope in producing images of unstained biological molecules and single heavy atoms with minimum alteration of the specimen by radiation damage. The STEM facility will be used jointly by the Brookhaven scientific staff and scientists from other institutions. The prototype STEM built at the University of Chicago demonstrated 3-Å resolution and was able to produce an image from single atoms as light as silver. This instrument can be used to "weigh" single unstained DNA molecules and virus particles by taking advantage of the quantitative relationship between electron scattering intensity and mass.

Construction of the Brookhaven STEM is nearing completion. The electron source and 100-kV accelerating system are operating at 10^{-10} Torr and undergoing final testing, while the short focal

Figure 3. Scanning electron micrograph of cytoplasm of cell of corn root, showing large nucleus and several smaller organelles. (9000 $\times$.)

length magnetic objective lens, specimen stage, and specimen-changing air lock are being constructed in the Instrumentation Division's machine shop. In addition, a small computer system to analyze the STEM output is being designed.

NEUTRON-SCATTERING ANALYSIS OF BIOLOGICAL STRUCTURES

Neutron-scattering studies on the oxygen-binding protein of muscle, myoglobin, were extended to determine structural changes on binding of carbon monoxide. The density map, derived from more than 10,000 reflections, showed that the binding of carbon monoxide introduced changes in the heme component and in hydrogen bonding that are relevant to understanding the reaction mechanism of myoglobin. Structural studies of the influence on binding of pharmacological agents such as dichloromethane showed that considerable conformational change accompanies relatively small changes in the uptake of carbon monoxide.

The different neutron-scattering powers of hydrogen and deuterium were used to study a number of large biological complexes. The structure of a model membrane was determined by H_2O , D_2O exchange, which elucidated the lipid bilayer and located bound water within the structure. Similar studies were performed on photoreceptor membranes to determine the structural role of rhodopsin in the light transcription process. To improve these low-angle studies a large two-dimensional position-sensitive counter (a proportional 3He counter equivalent to 8000 individual counters with a sensitivity of $>80\%$ and a spatial resolution of 2.5 mm) was developed. This novel counter is

being used to analyze the structure of ribosomes differentially labeled with hydrogen and deuterium. Current findings indicate that the RNA and proteins are not uniformly distributed; in the 50-S subunit the proteins are concentrated at the active site on the surface of the RNA cluster, while in the 30-S subunit the proteins surround the RNA like a shell. Data collection from weakly scattering biological systems was further improved by the development of a new artificial monochromator made by vacuum deposition of two different metals such as manganese and germanium to form a one-dimensional crystal. These monochromators have a variable-width wavelength band and are highly efficient.

SUPRAMOLECULAR STRUCTURE

A neutron-scattering method for determining the quaternary structure of enzyme complexes was tested with use of the allosteric enzyme aspartate transcarbamylase. This enzyme contains six regulatory and six catalytic subunits, and hybrids have been made in which one type of subunit is deuterated and the other is hydrogenated. Since neutrons are scattered very differently by deuterated and by hydrogenated proteins, a comparison of the neutron diffraction patterns of the two hybrids and of the all-deuterated or all-hydrogenated forms should provide substantial information about the enzyme's quaternary structure, i.e., the arrangement of its subunits. Preliminary diffraction data indicate two possible (alternative) arrangements of the subunits, one of which is known to be correct from x-ray crystallographic studies.

In an investigation of membrane structure, photosynthetic membrane vesicles (chromatophores) of *Rhodospirillum rubrum* were studied. Discrete x-ray reflections were obtained from centrifuged pellets, and new computational techniques were devised for analyzing this kind of data by the method of swelling stages.

PROTEIN STRUCTURE AND FUNCTION

To understand how enzymes function, a new type of protein chemistry known as affinity labeling has been developed. Small reagents are designed to be like normal substrates but, in addition, to be capable of attaching themselves to functional groups of enzymes by forming covalent bonds. The enzyme is thus inactivated, and the essential group can be identified. A variety of proteolytic enzymes, which function in blood coagulation, clot lysis, hormone formation, and other

regulatory processes, were studied. The results show that although the various enzymes are different molecular entities, they are fundamentally similar catalysts. Because the inactivation of a given proteolytic enzyme may be of therapeutic usefulness, the ability to devise a reagent capable of selective inactivation *in vivo* is another goal of this research. It was found that considerable specificity of inhibition can be achieved with the synthetic reagents.

BRAIN PEPTIDASES

Bradykinin, a hormone that affects blood pressure, has the peptide structure Arg-Pro-Gly-Phe-Ser-Pro-Phe-Arg. Two endopeptidases that hydrolyze bradykinin were isolated from rabbit brain and detected in other tissues. The enzymes hydrolyze bradykinin at the Phe⁵-Ser⁶ and Pro⁷-Phe⁸ peptide bonds, respectively. Native or de-natured proteins are not hydrolyzed, and the enzymes show selectivity for analogues and fragments of bradykinin. A peptide analyzer system based on the amino acid analyzer was developed to identify and quantitate the hydrolysis products of bradykinin. In addition to having a possible role in the metabolism of peptide hormones, enzymes of this type may be important in protein turnover within the cell.

PANCREATIC TRYPSIN INHIBITORS

The pancreatic secretory trypsin inhibitor was isolated from human pancreatic juice and post-mortem tissue. The amino acid sequence of the inhibitor was determined and compared with homologous inhibitors from bovine and porcine pancreas. Differences in the amino acid sequence at the reactive site of the human inhibitor are believed to be responsible for the fact that human inhibitor, but not inhibitors of bovine or porcine origin, can inhibit human pancreatic trypsin. Radioimmunoassays have been developed for bovine and human inhibitors which may be of diagnostic value in man.

CHLOROPHYLL-PROTEINS AND PHOTOCHEMICAL REACTION CENTERS

Crystals of bacteriochlorophyll-protein (Bchl-protein) (MW = 150,000) from the green photosynthetic bacterium *Chlorobium limicola* were examined by x-ray diffraction and found to contain two macromolecules per unit cell. From the sym-

metry properties of the unit cell it was deduced that each macromolecule consists of three identical subunits, each containing seven Bchl molecules.

Bchl-reaction-center (Bchl-RC) complexes (MW $\cong$ 1.5 million) from green bacteria contain Bchl-protein, carotenoid, cytochrome *c*, and reaction-center Bchl. Each Bchl-RC complex appears to contain four or five Bchl-protein macromolecules for a total of 84 to 105 Bchl molecules per reaction center. Comparison of low-temperature-absorption and circular-dichroism spectra of Bchl-protein with those of the Bchl-RC complex suggests that both absorption and circular-dichroism spectra of the complex are linear combinations of the spectra of Bchl-protein and a new reaction-center chlorophyll protein.

PHOTOSYNTHETIC PIGMENTS IN ALGAE

The dinoflagellate algae are one of the three dominant phytoplankton groups responsible for primary productivity in the oceans. They utilize a carotenoid, peridinin, as the principal light-harvesting pigment for photosynthesis. A group of six peridinin-chlorophyll *a* proteins, each having a distinct isoelectric point, were isolated from *Amphidinium carterae*. Two of these proteins were obtained in amounts sufficient for comparison of their amino acid compositions. The two proteins differed in composition by only a single arginine residue. Both proteins contain 9 peridinin and 2 chlorophyll *a* chromophores per molecule.

ELECTRON TRANSPORT AND ION MOVEMENTS IN CHLOROPLASTS

Photosynthesis in higher plants takes place within the chloroplasts, which are composed of green membranes containing chlorophyll and other pigments. Electron transport reactions take place between these pigments under the influence of light, and in consequence ions are selectively moved across the membranes. The electron and ion flows indirectly yield the reducing and phosphorylating power necessary for the fixation of CO₂ into sugars.

Electron transport processes were studied by kinetic and steady-state spectrophotometry, since the uptake or loss of electrons by a pigment alters its absorbance spectrum. An on-line computer was used in conjunction with a specially designed scanning spectrophotometer to resolve complex kinetics and overlapping absorbance bands. Light-dependent changes in the activities of the ions H⁺, Na⁺, K⁺, Mg²⁺, and Cl⁻ in a chloroplast suspension

were simultaneously monitored by ion-specific electrodes. Progress was made in determining the pathway of electrons in photosynthetic electron transport and in identifying the points at which electron flow is coupled to the movement of ions. In particular, the relative contributions of the various ions to the overall ion movement were assessed.

RESPONSE OF PLANTS TO IONIZING RADIATION

Acquisition of data for additional species allowed the extension of the inverse relationship between interphase chromosome volume (ICV = nuclear volume/chromosome number) and radioresistance of both herbaceous higher plants and ferns at various survival end points. A direct relationship between nuclear volume and the time of manifestation of radiation-induced death was observed. Although ICV appears to be the principal determinant of radiosensitivity, other variables have been shown to influence the level of response obtained after a given dose. Growth inhibition and survival studies with barley indicated two or three ranges of exposure rate with alternating trends of radiation response. Dependence of mutation induction in *Tradescantia* on dose-rate range was also demonstrated. Dose rates below an optimum range show a decreasing effectiveness per rad for a given dose.

The relative biological effectiveness (RBE) of neutrons (compared with that of x rays) was de-

Figure 4. Mutagenic effects of environmental pollutants. Pink mutation rates induced in *Tradescantia* stamen hairs were measured after 6-hr exposures to various gases. Relative effects of 10 and 50 rads of x rays are also indicated. (Control rates have not been subtracted.)

terminated for the blue-to-pink mutation rates in *Tradescantia* stamen hairs. RBE values ranged from 10.4 to 47.6 and were strongly dependent on both dose and neutron energy. Dose-rate effects were found for x rays but not for neutrons. The oxygen enhancement ratio (OER) determined for x rays was 3.2. In contrast, the OER for neutrons of different energies ranged from 1.32 to 1.68, were only weakly influenced by neutron energy, and appeared to be independent of dose. The data appear consistent with expectations derived from microdosimetric considerations.

PLANTS AS MONITORS FOR ENVIRONMENTAL MUTAGENS

In the past few years efforts have been accelerated to detect and identify the most serious or most toxic environmental pollutants and to assess their real or potential hazard to biological systems. The very sensitive *Tradescantia* plant somatic mutation test system is being exploited to study the genetic effects of various physical and known or suspected chemical mutagens. The objectives are to elucidate factors influencing the sensitivity of biological systems to these chemicals and to assess the usefulness of the plant genetic test system as a monitor for environmental mutagens. Recent studies of mutations induced in *Tradescantia* flowers by exposure to gaseous chemicals indicate that atmospheric oxidants such as ozone and SO₂ are at most very weak mutagens, whereas the gasoline additives ethylene dibromide and trimethyl phosphate appear to be fairly potent mutagens.

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CHEMISTRY DEPARTMENT

Research in the Chemistry Department encompasses the classical fields of chemistry – analytical, inorganic, organic, and physical – and in addition some specialized programs in nuclear, radiation, and hot-atom chemistry. The overall aim of the experimental and theoretical work carried out by chemists is to determine the properties of nuclei, atoms, and molecules and to understand how they react. Special facilities available at the Laboratory, such as the Alternating Gradient Synchrotron, High Flux Beam Reactor, Medical Research Reactor, and large computers, are used in most of

ECOLOGY

The focus of research in ecology continues to be the structure and function of ecosystems. Three programs are under way: a study of terrestrial ecosystems using the irradiated forest, a study of an estuarine marsh, and the experimental eutrophication of terrestrial and aquatic ecosystems with sewage. Continued studies of the previously irradiated forest have substantially advanced our understanding of the process of biotic impoverishment, the series of changes now occurring worldwide as the earth's biota are reduced. The studies in Flax Pond have revolutionized our understanding of the function of coastal marshes, especially with respect to their influence on the chemistry of coastal waters. Flax Pond has a powerful effect in removing organic matter from the tidal waters that flush it, and it also affects the nutrient cycles of sulfur and nitrogen. In the eutrophication program substantial advances have been made in developing biotic systems for treatment of sewage. The most promising systems will doubtless be combinations of marshes, ponds, and terrestrial communities. These systems appear to offer a method of sewage treatment with a minimum input of fossil fuel energy and with the possibility of recovering both water and nutrients for reuse. A general interest in world cycling of toxins was pursued with further work on cycling of DDT residues. The fact of world cycling was conclusively established, and the limits of rates of transfer through the air into the oceans were more precisely defined.

the studies. In addition, the Chemistry Department operates three accelerators in support of its research program.

Electron Van der Graaff. This accelerator is dedicated to the radiation chemistry program. The machine's most useful characteristic is its reliability and stability in delivering beam currents ranging in intensity from 0.1 μ A to 50 mA. The pulse length delivered is variable from 1 μ sec to a continuous beam.

Febetron. This facility, which is also used for radiation chemistry research, is capable of delivering up to 5000 A of current of 1.9-MeV electrons. These pulses, which have a width of 80 nsec, are available once every few minutes.

60-in. Cyclotron. The nuclear medicine and hot-atom chemistry programs of the Chemistry Department are the principal users of the cyclotron. It is an azimuthally varying field device and can deliver tens of microamperes of protons, deuterons, and helium-3 and helium-4 ions with varying energies up to 38, 24, 65, and 48 MeV, respectively.

Much of the emphasis in the research program is placed on the application of nuclear and radiochemical techniques to the solution of chemical problems and to the study of the nature and interactions of radiation, particles, and atoms with other atoms and molecules.

Many of these research programs complement and extend work in the life sciences and physics, and a number are multidisciplinary because of common interests shared by scientists in other BNL Departments. Many of the techniques and fields of expertise encompassed by the Department's programs are being extended and applied to basic research problems related to energy.

Nuclear chemists are studying the properties and reactions of nuclei in a number of ways. Products, usually radioactive ones, resulting from the irradiation of target foils in high-energy accelerators are measured and their properties determined. From this kind of information, details of the individual nuclear reactions that take place are deduced and information about nuclear properties is obtained. Many reactions of this type have their counterparts in natural processes occurring in the stars and in space. Thus information about these types of nuclear reactions obtained in the laboratory, combined with observations concerning the nature of radiation emitted from stars and the distribution of radioactive species in meteorite and lunar materials, allows a test of theories about ongoing nuclear processes and the history of these bodies.

Because one can measure extremely small amounts of radioactivity, the use of radioactive tracers as probes to study chemical reactions and as a means for sensitive, nondestructive methods of chemical analysis is an extremely valuable and widespread technique. In addition, because the radiation emitted during the radioactive decay process is penetrating, the use of radioactive chemical compounds that concentrate in specific organs to illuminate inaccessible areas is an important and growing field of study. These and other uses of radioactivity are continually applied to new problems.

The High Flux Beam Reactor provides crystallographers in the Chemistry Department with the means, available in very few places, of determining crystal structures with neutron beams to extend and complement similar studies using x rays. Since hydrogen atoms can be accurately located with neutron beams, but not with x rays, the combination of the two methods yields the structural arrangement of all the atoms in a molecule. This technique is especially useful in the determination of the structure of biologically important compounds in which hydrogen atoms play critical roles. In addition, the scattering of neutrons by atoms can yield information about dynamic processes taking place in crystal lattices, and this method is currently used to investigate theories of ferromagnetism.

The usual techniques used to study chemical reactions are limited to the investigation of stable species or relatively long-lived intermediates. To gain a fuller understanding of the primary reactions involved in chemical reactions requires the development of methods to produce, detect, and measure very short-lived unstable species. Energetic radiation can cause bond rupture in molecules, and the fate of the fragments thus produced is important to all branches of chemistry. This technique also provides one of the best methods of generating and studying chemical species important in biochemical reactions. At present, studies of the effects of electron beams on different chemical systems are being actively pursued.

At the low end of the energy spectrum are the reactions that occur concurrently with the transfer of kinetic energy when molecules and ions undergo collisions. The way in which these reactions occur and the energy distribution in the resulting chemical species are also being investigated. One valuable extension of these studies has been the development of techniques that allow the identification and analysis of structures of minute amounts of material of biochemical interest.

The following profiles provide a sampling of the areas under study.

THE BROOKHAVEN SOLAR NEUTRINO EXPERIMENT

Nuclear reactions, in which hydrogen atoms are converted into helium atoms, are the source of the sun's energy. Because the temperature necessary to sustain these reactions is high enough only in

the core of the sun, the only direct nuclear reaction products produced in the fusion process that are penetrating enough to escape from the sun and be detectable on earth are neutrinos. All other fusion products are absorbed and converted into heat.

The Brookhaven solar neutrino experiment was designed to observe the solar neutrino radiation and to test the theories that predict details of the fusion reaction chain, the temperature, pressure, and interior structure of the sun. Neutrinos are observed by their interaction with ^{37}Cl to produce ^{37}Ar , which is radioactive. Since neutrinos have an extremely small interaction probability, 100,000 gallons of target material (C_2Cl_4) is used to produce the few argon atoms per day which are predicted. Additional details of the experiment are described in the 1970-72 issue of *Brookhaven Highlights*.

Measurements extending over a period of six years have shown that the solar neutrino flux is lower than expected from theoretical models of the sun. Current theoretical models using the standard input data, solar composition, mass, age, and luminosity, and the accepted laboratory measurements of the nuclear reaction cross sections, predict a neutrino capture rate in ^{37}Cl of 5.8 SNU (SNU = solar neutrino unit = 10^{-36} captures/sec/ ^{37}Cl atom). Solar neutrinos have not been observed in the Brookhaven experiment, but the measurements have yielded a firm upper limit, set at 1 SNU, to the solar neutrino flux.

The low flux of neutrinos from the sun established by the experiment has stimulated a number of astrophysicists to reinvestigate the fundamental aspects of the structure and evolution of the sun. There are at present three possible explanations of the low neutrino emission. The sun could be depleted in heavy elements in its interior. If this is so, the sun was formed of hydrogen and helium, and at a later time the heavy elements were added to its surface. The added material, high in heavy elements, has not been mixed into the interior. Another mechanism proposed presumes that the sun was formed while spinning very rapidly. During its lifetime it has gradually been slowing down through the loss of angular momentum into solar wind particles. This theory would predict that only the inner 10% of the solar mass is now spinning rapidly. A third explanation being actively discussed is that the energy generation processes and the sun's luminosity are periodic. Presumably the

sun is now in a stage of low energy production. If this theory is valid it would provide a ready explanation of the periodic glaciation of the earth.

The calculated sensitivity of the Brookhaven solar neutrino detector is dependent upon knowing the neutrino capture cross section of ^{37}Cl as a function of the energy. The cross section used is deduced theoretically and this calculation is considered to be extremely reliable. In view of the unique character and the important implications of the Brookhaven experiment, it is generally thought that a measurement of the neutrino capture cross section in ^{37}Cl should be made. A joint experiment with Purdue and Northwestern Universities is being planned at the Los Alamos meson facility. This experiment will use the neutrinos from μ^+ decay that are produced when the full beam of the 800-MeV accelerator strikes the beam stop. Background studies are in progress.

Another solar neutrino detector system being studied involves the capture of neutrinos in ^7Li to produce ^7Be (half-life, 53 days). This reaction is chosen because of its high cross section to the relatively low energy neutrinos from the $\text{H} + e^- + \text{H} \rightarrow \text{D} + \nu$ reaction, which is an initiating reaction in the proton-proton chain. The ^7Li neutrino detector, if experimentally feasible, can resolve the crucial question of whether the basic reaction is occurring in the sun. Studies are being made of methods of extracting a few atoms of ^7Be from large quantities of concentrated lithium chloride. A major difficulty to be overcome is the development of a sensitive low-background counting technique for measuring ^7Be activity. If the ^7Li detector system proves feasible, a large-scale detector employing 120 tons of LiCl will be proposed.

It is generally believed that stars at the end of their evolution become sufficiently hot in their interiors to convert photons into neutrinos and anti-neutrinos. When this stage is reached the star suddenly collapses to form a neutron star. The event is the familiar supernova explosion, and the collapsed object is finally observed as a pulsed radio-source, a pulsar. It is important to have the highly sensitive Brookhaven detector in operation to observe the neutrino flux when a stellar collapse occurs. One experimental run in which the detector was exposed from July 7 to November 5, 1972, showed ^{37}Ar activity about fifteen times higher than the average of other runs. It is conceivable that the increase was attributable to an intense pulse of neutrinos during the period of exposure.

However, no other astronomical events that could be regarded as neutrino sources were observed in this period. On January 4, 1974, a possible pulse of antineutrinos 2.6 nsec long was observed by an antineutrino detector operated by the University of Pennsylvania in the Homestake Gold Mine. This event also has not been correlated with any other astronomical observation. A search was immediately made for ^{37}Ar in the Brookhaven neutrino detector. None was found, and it appears that the flux of neutrinos accompanying the event was at least four times lower than the antineutrino flux. Further searches for possible pulsed sources of neutrinos will be made in conjunction with the continuing program to detect solar neutrinos or, if one is reported, a special event.

HIGH-ENERGY NUCLEAR REACTIONS

Almost all studies of high-energy nuclear reactions in complex nuclei have been carried out by using protons with kinetic energies up to 30 GeV as incident particles. Recently a number of accelerators have been built or modified to provide beams of 300 to 400-GeV protons, 300-MeV pions, 800-MeV pions, and very energetic heavy particles such as 28-GeV ^{14}N ions. Results from experiments with these projectiles are being used to test and improve the model of high-energy reactions developed for protons of up to 30-GeV kinetic energy.

Extension of proton-induced reaction studies to the 300 to 400-GeV energy region has been made at the Fermi National Accelerator Laboratory with use of both the mica track detector method and radiochemical techniques. In the former method fragments with mass ≥ 30 are recorded and the results used to measure the probability for binary and ternary fission, single fragment production, and forward/backward ratios for all these events. In the radiochemical studies, yields of individual radioactive species are measured, and for light and medium-weight targets a good picture of product distributions is obtained for spallation-type reactions. Both types of experiment indicate that no drastic changes in the fission and spallation mechanisms of high-energy nuclear reactions are coming into play between 30 and 300 GeV. One must conclude that essentially all the additional kinetic energy brought in by the 300-GeV projectile appears as kinetic energy of outgoing protons and neutrons and as kinetic and

Figure 1. Comparison of product yield distributions obtained when copper is irradiated with 3.9-GeV protons and 3.9-GeV ^{14}N ions. Although the overall shapes are similar, there is a real difference between the slopes of the linear portions of the two curves.

rest-mass energy of outgoing mesons and anti-particles. Very little of this additional energy is effective in increasing the internal energy of the struck target nucleus.

Comparison of reactions initiated by heavy ions and protons of equal kinetic energies shows striking similarities as well as some real differences. Yield patterns obtained in 3.9-GeV ^{14}N ion bombardments of copper compared with those obtained in 3.9-GeV proton irradiations show that the mass yield curve for ^{14}N -induced reactions decreases more rapidly with decreasing product mass, except for very light products, such as ^7Be and ^3H , which have substantially higher yields. With the high-energy ^{14}N ions there is no appreciable production of nuclides heavier than the target, as there is with low-energy ^{14}N ions. These results can be understood, in part, in terms of the concepts of limiting fragmentation and factorization, which were developed to explain some features of reactions between elementary particles at very high energies. Very simply, these concepts predict that at sufficiently high energies product spectra and cross sections will be independent of energy; that target fragmentation spectra and cross sections will be independent of the beam; and that projectile fragmentation spectra will be independent of the target except for a total cross section term. Additional experiments with heavy ions of even higher energy will be performed to test the validity of these ideas.

Pion-induced reaction studies are now being started. Since the production and reabsorption of

pions in complex nuclei play important roles in present ideas about the transfer of projectile kinetic energy to nuclear excitation energy, these experiments will be critical tests of important details of the model calculations.

RADIOPHARMACEUTICALS FOR NUCLEAR MEDICINE

Nuclear medicine is a field in which radiation and radioactive nuclides are used in the diagnosis and treatment of disease. One branch of this field is the development, production, and use of radiopharmaceuticals for organ imaging, tumor localization, and regional function studies of metabolic disorders. Most radiopharmaceuticals in use today are labeled with relatively long-lived isotopes because the time between production of the isotope and its incorporation in the compound of interest and its actual use as a clinical tool is usually long, a few days. The disadvantage of using long-lived radioactive isotopes is that the total radiation dose received by the patient is high, since the material remains in the patient long after the diagnostic procedure has been completed.

In an effort to overcome this disadvantage, a multidisciplinary program at BNL involving physicians, physicists, chemists, and biologists is concerned with the development of radioactive pharmaceuticals containing short-lived isotopes and their use in treatment. Short-lived radioactive isotopes are produced at the 60-in. cyclotron or the 200-MeV linear accelerator, incorporated into medically useful compounds, and tested for their efficiency in concentrating in one or two specific organs for diagnostic procedures. Short-lived isotopes being used in this program include ^{11}C (20-min half-life), ^{13}N (10 min), ^{18}F (110 min), ^{123}I (13 hr), and ^{203}Pb (52 hr). Synthetic, biosynthetic, hot-atom, and radiation chemical methods are used in combination or individually to prepare compounds of interest. A wide variety of useful compounds has been prepared and tested for diagnostic procedures for a number of organs including the adrenal medulla, heart, thyroid, and pancreas. Recent work has included the use of ^{123}I -labeled antimalarial drugs for detection of melanoma in eyes, ^{123}I -labeled iodocyanine green in studies of liver function, and ^{203}Pb for tumor localization and pancreas function studies.

The list of compounds is constantly being expanded, with research emphasis on new com-

pounds and methods of preparation, to allow nuclides with half-lives as short as 17 sec to be used effectively in biological research and clinical evaluation.

GEOGRAPHIC ORIGINS OF ARCHAEOLOGICAL ARTIFACTS

Neutron activation analysis (NAA) has been used extensively in the Chemistry Department to determine the structure, basic composition, and trace impurity constituents of works of art and archaeological artifacts. Appreciable progress in this program has been attained recently as a result of the development here of new methods of statistical analysis to treat NAA data. True multivariate statistical procedures, readily applicable to all fields of activation analysis investigation, such as the forensic, the environmental, the medical-biological, and the geological, as well as the archaeological and art-historical fields, have been developed and are in day-to-day operation. Such procedures, for which new computer programs have been developed, have led to an enhanced understanding of internal relationships in the body of data and thus to more significant interpretations of the data.

Figure 2. Identification of the various oxidation states of iodine formed in the cyclotron production of ^{123}I , a necessary step in designing a purification procedure to ensure that ^{123}I -labeled radiopharmaceuticals are both chemically and radionuclidically pure before use in clinical studies.

Thus in the study of archaeological materials, principally ceramics, patterns of composition are compared to allow grouping of objects on the basis of their clay origins. For example, pottery from the ancient archaeological sites of Tell El Fiesi and Tell Gezer in Israel can be classified, on the basis of its composition, as to whether it was made from local highland clays or clay of the coastal plains, or was imported from Mesopotamia, Egypt, or the Aegean. It was possible to establish that commerce in several special types of pre-Columbian Mesoamerican pottery, e.g., Fine Orange and Thin Orange, extended over many hundreds of miles, but that outside of these ranges these styles of pots were often copied locally. Analyses of samples taken from clay beds have in several cases permitted the origins of specific pieces or groups of pottery to be determined exactly.

STAGGERED MAGNETIC FIELDS IN DYSPROSIUM ALUMINUM GARNET

Measurement of the energy and momentum changes undergone by neutrons scattered by a solid gives the complete space-time pair correlation function of the solid, from which, in principle, all its structural and dynamic properties can be obtained. In particular, in the case of magnetic

systems, from the correlation function one can deduce the spatial distribution of magnetization, its response to applied fields, and, as well, the decay of spontaneous magnetic fluctuations.

The behavior of magnetic materials in applied magnetic fields is of great theoretical and practical interest and has been studied extensively by a wide variety of techniques. In the case of certain antiferromagnets, substances in which the elementary atomic magnets (spins) take up an ordered pattern of alternation, application of a field can produce a phase transformation in which the arrangement of these spins is greatly altered.

Dysprosium aluminum garnet (DAG) exhibits this kind of behavior and, since this substance is of great interest as a prototype for these phase transitions, it has been studied by means of neutron diffraction at BNL in collaboration with a member of the Physics Department. The results lead to the surprising conclusion that, under appropriate circumstances, a uniform external field can produce, in a crystal, a magnetic field that reverses its direction on an atomic scale (a "staggered" field). Such a field, conceivable in principle, has always been considered unobtainable in practice. It is produced in the present instance because the uniform applied field interacts differently with positive and negative spins as a result of a difference in the arrangement of the nonmagnetic atoms surrounding the two types of spin.

This discovery has made it possible to understand a number of seemingly anomalous aspects of the transformation in DAG and opens the way for a wider investigation of the behavior of magnetic substances subjected to magnetic fields.

Figure 3. A group of early grave figurines from Tlatilco in Central Mexico. Neutron activation analysis has shown that they were made of local Tlatilco clay and hence were not imported into the region, as some archaeologists thought possible.

RADIATION CHEMISTRY

APPLICATION OF RADIATION-CHEMICAL METHODS TO BIOCHEMICAL PROBLEMS

Systems containing water, when irradiated, ionize and form hydrated electrons, OH radicals, hydrogen peroxide, and, if oxygen is present, superoxide ions O_2^- , in known quantities at controllable rates. These same substances figure in the basic enzyme-catalyzed oxidation reactions carried out by living things. Thus radiation provides one of the best methods to isolate and study certain biochemical reactions. At BNL radiation methods have been used to study the mechanism of action of the enzyme horseradish peroxidase.

Recently biochemists have reported that superoxide ion O_2^- appears to play an important role in many biological processes. The use of radiation-generated O_2^- at BNL has shown that the enzyme-catalyzed oxidation of the universal biochemical reductant NADH,* induced by O_2^- , proceeds *in vitro* by a chain reaction, so that one O_2^- brings about oxidation of several (up to 40) NADH:

where E is any one of several oxidative enzymes tried. This is believed to be the only enzyme-catalyzed reaction that proceeds by a chain mechanism, although whether such a chain actually occurs in living cells is not yet known. Also under way is an extensive program of systematic quantitative study of the ordinary uncatalyzed reactions of O_2^- with a variety of interesting reagents.

PROPERTIES OF EXCESS ELECTRONS IN HYDROCARBON LIQUIDS

In contrast to the vast amount of work done on the properties of conduction electrons in crystals, little is known about their behavior in liquids or amorphous systems. Mobilities of electrons produced by radiation in liquid branched and straight-chain paraffin hydrocarbons have been determined previously at BNL. Although the physical properties of isomeric liquids vary only slightly, electron mobilities in these media vary by

as much as a factor of 100. More recently, the energies V_0 of electrons injected into these liquids have been determined by shining light on metal plates immersed in the liquid or by illuminating solutions of a readily photoionized substance (tetramethylphenylene diamine) dissolved in the liquids. It was found that V_0 is lower in branched-chain than in straight-chain paraffins. The reactions of these electrons with small quantities of added substances are now being studied. They differ in some respects from ordinary chemical reactions and resemble the resonant dissociative-capture interactions of electrons with isolated molecules in the gas phase. In liquid hydrocarbons, V_0 plays the role of the energy of the free electron in the gas phase. Since in a given solvent V_0 increases with decreasing temperature, the electron reactions in solution may become either slower or faster with increasing temperature, unlike most other chemical reactions.

NEUTRON DIFFRACTION STUDIES OF BIOCHEMICAL BUILDING BLOCKS

Many large molecules necessary to biological processes are composed of nucleic acids and proteins. Nucleic acids are polymers of nucleotides and proteins are polymers of amino acids. Many of the functional characteristics of the macromolecules depend on the spatial order and exact arrangement of their individual subunits. Pauling and co-workers were able to predict, from x-ray crystallographic studies of amino acid structures, the basic types of protein structure. The famous postulate of Watson and Crick on the helical structure of DNA was based in large part on the known geometrical properties of the basic molecular building blocks that were known to make up the macromolecule. One important component of the exact way in which these small molecules join to form the large ones is the specific interaction between hydrogen atoms and other atoms – the hydrogen bond. In addition, knowledge of carbohydrate chemistry has been advanced greatly by studies of the detailed electronic structure and the role of hydrogen bonding in sugars.

Neutron diffraction is the only way in which hydrogen atoms can be accurately located in molecular crystals. A comprehensive series of such studies of the commonly occurring amino acids has been completed at Brookhaven and has led to a very good general picture of the geometries and

*Reduced nicotinamide-adenine dinucleotide.

energies of N—H...O hydrogen bonds. Studies of several nucleosides and a purine-pyrimidine base pair have also been carried out. (A drawing of the latter structure is shown in Figure 4.) The work is being extended to small peptides, dinucleoside phosphates, and sugars. The results of these studies will be invaluable in understanding the structure and function of biological molecules.

GASEOUS ION CHEMISTRY

Techniques developed in the study of gaseous ion chemistry have proved to be of great value in the identification and analysis of structures of molecules of biochemical interest. The development of a tandem mass-spectrometer system for

Figure 4. Stereoscopic drawing of the purine-pyrimidine base pair 9-methyladenine-1-methylthymine. H, hydrogen atoms; C, carbon atoms; N, nitrogen atoms; O, oxygen atoms. The computer is programmed to analyze the data collected by the neutron spectrometer, to determine the geometric position of each atom in the molecule, and also to draw figures of the type shown above, which allow the three-dimensional properties of the structure to be viewed.

Figure 5. Proton-transfer mass spectrum of a pentapeptide isolated from human pancreatic trypsin inhibitors at BNL by Dr. L. J. Greene and D.C. Bartelt. The pentapeptide contains the residues of the amino acids aspartic acid, serine, leucine, glycine, and arginine, in the order given. The mass spectrum contains ion fragments that establish this order of amino acid residues. Spectra were obtained from samples of <10 nanomoles (≈ 7 millionths of a gram) of peptide.

the selection of ionizing reagents that can in collision with neutral molecules effect ionization with varying degrees of fragmentation has made possible a variety of structural studies. The major obstacle to widespread application of this technique to biologically important molecules is that the latter must be converted to gaseous ions for study in a mass spectrometer. Many important molecular systems decompose extensively prior to evaporation and hence cannot be studied with the sensitive methods available here.

Techniques of volatility enhancement have been developed which provide for the gentle, relatively nondestructive evaporation of hydrogen-bonded systems such as peptides and porphyrins. The dispersal of very small samples of such molecules on relatively inert surfaces minimizes the energy holding these molecules to the surface and allows for lower temperature evaporation processes. An analysis of the relative rates of competitive evaporation and decomposition processes has shown that the rate at which samples are heated is a significant factor in limiting decomposition reactions.

With these considerations as a foundation, experiments have been carried out which demonstrate that sufficient concentrations of the relatively nonvolatile molecules such as the amino acid arginine can be produced in the gas phase to permit determination of their mass spectra. The technique has been extended to the study of a variety of peptides that hitherto required extensive chemical derivatization for their mass spectrometric study. The ability to sequence amino acid residues, that is, determine the order of amino acid residues in small peptides without derivatization, is important because much smaller samples are required and the technique is effectively one of much higher sensitivity.

A recent study of a group of underivatized tripeptides and pentapeptides that included species containing the least volatile and most difficult amino acid residues (≈ 15 different residues were involved) showed that structural mass spectrometry that gave amino acid sequences could be carried out on samples containing only a few nanomoles of peptide.

SOLUTION KINETICS

An area of continuing interest at BNL is the study of the kinetics of very rapid chemical reac-

tions in solution. The purpose of these investigations is the characterization of the elementary steps that lead from reactants to products.

SPIN AND CONFIGURATION CHANGES IN METAL COMPLEXES

Octahedral complexes of transition metals possessing four to seven *d*-electrons can exist in either high-spin or low-spin electronic configurations, depending on the strength of the ligand field. An intermediate ligand field may cause the two states to possess nearly equal free energies, resulting in thermal equilibrium between the high-spin and low-spin electronic isomers of the complex. This situation obtains in the complex bis[hydrotris(pyr-azoly)borate]iron(II), and the dynamics of the interconversion of the two spin states of the complex were studied by the laser Raman temperature-jump method. In this technique, which was developed at BNL, the temperature of a solution containing an equilibrium mixture of the two spin states is raised a few degrees in 25 nsec, and the approach of the system to the new equilibrium position is followed spectrophotometrically. The rate constant for the interconversion of the two spin states thus determined is 10^{-7} sec^{-1} . The magnitude of this rate leads to the conclusion that spin-state changes are not necessarily rate determining in electron transfer reactions of metal complexes.

The rate of configuration change of the nickel(II) complex of the quadridentate ligand $\text{NH}_2(\text{CH}_2)_2$ -

$\text{NH}(\text{CH}_2)_3\text{NH}(\text{CH}_2)_2\text{NH}_2$ [N-N'-bis(2-amino-ethyl)-1,3-propanediamine] was also studied by the laser Raman temperature-jump technique. The nickel(II) complex exists in aqueous solution as an equilibrium mixture of low-spin planar ($^1A_{1g}$) and high-spin octahedral ($^3A_{2g}$) forms:

Two kinds of perturbation were used to study this system. In the first, a wavelength of 1.41μ is used and the energy of the laser beam is absorbed almost exclusively by the water solvent; this produces a temperature jump of several degrees. At this higher temperature the original concentration of planar complex is *below* the new equilibrium value, and therefore the system (as written above) relaxes to the left. In the second method, the H_2O is replaced by D_2O and a laser beam wavelength of 1.06μ is used. In this case the primary absorption of the beam energy is by the octahedral complex, which undergoes very rapid photochemical conversion to the planar complex; the latter is now at a concentration *above* the equilibrium value, and the system relaxes to the right. The relaxation time after the temperature-jump perturbation is the same – 300 nsec – as that after the photochemical perturbation. This observation supports the concept that the photochemical reaction consists of a reaction between ground-state species, and this approach provides a unique means of making mechanistic assignments.

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HEALTH PHYSICS AND SAFETY DIVISION

The Health Physics and Safety Division functions primarily as a staff services group. The Division provides services in the following areas: health physics, safety, industrial hygiene, fire protection, and security. A small group devotes full time to basic and applied research on topics relevant to these service functions. In addition, various professional-level training courses are provided for AEC and EPA trainees and other professional groups.

ANGSTROM-SCALE DOSIMETRY

Studies were made of the spatial distribution of dose at angstrom distances ($1 \text{ \AA} = 10^{-8} \text{ cm}$) from

the tracks of heavy ions. Studies on this scale are important, since the two strands in a DNA molecule are separated by only about $17 \text{ \AA}$ and damage to DNA molecules is probably a principal step in many, if not most, biological effects following irradiation. Experimental measurements were made of 33 to 62-MeV oxygen and iodine ions with use of a unique variable pressure ionization chamber to expand the track of ionization by as much as a factor of 10^8 . In addition, detailed Monte Carlo-type computer calculations were made to relate theory and experiment. Programs were also written to provide detailed plots of secondary electron tracks and positions of all ionizations.

Figure 1. Computer-simulated end view of a 980-Å segment of a track formed by a 4-MeV α particle passing through tissue. Paths of ejected secondary electrons are shown as lines. Ionization events are shown as small circles.

RADIATION CARCINOGENESIS

Published data on neutron induction of mammary tumors in rats were analyzed. The data contained several unexplained features, including saturation of effect at doses above 50 rads and greater effectiveness per unit dose at progressively lower doses. A mathematical model that correctly predicts both the dose response and the kinetic (time) response was developed. This analysis indicates that five events (mutations?) are required to complete the process of carcinogenesis. Two of these occur simultaneously, along a single proton recoil track, during irradiation. The three other events occur in the course of natural processes.

FIRE SAFETY

A series of fire tests was conducted of a prototype Halon 1301 (bromotrifluoromethane) fire

extinguishing system. Humans can tolerate a high concentration of this agent, and thus workers can remain in the vicinity of the fire to carry on shut-down or other necessary operations. However, decomposition products formed in a high-temperature flame can be a problem under some conditions. Concentrations of these products were measured in various test fires and at different extinguishing rates to determine the applicability and limitations of the system for use at Brookhaven.

NEUTRON SKYSHINE

Large high-energy accelerators act as large-area low-intensity sources of neutrons. Optimum shield designs for these machines can be made only if one has knowledge of the energy and intensity of the radiation (primarily neutrons) that is backscattered from the atmosphere (skyshine). A mobile system of eight neutron detectors is used to study neutrons with energies from thermal to ≈ 20 MeV. These detectors are radio controlled and gated so that they measure accelerator-produced neutrons while the accelerator beam is on a target, and background neutrons at other times. These studies have shown significant differences between the energy spectrum of skyshine neutrons and that of cosmic-ray-produced neutrons.

NEUTRON PERSONNEL DOSIMETERS

The measurement of small neutron doses received by experimenters working near high-energy accelerators and beams is difficult because of the wide range of neutron energies involved. Methods of reducing fading of the latent image in conventional nuclear track emulsions were examined. In addition, a new dosimeter, incorporating a combination of thermoluminescent detectors and plastic track detectors in contact with a thin thorium foil, was developed and tested in a variety of accelerator radiation fields. The new dosimeter can be worn for many months without the introduction of large errors due to fading.

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INSTRUMENTATION DIVISION

The Instrumentation Division engages in research and development on recognized problems

in scientific instrumentation that are important to the long-term goals of the Laboratory and the AEC. The Division also provides consultation, advanced instrument design, construction of instruments not commercially available, and repair

Figure 1. Charge spectrum obtained with a large liquid-argon ionization chamber and with a 7-GeV/c negative beam. Peaks from left to right are muons, pions, electrons, and calibration pulser.

Figure 2. Charge spectrum like that of Figure 1, but with electrons enhanced by gating with a Čerenkov counter.

services for other departments of the Laboratory. Members of the Division also collaborate in experiments at BNL and other laboratories when they can contribute significantly to the advance of scientific research with new devices, methods, and techniques.

The principal areas of research activity are the detection of nuclear particles and of radiation with semiconductors and gaseous and liquid detectors; application of nuclear techniques in medicine and other fields; processing of signals from detectors; low-noise and other special electronic circuits; and computer system applications in sci-

entific experiments. Some of the more important recent results are described below.

LIQUID-ARGON IONIZATION CHAMBERS AS TOTAL ABSORPTION DETECTORS

The liquid-argon ionization chamber, a total absorption spectrometer (calorimeter) for use in high-energy physics, is a segmented ion chamber with finely divided plates and liquid argon as the working medium. The ionization released in the liquid argon is a good measure of the total energy of incident particles and helps in their identification. In a collaborative effort between Yale University, the Accelerator Department, and the Instrumentation Division, a large test chamber was constructed of 200 steel plates 2 mm thick, with 1.6-mm gaps filled with liquid argon; it is 72 cm long and has an area of 600 cm².

The feasibility of this approach has been proved in tests conducted during the past year. Charge collection properties in liquid argon have been determined. Signal processing methods have been developed that will allow operation of the detector at very high event and background rates.

Some illustrative test results are shown in Figures 1 and 2. Figure 1 shows the pulse-height (charge) spectrum obtained with a 7-GeV/c negative beam. The peaks from left to right are muons, pions, electrons, and the calibration pulser. Figure 2 shows the spectrum for 7-GeV/c electrons gated with a Čerenkov counter.

ELECTRON DRIFT VELOCITY INCREASE IN LIQUID-ARGON ION CHAMBERS

The drift time of the electrons across the ion chamber gaps filled with liquid argon limits the maximum applicable particle rate. In an effort to increase the saturated electron drift velocity without diminishing the collected charge, several additives to liquid argon were investigated.

A double-gap ion chamber with built-in electron and α -particle sources was used. Minimum ionizing tracks were selected by coincidence counting of the two gaps. The α -particle-induced pulses provide a measure of electron drift velocity, and in addition their amplitude is a sensitive indicator of "poisoning" of the liquid by electronegative impurities.

The best results so far were obtained by the addition of methane, which increased the saturated electron drift velocity by the logarithm of the methane concentration between 0.01 and 1%. An

improvement of about a factor of 4 in the drift velocity (from 200 nsec/mm in pure liquid argon to 50 nsec/mm with methane) can be achieved without significant reduction in the collected charge.

A NEW TRANSITION RADIATOR-DETECTOR SYSTEM

A new type of particle detector using transition radiation was developed and tested in collaboration with the Accelerator Department and Yale University. These devices permit the identification of very-high-energy particles at energies where

more conventional detectors like Čerenkov counters become inefficient. Because of their low mass the new devices do not appreciably interfere with the particles traversing them.

The radiator, whose x-ray emission increases almost linearly with the γ ($=E/mc^2$) of the particle traversing it, consists of lithium metal foils which display a low self-absorption for x rays because of the low atomic number ($Z=3$). This allows the efficient use of a large number of foils (e.g., 1000), and many more photons are produced than in previous work. The photons are detected in a multiwire proportional detector filled with xenon at atmospheric pressure. The high atomic number ($Z=54$) of xenon allows reasonably efficient ($\approx 50\%$) detection of the x rays in only 10 mm of gas. This gives a very favorable ratio between the energy deposited in the form of transition radiation x-rays and the energy lost by the incident particle through ionization. The incident particle also traverses the proportional chamber. Figure 3 shows examples of the pulse-height spectra for e^- and π^- taken (a) at 1.4 and (b) at 2.5 GeV/c with use of a single radiator-detector set (1000 lithium foils, each 51μ thick).

Up to now, the reported x-ray energy collected with Mylar or similar radiators and argon or krypton detectors was less than the ionization loss in single radiator-detector sets for this γ range. Here, with γ already >2000 , the x-ray energy is a few times larger than the ionization loss, which results in the good particle-discriminating properties of the Li-Xe combination.

MULTIWIRE PROPORTIONAL CHAMBER FOCAL PLANE DETECTOR

Multiwire proportional chambers were developed for use in the 2.5-m focal plane of a high-resolution magnetic spectrometer (QDDD) at the BNL Tandem Van de Graaff, which would simultaneously provide good position resolution and linear dE/dx information for particles ranging from protons to heavy ions, at angles of incidence ranging from 22 to 47° off normal. Particle positions are read out from the cathode wires, which are connected at equal intervals to a delay line employing "electronically cooled" terminations for improved signal-to-noise ratios and spatial resolution. The particle position is determined from the arrival times of the induced cathode signal at the two ends of the delay line. The energy loss of the particles traversing the chamber is determined from the signal at the anode wires.

Figure 3. Pulse-height spectra for e^- or π^- taken with a single radiator-detector configuration (1000 lithium foils in ≈ 10 mm xenon) at (a) 1.4 and (b) 2.5 GeV/c. The spectrum for e^- with lithium represents the signal due to transition x rays, background radiation, and ionization loss, while the other spectra do not contain the transition x rays. The pion (π^-) data contain an electron contamination of 0.5 and 1.8% at 2.5 and 1.4 GeV/c, respectively. The histogram of e^- with dummy at 2.5 GeV/c is not shown. However, the distribution is quite similar to the one at 1.4 GeV/c because of the saturation of ionization loss due to the density effect in xenon.

The spatial resolution for 12-MeV protons was $250\ \mu$ full width at half maximum (FWHM) with argon gas at atmospheric pressure. Figure 4 shows the position spectrum for 48-MeV oxygen ions at 30° incidence. The spatial resolution is $\approx 150\ \mu$ FWHM with gas pressure of 50 to 200 Torr.

A 20×4 -cm chamber has already found use in the initial setup experiments of the QDDD. The detector's spatial resolution exceeds present requirements. A 50×4 -cm chamber is under construction.

POSITION-SENSITIVE NEUTRON DETECTOR

A 17-cm^2 two-dimensional position-sensitive ^3He gas-filled multiwire proportional chamber for the imaging of neutron diffraction patterns has been developed. Spatial resolution is $<3\text{ mm}$ and efficiency is $>80\%$ for $4\text{-\AA}$ neutrons. The position of an event is decoded from the ends of each serially connected wire of each cathode via charge-sensitive amplifiers in a divider network. The information is then processed via analogue-to-digital converters interfaced to a computer. Preliminary data are being collected with this device in experiments on low-angle neutron scattering from biological specimens. This detector is a prototype for a larger system of detectors that will have an active area of 1 m^2 .

SOLID-STATE DETECTOR DEVELOPMENT

Silicon and germanium detectors compensated by lithium drifting have been the major spectrometers for x and γ rays, respectively. X-ray energy resolutions as low as 200 eV with Si(Li) detectors have permitted the resolution of characteristic x rays of elements down to sodium and have stimulated the field of x-ray fluorescence analysis. The availability of these high-resolution detectors has evoked renewed interest in proton- and x-ray-induced fluorescence for convenient detection down to concentrations of a few ppm for a wide range of elements. Ge(Li) γ -ray spectrometers having active volumes of up to 80 cm^3 and energy resolutions below 2 keV at 1.332 MeV (^{60}Co) have been developed and made available for Brookhaven experiments. Recently, a high-purity ($\approx 10^{10}$ impurities/ cm^3) germanium that does not require lithium compensation has been produced by the General Electric Company. Use of this material allows the detector to be returned to room temperature when not in use (although germanium must be used at liquid nitrogen temperature); the na-

Figure 4. Position spectrum obtained with the multiwire proportional detector for 48-MeV ^{16}O ions collimated into a narrow beam. Two beam positions displaced by 1.2 mm are shown. Chamber gas, argon + methylal, 200 Torr.

ture of surface stabilization to ensure complete temperature and ambient cycling is under investigation. Epitaxial GaAs in thin wafers grown from the liquid phase has been found to possess adequate mobilities and lifetimes for both holes and electrons, which results in reasonable performance as a (low-energy) spectrometer, specifically, 2.4-keV resolution of a 60-keV γ ray. This high band gap material is operated at room temperature and should find some application as a simple x-ray spectrometer.

Studies of the fast neutron radiation damage effects on germanium γ -ray spectrometers have been carried out by using representative detectors with controlled irradiations. Damage-induced traps cause worsened energy resolution in the range between 10^9 and 10^{10} n/cm^2 ; little difference in the dose threshold has been noted between Ge(Li) and Ge(HP) detectors; however, the annealing of damage is distinctly different for each type of detector.

APPLICATIONS IN NUCLEAR MEDICINE

Several applications of high-resolution semiconductor detectors have been made in the field of nuclear medicine. A large-area Ge(Li) detector has been compared with a conventional NaI(Tl)

detector in a rectilinear scanner and found to possess superior scatter rejection and adequate sensitivity. A high-resolution x-ray detector system has allowed spectroscopy to be employed in a system of transmission scanning.

The distribution of an element may be imaged by comparing the transmission of x rays of energy just above and just below the critical absorption edge. Good images of low-level amounts of iodine and xenon have been obtained in humans and animals. A high-resolution Si(Li) detector has been used in conjunction with the scanning electron microscope to produce elemental as well as morphological images of a wide variety of samples. The usefulness of the analytical capabilities of proton elastic scattering (of several MeV) in the area of light rare isotopes has been explored. Measurements of ^{13}C and ^{18}O in thin samples can be made easily. Proton-induced fluorescent x-ray analysis has also been studied by this group and found to be comparable in sensitivity to analysis by x-ray-induced fluorescence.

COMPUTERS IN SCIENTIFIC EXPERIMENTS

A major project under development by the Computer Systems Group is an advanced experiment control and data acquisition system (RECF) for use at the High Flux Beam Reactor at BNL. This system simultaneously controls triple-axis spectrometers for ten neutron experiments and one x-ray diffraction experiment undertaken for molecular structure determinations. The system has a "finger" structure in which eleven small computers (or private processors), each supervising a single spectrometer system, communicate directly with a central or common node computer.

The primary objective determining the concept of the system is to provide as much isolation between individual experiments as possible. A hardware or software failure occurring within a proces-

sor controlling one experiment must not affect any other experiment. This isolation can be achieved by confining control operations, which tend to be complex and may often be modified, to a processor assigned to a single experiment. On the other hand, operations that can be assigned a fixed and rigid form (such as input/output operations to a peripheral device) are performed by the central processor upon receipt of a request initiated by the private processor via the communication link. This scheme also has great economic advantages in that each private processor has access to an entire array of costly peripheral devices. It would be impossible to provide a set for the exclusive use of each individual experiment.

A second design objective is ease of program development for the private processors. This objective is met by employing FORTRAN, a scientific computer-programming language familiar to many scientists, as the private processor language. The usual obstacle to using FORTRAN in a small computer, the great length of the resulting code, is surmounted by dividing the experiment control programs into sequentially executed parts (overlays) and storing these sets of program parts on the central computer's random access device. The overlays are loaded to the memory of the private processor and executed in response to a request initiated by the private processor over the communication link. Thus the experimenter is relieved of the tedious job of writing and optimizing an assembly language code for experiment control.

The RECF system utilizes a large amount of special-purpose hardware that has been completely designed and built to the prototype stage by the Instrumentation Division. Two such hardware subsystems are the communication links between the private processors and the central computer and the required interfaces between the private processors and the spectrometers.

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MEDICAL DEPARTMENT

The Medical Department carries out both fundamental and applied research dedicated to the betterment of man's health. The Department's broad framework permits investigation in many

areas, some overlapping; encourages collaboration with neighboring academic and health care institutions; and fosters interaction with the other scientific disciplines at Brookhaven. The Hospital of the Medical Research Center provides exceptional facilities for clinical research, which is supported by basic laboratory studies.

Interests range from studies of the function of unique biochemicals to investigations of subjects as complex as the physiology of the central nervous system of man in health and disease. Related to the projects under way on the effects of radiation on human cells and tissues are new programs examining the biological effects of other phases of our environment. The unusual organization of the Laboratory and the Medical Department under Associated Universities, Inc., and the Atomic Energy Commission provides the latitude necessary for development of a project in both breadth and depth, as progress dictates. Furthermore, this organization enables the Department to respond to both immediate scientific goals and national needs.

The following report, although brief, gives some idea of the types of work being done. Additional information may be obtained from publications of the Department.

EFFECTS OF RADIATION

RADIOLOGICAL RESEARCH ACCELERATOR FACILITY

The Radiological Research Accelerator Facility (RARAF) is a joint enterprise of Brookhaven's Medical Research Center and the Radiological Research Laboratories of Columbia University. The Brookhaven Biology Department and the Department of Applied Science are also involved.

Research at the RARAF is centered on basic and applied investigations of radiation effects on living systems. Projects include radiobiological experiments on the genetic, cytogenetic, and somatic effects of monoenergetic neutrons on plant, insect, and mammalian cells. During the past two years the principal accomplishments in radiobiology have included initiation of neutron irradiations of Chinese hamster lung cells, hamster embryo cells, and spores of *Osmunda regalis*, with use of a wide range of neutron energies. Neutron irradiations of *Tradescantia*, to study the oxygen enhancement ratio and relative biological effectiveness, and of rats, to investigate induction of mammary-gland neoplasms, were continued.

In addition to dosimetry and radiation quality studies performed for all biology work, radiological physics studies included completion of an International Neutron Dosimetry Intercomparison, sponsored by the International Commission on Radiation Units and Measurements; 14 scientific groups, including 8 from outside the United States, were involved. This project entailed the develop-

ment and installation of special equipment for alignment, monitoring, and calibration. For the molecular ion beam experiment, a new project, the facility has been prepared for operation with a choice of several atomic and molecular ions to permit cell irradiations at various absorbed dose rates and linear energy transfers, and the sophisticated instrumentation and experimental techniques required to begin this work are ready.

A 4-MV Van de Graaff accelerator is utilized for the ion beams and for irradiations involving neutron energies ranging from 15 to <0.1 MeV.

RADIATION CARCINOGENESIS OF THE F MAMMARY GLAND

Data obtained in large part with use of the RARAF have given rise to a theory which suggests that radiobiological effects are due to primary lesions that may be produced by one densely ionizing particle but that require the action of at least two electrons. According to this theory, and in general agreement with experimental data, the relative biological effectiveness of highly ionizing radiation is larger at smaller doses.

The well-defined, rapid, and large mammary tumor response of the rat mammary gland to x- and neutron-irradiation has been used to determine the relative biological effect of neutrons on mammary carcinogenesis. Fourteen months after exposure either to 0.1, 0.4, 1.6, or 6.4 rads of 0.43-MeV neutrons, or to 28, 56, or 85 rads of x rays, the neutron irradiation appeared to be about 10 times more effective than x-irradiation at the higher doses and about 100 times more effective at the lower doses.

LOW-LEVEL IRRADIATION STUDIES

In these continuing studies, answers are being sought to questions that have arisen regarding the shape of the radiation dose-response curve in the vicinity of radiation levels equal to or less than background. The first system to be tested consists of a sensitive strain and an indicator strain of *Escherichia coli*. The sensitive strain is *E. coli* K-12 (λ) grown to mid-log phase, from which a bacteria-free λ phage extract is obtained.

An aliquot of the phase is coplated with an aliquot of the indicator strain, Lederberg's W 1485, that has been grown to saturation. This is grown overnight and the resulting cultures are scored for plaques. Comparisons will be made with colonies grown under heavily shielded conditions and with

a reduced ^{40}K content to minimize the background radiation.

EVALUATION OF LONG-TERM EXPOSURE TO TRITIUM

The objective of these studies is to determine the toxic effects of tritium (the radioactive isotope of hydrogen) in the mammalian system. Special attention is given to the effects on the blood-forming tissues and reproductive systems of experimental animals that continuously imbibe water containing tritium.

Groups of male and female mice have been maintained on tritiated water at a concentration ≈ 100 times the current maximum permissible concentration guidelines. After 26 weeks or more the bone marrow is tested for any changes in its ability to grow following transplantation into other lethally irradiated mice. Preliminary results indicate that there is some reduction in the viability of the bone marrow in these animals.

Other mice have been bred and the offspring kept on tritiated water until they are young adults. These second-generation animals are then bred and the pregnant females are examined to determine whether the tritiated water regimen has had any effect on the number of live embryos they produce. Results indicate that there is a reduction in the number of live embryos produced by the female when both she and her breeding partner, as well as their parents, had been given the tritium.

ANTIBODY RESPONSES ELICITED WITH COMPLEXES OF TETANUS TOXOID AND SPECIFIC MOUSE GAMMA GLOBULIN

It has long been evident that antibody formation must be regulated by homeostatic mechanisms. Primary research interest has been focused on the role of serum antibody in the control and suppression of antibody production. Inhibition of antibody synthesis appears to depend on the presence of an immunologically specific antibody for each antigen being tested. Presumably, *in vivo* combination of antibody with antigen lowers the relative capacity of antigen to elicit antibody formation. On the other hand, antithetic effects (enhanced antibody responses) have been obtained when animals are immunized with complexes of antigen and antibody formed in equivalence and in antigen excess. Early in this century, pioneer immunologists tested the antigenic properties of mixtures of antigen and antibody. Animals and

Figure 1. Primary tetanus antitoxin responses in mice immunized with complexes of fluid tetanus toxoid (FTT) formed either in antigen excess (AGEX), equivalence (EQ), or antibody excess (ABEX) with specific mouse gamma globulin (M- γ G). The amount of toxoid in the various complexes represents the same dose given as antigen only.

humans were immunized with a mixture of diphtheria toxin and horse antitoxin. Occasionally this led to tragic results when the toxin had not been completely neutralized.

Immunization with the detoxified fluid and absorbed tetanus toxoids available today provides, in general, an effective immunity against tetanal infections. It is possible, however, to elicit early and enhanced primary antitoxin responses in mice with fluid tetanus toxoid (FTT) complexed with antitoxin. The antibody response curves shown in Figure 1 indicate that early and high-titred antitoxin responses are obtained when mice are immunized with complexes formed in antigen excess (AGEX) or equivalence (EQ). In contrast, the response to FTT only was minimal at day 20. When complexed FTT was given in antibody excess (ABEX), the animals failed to produce their own antibody response until between days 20 and 30. The titer of antitoxin observed initially on days 0, 10, and 20 (ABEX) represents excess passively injected antibody since the complex was formed in ABEX. This situation results in an initial passive protection of the animals against tetanal infections, followed by active antitoxin production. This experiment shows the importance of ratios of antigen and antibody formed in complex, which may either enhance or temporarily inhibit antibody formation. Similar results have now been obtained in

man after immunization with complexes of FTT and specific human gamma globulin. These data provide substantive evidence for the efficacy of immunization with antigen-antibody complexes when early passive protection and/or later active immunization is of importance.

THYMOCYTE MIGRATION

It is well known that the thymus plays an important role in the development of peripheral lymphoid tissues and immunologic responsiveness, particularly of the so-called cellular immunities. This role is assumed to be accomplished principally by production within the thymus of immunocompetent T-cells which subsequently leave the thymus and migrate to peripheral lymphoid tissues, where they contact antigen.

Lymphocytopoiesis within the thymus is extensive; production by mitosis has been estimated to be $\approx 5 \times 10^4$ cells/mg thymus/hr in rodents. Although it has been directly shown that some lymphocytes produced within the thymus emigrate, the fraction of newly formed thymocytes emigrating, as opposed to the fraction disintegrating within the thymus, as well as the life-span and ultimate fate of emigrants, remains controversial. In view of current immunologic dogma, it is important that these kinetic parameters be ascertained.

Two related experimental approaches have been used to obtain additional information pertaining to these questions. Comparison of DNA renewal rates measured with tritiated thymidine and those measured with iododeoxyuridine (a thymidine analogue specifically incorporated into DNA but poorly reutilized) permits an estimation of thymidine reutilization and, by inference, cell death. Data obtained in newborn mice indicate that possibly as much as 60% of the thymidine in the thymus is replaced via the salvage pathway, an indication of substantial intrathymic cell death during this period. Local labeling of the thymus by topical application of ^{125}I -iododeoxyuridine (IUdR) and subsequent tracing of the activity to various body tissues and fluids allow some quantitative estimation of thymocyte migration. Preliminary results in young adult mice suggest a relatively small degree of migration to peripheral lymphoid tissues. The majority of the activity appears in the urine within 5 to 8 days after application of IUdR, which suggests that most thymocytes disintegrate rather rapidly, either in the thymus or after a very short intrathymic life.

BLOOD CELL KINETICS

In order to examine their pattern of proliferation and maturation, the blood and marrow cells of patients with myelofibrosis have been cultured in the diffusion chamber system. Two studies were done, one with blood nucleated cells of a patient who had classical features of myelofibrosis with myeloid metaplasia (MMM), and one with marrow nucleated cells of another patient who also had features of MMM.

Results indicated that the total cell recovery from cultures of MMM cells differed slightly from that from normal cell cultures and markedly from that from chronic myelocytic leukemia (CML) marrow cultures. Erythropoietic cell recovery, as measured by the normoblasts recovered from the cultures on day 9, was at least 2 to 40 times greater in MMM cell cultures than in normal or CML marrow cultures. These results suggest that the two MMM samples contained an increased number of neutrophilic and erythrocytic progenitors.

Although the diffusion chamber culture system has been used to study the proliferation and maturation of hemopoietic cells, the rates of proliferation and maturation in the culture system have not been compared with those occurring in man. This relationship is important if the system is to be used for studies of the kinetics of proliferation and regulation of hemopoietic cells.

Two studies have been completed in which the kinetics of proliferation and maturation of neutrophilic cells in culture has been compared with that *in vivo* (patients). In the first, the patient was suffering from MMM, and in the second, the patient had CML. $^3\text{HTdR}$ was given as a flash label to these patients. An hour later, bone marrow from the CML patient and peripheral blood from the MMM patient were obtained and cultured in the culture system. At intervals, bone marrow from the CML patient and blood from MMM patients were obtained to follow the labeled cells' pattern. Chambers were also harvested at intervals and the labeled cells were followed. Results indicate that the maturation pattern of neutrophilic cells in the cultures is orderly but that the rate of maturation is higher than *in vivo*.

CULTURE OF AUTOLOGOUS BONE MARROW IN DIFFUSION CHAMBERS: EFFECT OF HOST IRRADIATION

Autologous bone marrow cells were cultured in diffusion chambers implanted in whole-body ir-

radiated and nonirradiated goats. Proliferation of bone marrow cells was apparent under both conditions. However, bone marrow cells cultured in the irradiated host began to increase in number earlier and at a faster rate than their counterparts in nonirradiated animals. The number of cells harvested from diffusion chambers in irradiated hosts 12 days after implantation was 3 to 4 times larger than input values. Control values did not significantly exceed the number of cells inoculated. The simultaneous increase in the number of granulocytes in peripheral blood and in diffusion chambers of irradiated hosts was paralleled by an initial increase in serum colony stimulating factor in these animals. Proliferation of erythrocytic and megakaryocytic cells was observed in chambers of irradiated hosts only, at a time when there was a radiogenic ablation of host marrow. These observations provide strong evidence for diffusion of humoral stimulators from the host into the diffusion chambers. The stimulation appears to be elicited or enhanced by irradiation of the host.

Figure 2. Interconnected multilayers of cells derived from a human cancer of the cervix grown in diffusion chamber cultures. 2000 $\times$.

TUMOR CELLS IN DIFFUSION CHAMBER CULTURE

Cancer is characterized by the uncontrolled growth of cells, but in its various forms it may be considered as many diseases affecting many organs. Even the growth of cancerous cells of the same type varies from individual to individual. The variability of cancerous growth and the varied response of malignant cells to therapy have made the understanding and treatment of cancer complex and difficult. These complexities have led to investigation of the reproducibility of tumor cells grown under physiological conditions in diffusion chamber cultures. These cultures consist of cells grown in cylinders made with pores small enough to contain (or exclude) cells and large enough to allow the passage of nutrients from the abdominal cavity of the host in which the cylinder is placed. Work done at BNL has shown that the growth of a population of HeLa tumor cells (derived from a human cancer) slows when the cells are transferred from cultures *in vitro* to diffusion chamber cultures. The reproducibility of diffusion chamber cultures is as good as or better than that estimated for tumor growth *in vivo*. It was discovered that HeLa cells in diffusion chamber culture grow in interconnected multilayers (see Figure 2). These results suggest that diffusion chamber cultures of tumor cells may mimic tumor growth in animals and patients and that such cultures may be used to determine reproducibly the growth of tumor cell populations grown under physiological conditions.

PHYSIOLOGY OF ERYTHROPOIESIS AND REGULATION OF ERYTHROPOIETIN PRODUCTION

It has been shown at BNL that long-term cultures of renal glomeruli are capable of producing erythropoietin in significant quantities. The objective of this study is to further develop the culture system in order to provide a source of hormone for research and clinical testing. Basic mechanisms regulating erythropoietin production and release are studied in hormone-producing cultures exposed to assorted stimuli by seeking the underlying enzymatic determinants and correlates of altered hormone production. Purification and chemical characterization of culture-produced hormone are approached via affinity chromatography and other purification procedures. Efforts are being made to prepare radioactively labeled hormone in culture for use in developing a sensitive and reliable radioimmunoassay for the hormone.

In a related study ^{55}Fe is used as a cytotoxic agent to selectively kill erythropoietic precursor cells during the stage in which iron uptake is high. The method is applicable to current scientific problems in three areas:

1. Increased human body burdens of ^{55}Fe have been found after atmospheric atomic bomb tests. While the resulting damage is difficult to predict because of this isotope's extremely short range of energy deposition, this method will make possible a more precise investigation.

2. During cytocide, the hemopoietic stem cell pool must provide fresh red cell precursors at a rate that guarantees survival of the animal by overcompensating for the cytocide rate. This creates a drain on stem cells that leads to stem cell exhaustion if their division potential is limited. Thus ^{55}Fe cytocide may provide an *in vivo* test of Hayflick's hypothesis, which states that normal mammalian cells cannot divide indefinitely.

3. It is possible that an intramedullary feedback loop exists that regulates cell flux from the stem cell pool into red cell formation. This can be tested by using ^{55}Fe cytocide when intramedullary erythropoietic depopulation occurs without initial anemia and without direct damage to stem cells.

MEDICAL STUDIES OF MARSHALL ISLANDERS ACCIDENTALLY EXPOSED TO RADIOACTIVE FALLOUT IN 1954

Recent medical examinations of the Marshallese people reveal further development of thyroid nodules as a result of absorption of radioiodines from accidental exposure to fallout in 1954. During the March 1974 survey, nodules were found in two exposed Rongelap adults and for the first time in one of the four children exposed *in utero*. In addition, an unexposed woman was found to have a goiter. The patients were brought to the Medical Research Center at Brookhaven National Laboratory for special studies prior to surgery at the Cleveland Metropolitan General Hospital. The nodules proved to be benign adenomata. Thyroid lesions have been noted in 28 Rongelap people (about $\frac{1}{3}$ of those exposed). Of 29 children exposed at <10 years of age (including 4 *in utero*), 22 have developed lesions. The children received larger doses to their thyroids (up to 1200 to 1400 rads for small children compared with about 135 to 335 for adults) because of the smaller size of the gland. Twenty-five Rongelap people have had thyroid surgery. Three nodules were found to be malignant. Surgery was successful in all cases, with no

recurrence of lesions. The 157 people on Utirik Island received a much lower dose to the thyroid and the incidence of thyroid lesions there is about the same as that found in the unexposed populations examined.

The exposed Rongelap people have received routine thyroid hormone treatment since 1964. Although enhancement of growth in children appears to have been achieved, it is not certain that the treatment has reduced the development of thyroid lesions.

A fatal case of acute myelogenous leukemia, believed to be due to radiation exposure, developed in a 19-year-old Marshallese boy in 1972. He had shown greater granulocyte depression than did other exposed boys over the 19 years preceding development of the disease.

BIOCHEMICAL AND MOLECULAR STRUCTURE AND FUNCTION

BIOENERGETIC MECHANISMS INVOLVING FREE RADICALS

The properties of certain hormones and drugs may derive from free radical forms, and some theories of carcinogenesis and of somatic aging invoke free radical mechanisms. The need to detect relatively small numbers of free radicals in biomedical experimentation has led to widespread use of electron paramagnetic resonance (EPR) spectrometry, since EPR and related magnetic resonance techniques can identify and describe free radicals with the greatest sensitivity and specificity.

Figure 3. Recently acquired AEC ship used for conducting medical examinations and radiological surveys in the Marshall Islands.

Figure 4. First indications of spectral detail from the EPR spectrum of a chlorophyll free radical. The free radical produced by electron transfer from bacteriochlorophyll (BChl, the active pigment from photosynthesizing bacteria, *Chromatium* in this example) was stabilized in a sealed system containing dry and degassed solvents. Careful EPR study (a, upper left) revealed for the first time EPR spectral detail (so-called hyperfine structure, HFS) from a chlorophyll radical involved in photosynthesis. To achieve this, high-resolution low-sensitivity recording conditions were required, which necessitated an overnight run with computer adjustment of instrument drifts. The excellent signal-to-noise ratio of the spectrum thus recorded (a, upper left) then permitted accentuation of the HFS by presentation of a computer-derived second-derivative spectrum (a, upper right). Paradoxically, the spectral detail thus achieved was too rich to allow unambiguous analysis and assignment of the spectral lines. With use of a special sample cavity that focused high radio-frequency power on the BChl⁺, it was possible to obtain a spectrum by electron-nuclear double resonance (ENDOR) of the radical still in solution (b). The simpler ENDOR spectrum identified seven sets of hydrogen atom centers in the BChl⁺ molecule, each giving rise to HFS with the splitting constants listed (b). With this analysis and additional guidance from studies with "model" chemical analogues, a full set of splitting constants could be assigned to BChl⁺ (a, lower left). $a/2$ of 1 MHz in ENDOR (b) is equivalent to 0.71 G in EPR ($a/2$ = half splitting constant). This reconstruction was supported in turn by highly satisfactory computer simulation of the experimental EPR spectra, in both first-derivative (a, lower left) and second-derivative (b, lower right) presentations.

The effects of radiation attack on the component bases and nucleosides of DNA have been investigated in two types of study. In one, a fast-flow mixing system is used to produce the OH-radical species normally associated with irradiation of water, which causes much biological damage in living tissue. In this system the short-lived radical species formed from the DNA bases may be studied and identified by EPR. During the past few years the apparatus has been greatly improved, and very weak signals can now be interpreted. A special mixer was also developed for studying two-stage reactions with use of very small quantities of chemicals, including carcinogenic agents. Preliminary results have identified a reactive free radical from the carcinogen nitroquinoline-1-oxide (NQO); however, it reacts very slowly, if at all, with nucleic acid constituents. Since activated forms of known carcinogens are electron attracting, it is concluded that this radical, which is electron-rich, does not represent the generalized or ultimate carcinogenic radical of NQO.

The flow apparatus was also used in studies of the reactions of the OH-radical on purine bases and their nucleosides. Purine base radicals, plus sugar radicals (in the cases of nucleosides) were always observed, and some were identified through analysis of their EPR spectra in conjunction with isotopic substitution, molecular orbital calculations, and computer simulations.

The second type of study involves the analysis of free radicals formed in single crystals. The order of a crystal allows precise EPR measurements, and useful information has been obtained on several radical species in irradiated DNA components although they have not yet been positively identified.

Analysis of irradiated 1-methylthymine (a nucleic acid base analogue) provided evidence for a newly defined heat-stable radical.

PORPHYRIN STUDIES

Porphyrins and their oxidation and reduction products have been studied in order to better understand the mechanism of action of enzymes in which a porphyrin entity is the active center. As shown by EPR, porphyrin radicals are produced on oxidation or reduction. The cation radicals have been found to fall into two classes with characteristic optical and EPR spectra. The intermediates formed by catalase in its decomposition of peroxides are radicals of one class, whereas those formed with horseradish peroxidase fall into the

other class. Halide ions, which are known to be efficient bridges in many electron transfer reactions, have been shown to form complexes with the porphyrins and their cation radicals. Chemical kinetic studies have also been carried out to determine possible electron pathways in the reduction and oxidation of metalloporphyrins.

Chlorophylls, which are closely related to porphyrins, have also been studied. For the first time, EPR spectral detail was obtained from a bacteriochlorophyll free radical that is involved in photosynthesis. With the aid of electron-nuclear double resonance (ENDOR) the spectrum of the radical in solution was analyzed. (See Figure 4.)

NUCLEIC ACIDS

An attempt is being made to establish the various nucleic acid structures and their interaction among themselves and with environmental chemicals with the greatest possible accuracy. Approaches include investigations of the three-dimensional structure of natural double-stranded DNA, various RNA's, and synthetic polynucleotides, as well as complexes of these macromolecules with smaller molecules such as histones and novel chemicals; and studies of the effects of synthetic polynucleosides on viruses.

Earlier collaborative x-ray studies of the DNA double helix showed that it could exist in two distinct forms, *A* and *B*. *In vitro* DNA is in the *B* form, in which the base-pairs are perpendicular to the helix axis. In fibers having a low water content, DNA can go into the more compact *A* form, in which base-pairs are tilted at an angle of about 70° to the helix axis. Earlier studies have also shown that RNA has a conformation similar to that of *A*-DNA, but no x-ray evidence has been obtained for an RNA structure similar to that of *B*-DNA. This base difference in conformation between RNA and DNA double helices has been recognized by several pharmaceutical companies as having considerable potential for the development of drug molecules that act specifically against organisms (e.g., some viruses) whose genetic material is RNA and not DNA. In this context, considerable interest has been evinced in the possibility of intercalation into an RNA double helix. The conclusions from physicochemical studies on this point are conflicting. The x-ray data obtained so far do not support intercalation into RNA. Ethidium bromide has been bound to double-stranded poly(rA·rU), and this has induced a structural tran-

sition from an 11-fold to a 12-fold helix. However, no evidence for intercalation has been obtained, even at high drug/polymer ratios.

FUNCTION OF DNA POLYMERASES

Animal tissues contain at least three DNA polymerases, enzymes that synthesize DNA, the genetic material of cells. Although the biochemical reaction that these enzymes carry out *in vitro* is understood, there is little understanding of the way in which they function in replication of DNA during cell division, or in repair of DNA damaged by radiation or other environmental insults. One of the enzymes (DNA polymerase III) is unique in its preference, under certain conditions, for an RNA template. To obtain information on the physiological significance of this polymerase, its concentration and intracellular distribution have been studied in cells at various levels of proliferative activity. In the chicken red cell series, the concentration of this polymerase is high in cells that are still dividing. With the last cell division, the concentration in both nucleus and cytoplasm begins to decline, and it is quite low in mature red cells. In young dividing cells, polymerase III is located predominantly in the nucleus, but in the mature erythrocyte what activity remains is found predominantly in extracts of the cytoplasm. Chicken red cells were used in this study because they retain a nucleus even in mature circulating erythrocytes.

In other studies on HeLa cells in culture, the DNA polymerase III concentration was found to remain relatively constant throughout the cell cycle, but during *S* phase (the DNA synthetic period of the cell cycle) a large part of the total cellular enzyme is present within the nucleus. When DNA is not being made, the enzyme is found predominantly in the cytoplasm. Under all circumstances, the fraction of the enzyme in the nucleus is very firmly bound and not freely diffusible into the cytoplasm.

The most probable explanation for these observations is that DNA polymerase III takes part in DNA replication. It probably has a long lifetime in the cell and thus is present in cells after it is no longer needed.

ABNORMAL ASCORBIC ACID METABOLISM ASSOCIATED WITH HEMOSIDEROSIS-SCURVY

Hemosiderosis may be caused by the ingestion of large quantities of iron in food prepared in

metal cans. This disease is quite prevalent in South Africa. Severe grades of the disease show a scurvy-type skin and osteoporosis. The hemosiderosis is the primary condition that produces an ascorbic acid deficiency. The association between the hemosiderosis and ascorbic acid deficiency is a direct one and not simply a reflection of dietary inadequacy, since reduced stores of vitamin C have been found in some well-nourished patients suffering from iron overload, due either to multiple blood transfusions or to ingestion of excessive quantities of commercial vitamin-mineral preparations. Studies in which these patients are given very small doses of labeled ascorbic acid show the conversion of as much as 47% of ^{14}C -labeled ascorbic acid into $^{14}\text{CO}_2$ in the first 24 hr, compared with a "normal" conversion of about 2%. The half-life of ascorbic acid in these patients was only 1 day, compared with 7 days in a "normal" group. The isolation of labeled compounds from the urine of the patients demonstrated that the ascorbic acid was metabolized very rapidly by a pathway other than the one considered to be normal.

The osteoporosis of these patients may be described as a degeneration of the bones. Ascorbic acid is known to be essential in the synthesis of collagen, a compound of importance in bone structure and maintenance. Further studies of vitamin C metabolism in these patients may lead to the proper use of vitamin C in the treatment of a number of different disease entities.

CLINICAL AND METABOLIC STUDIES

In Vivo MEASUREMENT OF RADIONUCLIDES IN MAN, KINETIC STUDIES, AND *In Vivo* NEUTRON ACTIVATION ANALYSIS

Calcium metabolism is studied in various disorders of the skeletal system. The principal techniques employed are total-body neutron activation analysis, ^{47}Ca tracer kinetic analysis, and whole-body counting.

The development of total-body neutron activation analysis (TBNA) has opened up new research possibilities. TBNA is the only technique currently available for determination of the elemental composition of a living organism. The clinical usefulness of the TBNA technique is most clearly demonstrated by the measurement of total-body calcium. This measure provides useful data for the diagnosis and management of meta-

bolic bone diseases. Total-body calcium measurement has been applied in establishing absolute and relative deficits of calcium in patients with osteoporosis, as compared with a normal contrast population. Changes in total-body calcium (skeletal mass) have been most useful for quantitating the efficacy of various therapies in osteoporosis. Currently, the effects of long-term administration of synthetic salmon calcitonin, sodium fluoride, calcium supplements, and growth hormone are being evaluated in the treatment of osteoporosis.

It is also of clinical value to relate the skeletal mass (total calcium) to muscle mass (total potassium) in various disorders. Both total-body calcium and potassium have been measured simultaneously in patients by TBNA and by whole-body counting, respectively, to establish this relationship.

In renal failure, bone disorders and disturbances of sodium and chlorine are being studied. The measurement of the total-body levels of these elements gives the clinician data useful in designing his therapy. For example, changes in the concentration of calcium in the dialysis bath solution of patients on chronic dialysis have been shown to be reflected quickly in the total-body calcium of the patient. Thus dialysate concentrations can be adjusted to reduce the loss of calcium from the body that is associated with dialysis.

The therapeutic effects of vitamin D and 25-hydroxy-cholecalciferol have been investigated. A compartmental analysis of ^{47}Ca kinetic data was employed to evaluate parameters of calcium metabolism before and after therapy.

In endocrine dysfunctions, the measurement of bone changes has been studied, particularly in patients with disorders of the thyroid and parathyroid. Skeletal metabolism and body composition are being studied in diabetes, acromegaly, rheumatoid arthritis, osteogenesis imperfecta, and in a number of other bone disorders.

These are some of the recent clinical applications of TBNA. It is clear that they only suggest the large potential of this technique. The Brookhaven TBNA facility can serve as a prototype for other activation facilities in other medical research centers.

STUDIES ON CARBOHYDRATE AND LIPID METABOLISM

The metabolism of various isotopically labeled carbohydrates has been followed in control subjects and in patients with obesity, diabetes, and hyperlipidemia (high blood fat). Methods have

been developed with which an individual's lipogenic potential can be evaluated by the extent of conversion of carbohydrate to blood triglycerides. A tracer dose of ^{14}C -labeled carbohydrate was orally administered to individuals in conjunction with a "cold" carbohydrate load (40 g/m² body surface area), and the blood was sampled at various times up to 12 hr for isolation of triglyceride-x as well as triglyceride-fatty acid- ^{14}C . This study indicates that the peak radioactivity is usually reached between 3 and 6 hr and that its value correlates well not only with the fasting plasma triglyceride concentration but also with the production or turnover rate of plasma triglyceride obtained by an independent technique, *viz.*, endogenous labeling with ^3H -glycerol. The method of ^{14}C -loading, however, provides the additional advantage of studying an individual in the postprandial as well as the postabsorptive state. It is in the former state that the formation and removal of plasma triglyceride is most active.

One objective in these studies is to gain an understanding of hypertriglyceridemia (high blood triglycerides) induced by high carbohydrate feeding – its pathogenesis and prevention. In recent years, this condition has been found to be extremely prevalent in our population, and certainly it ranks as one of the major risk factors in coronary heart disease. Heavy consumption of sucrose (table sugar) has been particularly implicated as causative. Therefore, sucrose-induced hypertriglyceridemia could serve as an interesting disease model both for understanding carbohydrate induction in general and for evaluating any unique effects of high sucrose feeding. With use of the ^{14}C -loading technique, it has been shown that after a period of sucrose-rich diet the peak radioactivity in plasma triglyceride is greater and appears earlier than before the diet (Figure 5). Simultaneous measurement of the rate of conversion to breath $^{14}\text{CO}_2$ also shows an increase after sucrose-rich diet during the first 2 hr after ^{14}C -loading. The increase in both the lipogenic and the oxidative pathways suggests that more sucrose from the oral load is being absorbed and presented to both pathways, and this is probably related to an increase in sucrase (a disaccharidase) in the intestinal mucosa induced by the sucrose-rich diet. In addition, a selective increase of ^{14}C in the fatty acids, but not in the glycerol moiety of the plasma triglycerides, is found. This is a characteristic feature of insulin effect. Previously, a higher insulin response to oral sucrose

Figure 5. Relative conversion of "sucrose- $\text{U-}^{14}\text{C}$ " to plasma triglyceride- ^{14}C , triglyceride-fatty acid- ^{14}C , and glyceride-glycerol- ^{14}C after a labeled oral load of 40 g sucrose per m² body surface area, with low and high sucrose diets. Left bars represent values with low sucrose diet, right bars, values with high sucrose diet. Total triglyceride- ^{14}C is represented by the entire bar, triglyceride-fatty acid- ^{14}C by the shaded area, and glyceride-glycerol- ^{14}C by the difference between the two.

load after high sucrose feeding was observed, and this may represent another effect of the sucrose-rich diet on the intestinal mucosa, *i.e.*, the induction of insulin secretagogue(s). On the basis of these findings it is concluded that an acute intake of sucrose will cause a higher conversion to plasma triglyceride, if one habitually consumes proportionally more sucrose than other carbohydrate in the diet.

Studies such as the above can be modified and extended to large groups of high-risk patients, including females on contraceptive steroids, or patients with atherosclerosis, diabetes, etc. Both the basal lipogenic potential of an individual and his susceptibility to high sucrose feeding can be evaluated. Such information will be of great interest from investigative, diagnostic, and preventive points of view.

STUDIES ON HYPERTENSION

In investigating the etiology and pathogenesis of hypertension (high blood pressure), emphasis is placed on the interaction between genetic determinants and modifying environmental factors. The impetus for these studies was provided by the observation that sodium intake could modify blood pressure in man and in rat. For man, conclusions had to be based on statistical evaluation of clinical and epidemiological data, since individual responses were unpredictable. With rats, this prob-

lem was solved at BNL by selective breeding that produced two colonies whose blood-pressure responses were opposite and predictable. One colony, designated R rats, develops hypertension only after extraordinary insults. The other colony, the S rats, develops hypertension readily from insults to which the R rats are generally unresponsive.

When any of the many factors regulating blood pressure varies from its "normal" range, hypertension may develop. Some animals are more likely than others to develop hypertension because of a genetic component that determines how much variation is tolerated. Extensive epidemiologic and experimental evidence suggests that salt intake is one of the factors that may trigger hypertension in some animals and man. However, in studies with these two unique rat colonies it has been shown that animals sensitive or resistant to the effects of salt are generally sensitive or resistant to other noxious stimuli considered to be "causes" of hypertension. It is therefore probable that different forms of hypertension have more in common than might be suggested by the variety of so-called causative agents.

Because of the genetic and environmental heterogeneity of man, it is difficult to separate and evaluate the relative importance of environmental and genetic influences. With the two rat colonies, environmental influences can be controlled when studying the genetic aspect, and vice versa. The results of a large, formal genetic study extending over a period of six years indicated that from two to four genes might be responsible for control of blood pressure in these animals. Attempts are being made to determine the specific biochemical functions controlled by each of these genes, and one such gene-action has been identified. More of a special mineral-steroid (18-hydroxydeoxycorticosterone) is produced by adrenal glands from the hypertension-prone (S) rats than by those from the hypertension-resistant (R) rats. With use of classical genetic breeding techniques, the difference in steroid production has been shown to arise from the action of a single Mendelian gene inherited by codominance. Calculations indicate, however, that this gene accounts for only about 16% of the disparity in blood pressure between the two strains. The other genes predicted from the original genetic analysis must therefore account for the remaining blood pressure difference.

It had been found earlier at BNL that specific receptors of the S rats were twice as sensitive as

those of R rats to angiotensin II, which causes elevation of blood pressure, but that plasma renin activity was only half that in R rats. (Renin, an enzyme normally found in the body, initiates the chain of reactions leading from angiotensinogen through angiotensin I to angiotensin II.) No difference was found between the two strains in concentrations of converting enzyme (which catalyzes the conversion of angiotensin I to angiotensin II) and angiotensinogen. Preliminary analyses of angiotensin I by radioimmunoassay do not show differences between the strains. These studies tend to minimize the importance of the renin-angiotensin system in the pathogenesis of hypertension in S rats.

An additional factor derived from plasma of either strain gives a vasopressor response in the S rats, but not in the R rats. Its sensitivity to pepsin and chymotrypsin indicates that it is a peptide, but its insensitivity to trypsin suggests that it is not related to angiotensin. This factor, unidentified as to origin, structure, and function, is of interest since, if it proves to be unique to S rats, it may constitute a genetic "marker" for hypertension.

STUDIES OF PARKINSONISM AND RELATED CONDITIONS

The search for new dopaminergic agents as substitutes for levodopa led to an analogue of apomorphine, *n*-propyl apomorphine. This drug, in

Figure 6. Effect of incorporating levodopa in diet of young male mice. Both mice were 18 months old when the picture was taken. Mouse A consumed 40 mg levodopa per gram Purina for 17 months. Mouse B consumed only Purina.

small oral doses, was found to be more potent than apomorphine and to demonstrate therapeutic effects comparable to those of levodopa in some patients. Thus, for the first time the administration of an amine, instead of an amino acid such as levodopa, was shown to be effective in the treatment of Parkinsonism. Unlike levodopa, however, this agent was shown to progressively lose its therapeutic effectiveness. Newly synthesized analogues of apomorphine and piperidine are continuously being tested in animals for dopaminergic activity prior to investigations in man.

Studies of the effects of levodopa on general health led to the significant finding that tolerable amounts of levodopa incorporated in the diets of young male mice and administered indefinitely induced a youthful appearance and prolonged the life-span of these mice (Figure 6). Chemical or traumatic keratitis was induced in some animals. These experiments can serve to further reassure patients with Parkinsonism of the safety of long-term levodopa treatment.

NUCLEAR MEDICINE

DEVELOPMENT OF DIAGNOSTIC IMAGING TECHNIQUES

The interdisciplinary program with the Department of Applied Science and the Chemistry Department has concentrated primarily on the development of radiopharmaceuticals labeled with short-lived, accelerator-produced radionuclides from the 60-in. cyclotron and the Brookhaven Linac Isotope Producer.

^{123}I , a superior radionuclide for thyroid imaging, is now being studied as a label for a number

of molecules of biological interest. Among these is 4,3 DMQ (an isoquinoline analogue), which selectively localizes in melanomas, and indocyanine green, which is useful for hepato-biliary imaging and function studies. ^{123}I -orthoiodohippurate has been shown to be useful for assessing renal function, especially in patients with poor renal function, because the radiation dose required is much lower than that with ^{131}I . The lower gamma energy of ^{123}I is more efficiently detected and collimated than the emissions from ^{131}I .

The myocardial imaging agents currently in use suffer from various deficiencies such as high gamma energies and general unavailability. A method has been developed for production of high-purity ^{201}Tl , a radionuclide with excellent physical properties. Study of its biological distribution in large animals indicates that it should be useful as an "off-the-shelf" agent for noninvasive study of myocardial infarction and insufficiency. Studies in patients have confirmed the expectation that the radionuclide would be superior in its ability to image the myocardium.

Another material useful for evaluation of myocardial function is ^{99m}Tc -labeled red blood cells. A new method, available in kit form, has been developed that greatly simplifies the procedure of labeling and gives a 97% yield. Electrocardiographic gated images in systole and diastole have had excellent resolution and allow the measurement of left ventricular ejection fraction.

Clinical evaluation of ^{18}F -fluorotryptophan for pancreas imaging is just beginning. ^{11}C -dopamine preclinical studies for adrenal imaging have been completed and clinical studies have been instituted.

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PHYSICS DEPARTMENT

The Physics Department carries out fundamental research in elementary-particle (or high-energy), nuclear, and solid state physics. In each discipline, the experimental program is based in large part on one of Brookhaven's major facilities. These research facilities provide unique capabilities not only to the BNL staff but also to the national scientific community. BNL operates and continuously develops and improves these facilities, and

the Physics Department staff has a role in fulfilling this important mission. In this short report, only samples of these activities can be offered.

LOW-ENERGY NUCLEAR PHYSICS

NUCLEAR PHYSICS

A simple way of characterizing the nature of an experimental program in nuclear physics is in terms of the source or accelerator it employs. Thus the research program can be separated into charged-particle and neutron nuclear physics,

based on the Tandem Van de Graaff Facility and the High Flux Beam Reactor. The Physics Department is also responsible for operating and developing the Tandem Van de Graaff Facility (described in the Facilities section) for the whole nuclear community. The theoretical group interacts with these experimental programs and pursues basic theoretical studies.

RESEARCH WITH THE TANDEM VAN DE GRAAFF

The experimental program based on the BNL Tandem Van de Graaff Facility is divided into two parts. The study of reactions induced by projectiles with mass $A > 4$ which span the range from ${}^6\text{Li}$ to ${}^{208}\text{Pb}$ comprises the largest part. A smaller part is concerned with the study of reactions induced by light particles ($A \leq 4$).

The wide variety of heavy-ion beams available as high-energy probes of nuclear matter has opened up new, exciting avenues of research in nuclear physics. When two heavy nuclei, such as ${}^{14}\text{N}$ (projectile) and ${}^{48}\text{Ca}$ (target), collide, the phenomena that occur can be roughly divided into three categories. If the energy of the projectile is low, the ions are held apart by the large electrostatic Coulomb repulsion between them and the only reactions that can take place are those mediated by this long-range force. As the energy of the projectile is increased the electrostatic repulsion is overcome and the peripheries of the nuclear surfaces can "touch." When this happens the ions begin to experience the attractive nuclear forces as well as the repulsive electrostatic ones. Consequently

small pieces of the nuclear matter (one or two nucleons) of the projectile can transfer between target and projectile. The reaction ${}^{48}\text{Ca} + {}^{14}\text{N} \rightarrow {}^{49}\text{Sc} + {}^{13}\text{C}$ is an example. As the energy of the projectile is increased still further, the projectile and target may completely intermingle to form a compound system. A variety of compound nucleus, fusion, and fission reactions may then occur, with the reaction products bearing little resemblance to the original projectile and target. Experiments have been performed at the BNL Tandem Van de Graaff Facility to investigate all three types of phenomena.

A large and particularly rewarding part of the research program has been devoted to the second category of heavy-ion reactions: peripheral reactions involving the transfer of one or two nucleons. Several unexpected and surprising results have been obtained which contradict previous beliefs. These experiments lead to new interpretations of the reaction process and to the ability to extract various kinds of nuclear information from such reactions. One experiment involved bombarding a ${}^{48}\text{Ca}$ target with ${}^{14}\text{N}$ and measuring the angular distribution of ${}^{13}\text{C}$ particles. In this reaction a proton is transferred from the ${}^{14}\text{N}$ projectile to the ${}^{48}\text{Ca}$ target. It had been believed that only at intermediate angles was there an appreciable intensity of ${}^{13}\text{C}$ particles. The trajectories leading to small angles involved separations too large for appreciable transfer, while trajectories leading to large angles brought the ions too close for simple transfers to be probable. Only in the collisions involving the nuclear periphery, which lead to trajectories that emerge at intermediate angles, could a simple transfer reaction have a reasonable probability of occurring. If such were the case, all the angular distributions, here termed classical, would look very similar, and the amount of nuclear physics information obtained from such experiments would be minimal. In particular, no oscillations in the angular distributions would be observed and the cross section at small angles would be small. Since the wavelengths of the heavy projectile and target are short, the classical result was believed to be the inevitable one. Figure 1 shows the angular distributions measured at Brookhaven. The strong oscillations and the large peak at small angles appear superimposed on the smooth, classical angular distribution anticipated. Experiments performed with other projectiles, bombarding energies, and targets confirm that this oscillating and forward-

Figure 1. The ${}^{48}\text{Ca}({}^{14}\text{N}, {}^{13}\text{C}){}^{49}\text{Sc}$ angular distributions to the ground state and first excited state of ${}^{49}\text{Sc}$. The projectile energy is 50 MeV. Solid lines are theoretical fits to the data.

peaked behavior is a general feature of the transfer reaction. The results were interpreted by theorists and experimentalists in close collaboration.

What nuclear physics information can be extracted from these oscillating angular distributions? Some answers are already known: the characteristics of the oscillations depend on the angular momentum of the nuclear states involved and the details of the density distribution of nuclear matter in the peripheral regions. Such reactions are thus valuable tools to extract these nuclear properties. Other nuclear properties may also be involved, and experiments are continuing to fully explore the possibilities.

In this class of experiments the ability to "see" the transfer at the very forward angles is crucial. At such angles, there is inevitably an extremely large number of primary beam particles whose only interaction with target nuclei has been to experience the long-range electrostatic repulsion that is the main cause of small-angle scattering of the projectile. The reaction products, which result from the transfer of one or two nucleons between the projectile and target, are often of very low intensity in the forward direction, where the most interesting nuclear information is to be found. It has proved to be virtually impossible to detect such low-intensity transfers in the presence of the high-intensity "elastic" background by using the usual counter-telescope detection systems at forward angles. The newly constructed QDDD magnetic spectrometer has the ability to eliminate such "elastic" events from its focal plane detector and thus easily allows observation of the rare transfer reaction products at the forward angles. The success of these experiments is due in large measure to the quality of this spectrometer's operating characteristics.

In the third category of heavy-ion induced reactions, namely, those leading to compound nucleus formation, fascinating new phenomena have also emerged. This is due in part to the advantages inherent in the use of heavy ions as projectiles. There is an extremely large input of both linear and angular momentum into the composite system of target and projectile. The creation of a nucleus in states of high rotational spin at high excitation energies subjects the nuclear matter to stresses caused by the high rotational frequencies. These stresses force the nuclei into new configurations, and many of the properties of nuclear matter as measured at low excitation energy and low spin appear to un-

dergo radical changes. Moments of inertia, for example, increase dramatically with increasing spin. This is true not only for the nuclear states associated with the ground-state rotational band but also for the states of new rotational bands, which are based on particle configurations that have been excited by the internal stresses due to the rapid rotations. New bands with very large moments of inertia have been discovered in ^{126}Ba , ^{128}Ba , and ^{156}Er , with ^{12}C and ^{16}O ions used as projectiles.

The large, directed linear momentum associated with the heavy-ion projectiles causes the fused system of projectile and target to recoil at very high velocity. This rapid recoil is crucial in experiments that attempt to measure the very rapid decay times of excited nuclear states created in the reaction. If the system is still recoiling when the nucleus emits a γ ray, for example, the observed frequency of the γ ray is changed from its "normal" value. This "Doppler shift" is an indication that the recoiling nuclei have emitted the γ ray before reaching a recoil stopper placed at a variable position downstream from the target. The fraction of the recoils reaching the stopper before emitting a γ ray provides a measure of the lifetime of the excited nucleus. Times of the order of 10^{-12} sec have been measured in such experiments. In related experiments, the stopper consists of other atoms in the target material itself. In this case, the available time during which the recoiling nucleus may emit its Doppler-shifted γ ray is only the time needed to traverse the distance between atoms. The lifetime range that can be measured is about 10 to 100 times shorter, 10^{-13} to 10^{-14} sec.

When ^{16}O projectiles near 40 MeV are used to bombard a ^{27}Al target, the residual nuclei formed are predominantly ^{41}Ca or ^{41}K . The "recoil-distance" method described above was successfully exploited in measuring the lifetimes of a number of high spin excited states in both nuclei. The measured γ -ray decay rates for the electric quadrupole transitions in these nuclei were found to be unusually small. The absence of a collective effect, which would enhance such transitions, is not yet theoretically understood.

Lifetime measurements made by the second of the above techniques have also been carried out for other nuclei. An interesting example is the measurement of the lifetime of the 1219-keV excited state in ^{35}Cl . Instead of bombarding ^{34}S with a deuteron projectile, the large linear momentum associated with a heavy-ion beam was exploited in

the reaction $^{34}\text{S} + ^2\text{H} \rightarrow ^{35}\text{Cl} + n$ by using ^{34}S as the projectile at 60-MeV bombarding energy against a deuteron target to excite this ^{35}Cl level. The lifetime of this state was determined to be $(2.9 \pm 0.4) \times 10^{-13}$ sec. The relatively high accuracy of this determination is mainly due to the large, highly directed momentum of the heavy-ion projectile.

Exploratory study of the nuclear domain is important to provide the fundamental underlying facts on which nuclear physics rests. Much of what is now known of nuclear phenomena comes from the nuclei that are stable or nearly so. In terms of their location on the isotope charts according to neutron and proton number (N, Z), these lie in the "valley of stability." To find ways of creating nuclei that lie far outside this valley is an important goal for the nuclear physicist.

In the past two years, new isotopes have been produced in compound nucleus reactions at the BNL Tandem Van de Graaff Facility. Among them are ^{23}F , ^{29}Mg , and ^{31}Al , produced by bombarding targets such as ^{18}O , ^{13}C , or ^{10}Be with accelerated beams of ^{18}O or ^{19}F . All are neutron-rich radioactive nuclei with half-lives ranging from 0.6 sec for ^{31}Al to 48 sec for ^{35}P (discovered somewhat earlier). They are part of a sequence in the isotope charts known by their isobaric spin classification as $T_z = +5/2$.

Their properties, including the radioactive decay schemes, spins, half-lives, and masses, have been measured, as have those of two other previously known members of this same sequence, ^{25}Ne and ^{27}Na . While the decay schemes, spins, and half-lives of all these nuclei agree with expectations based on the nuclear shell-model theory, their masses deviate from theory in a curious way not yet understood. Figure 2 shows the differences between the measured masses of this family of isotopes and those expected according to theory; i.e., if all masses agreed with the theory the points would lie on a horizontal line ($\Delta M = 0$) at the middle of the plot. What applications these new nuclei may have is not yet known, but it is clear that their physical properties have interesting implications in the study of nuclear structure. For example, semiempirical mass formulas based on measured masses on or near the line of stability are not always reliable in their predictions and need correction as nuclei farther and farther removed from the valley of stability are created.

Other heavy-ion induced reactions under intensive study both by BNL scientists and by members of the outside user community are those leading to fusion or fission of the compound system. High-mass, high-energy sulfur ions incident on, for example, a ^{40}Ca target fuse with the target to form a system that is highly excited and also recoils with high velocity because of the extremely large linear momentum associated with the heavy projectile. Evaporation of particles from the highly excited fused system leads to a spectrum of residual masses that can be analyzed by measuring the times of flight of these reaction products in a given direction and over a known flight path. In addition, if the time-of-flight system is replaced by collectors for these mass fragments, known radioactivities can be identified and the residual mass distribution derived from these measurements. Although such experiments (consisting, to date, of the bombardment by sulfur projectiles of Ca, Mg, Ni, and Co targets) are still in an exploratory phase, the technique has already made possible a better dynamic measurement of the mass distribution of fusion products resulting from these compound nuclear reactions. For example, a mass resolution of about 1 mass unit near 90 ($\delta M/M \sim 1\%$) has already been achieved. These experiments are primarily a BNL-MIT collaborative effort.

Although BNL physics research at the Tandem Van de Graaff Facility has been concentrated on

Figure 2. Differences between measured masses and those predicted by theory (vertical scale), plotted against mass number for the complete set of $T_z = +5/2$ nuclei in the $2s-1d$ shell. In addition to the BNL measurements, results shown are those of Dubna (Russia), LBL (Lawrence Berkeley Laboratory, California), and the Orsay Laboratory (France).

heavy-ion physics, the capability of the facility to furnish high-energy, high-quality beams of protons, deuterons, and α particles has led to their extensive use in the investigation of important nuclear physics questions. The interesting dynamical modes of motions known as the collective modes are common to all nuclei. They are exhibited dramatically in the form of "giant resonances" that can be excited by the absorption of high-energy γ rays. The decay of such giant resonances occurs principally by particle emission. At Brookhaven, these giant resonances are studied by the inverse reaction. In an experiment in collaboration with the State University of New York at Stony Brook, high-energy protons with precisely known energy are used to enter the giant resonance, and the details of the resonance are studied by observing the γ -decay branch of the resonance with a large, high-resolution, high-energy γ -ray detector and by measuring the γ -decay probability as a function of angle relative to the beam. The structure of the giant electric quadrupole resonance in ^{16}O as observed in high-energy electron inelastic scattering (e, e') experiments at other laboratories is clarified by this different experimental approach because this experiment, which measures the angular distribution, can distinguish between electric monopole and electric quadrupole excitation. Nevertheless, a certain ambiguity still remains between dipole and quadrupole excitation. At Stanford University, polarized protons are available at energies up to 16 MeV. The use of polarized protons at that institution at such low energies does uniquely identify the electric quadrupole strength. The BNL Tandem Van de Graaff capability to provide variable energy protons to much higher energies permits an overlap with the Stanford work and thus serves to establish the persistence of the electric quadrupole excitation at higher energies.

NEUTRON NUCLEAR PHYSICS

At the Brookhaven High Flux Beam Reactor (HFBR) a trio of specialized instruments focuses on the interaction of neutrons captured by nuclei, leading to the emission of γ rays. These are (1) a crystal monochromator, which diffracts neutrons of a specific wavelength, or energy, on a target; (2) a neutron chopper and time-of-flight equipment, which employs timing to separate effects caused by neutrons of various energies; and (3) a "tailored-beam" facility, which uses various filters

to provide a suitable energy-tailored beam on a target. These facilities are complementary and provide a means of studying neutron interactions, from thermal energy to many kiloelectron volts of energy, and the succeeding electromagnetic transitions. Experiments on neutron captures followed by electromagnetic radiation, or (n, γ) reactions, provide the basic means of study. The research is important for what it reveals of nuclear structure and dynamics. In addition, the γ -ray spectra that are observed provide information useful in predicting how much shielding is required for slow and fast neutrons.

Even for well-studied nuclei there is a gap, or "excluded middle," of nuclear excitation that is inadequately explored and for which theoretical

Figure 3. Two contrasting instruments for measuring neutron energies at the HFBR. H_1 is a crystal monochromator, which diffracts neutron beams of heterogeneous energies in much the same way as a diffraction grating separates white light into its various colors. H_2 , a neutron "chopper," chops beams into packets which travel down a 48-m flight tube. The time of arrival of the neutron is a direct measure of its velocity and, therefore, its energy.

concepts are not well developed. This is the region above the first few million electron volts of excitation and below the neutron continuum, which is several million electron volts higher. The Nilsson model successfully describes the many properties of the nonspherically shaped nuclei at low excitation energies; however, its predictive power breaks down suddenly at slightly higher energies. With the use of thermal and resonance neutron captures and capture of neutrons from the tailored-beam facility (neutrons of 24-keV energy) the nuclei ^{179}Hf , ^{183}W , ^{184}W , and ^{187}W were studied and the existence, spin, and parity of a large class of states in this "middle" region were observed. The results indicate that many more states exist than are envisaged by the Nilsson model. It appears that these new results can be largely explained by adding to the bases of the Nilsson model, predicated on a purely spheroidal shape for the nucleus, the interesting shape wiggle that has four-fold symmetry, known formally as a hexadecapole de-

formation. This information on the fundamental nuclear shape correlates with the results of high- and low-energy scattering experiments done during the past several years by groups at the University of California at Berkeley and Oak Ridge National Laboratory.

Nuclei with certain "magic" numbers of protons and neutrons are spherical and display very simple properties. Highly deformed nuclei also exhibit simple level structures. In between these limiting cases nuclei can be extremely complex. It is important to investigate the latter both to understand the nature of the transition region where no simplified model applies and to provide tests for more sophisticated calculations that are becoming available. The mercury isotopes represent such a group of nuclei, near the doubly magic nucleus ^{208}Pb . A series of experiments utilizing several (n, γ) techniques has been performed to deduce detailed properties of ^{200}Hg and ^{202}Hg up to excitation energies of 3.2 and 2.2 MeV, respectively. In addition to providing extensive new information on their level schemes, these studies have shown the existence of several 1- levels at relatively low energy in ^{200}Hg . This is a significant discovery because such states are uncommon near closed shells. In fact, the most likely explanation of their low energy implies that ^{200}Hg , at least in these states of excitation, has an oblate (doorknob) shape. Other results of these studies indicate that, surprisingly, the very close neighboring nuclei ^{200}Hg and ^{202}Hg differ significantly in their low-lying energy levels and in the γ -radiation they emit; this in turn implies as yet unexplained differences in their nuclear structure. Why the change produced by the addition of two neutrons is so abrupt is not yet known.

Nuclear dynamics, or the reaction mechanisms involved in neutron capture, are an important objective in studies focused on regions of the periodic table where low-energy neutrons are known to "resonate" within the attractive neutron-nucleus interaction. A particularly interesting question is that of the relative importance of the single neutron particle in the capture process as against the compound process in which the neutron is taken in by the nucleus in a much more complex rearrangement of its components. Much of the evidence for single-particle effects in the (n, γ) reaction comes from resonance capture measurements at Brookhaven. In recent work these measurements have been extended to energies near 24 keV by

Figure 4. Neutron capture γ -ray intensities in niobium, compared with the direct (d, p) reaction intensities for the same target. The degree of correlation between these two experiments measures the amount of direct component in the neutron capture process. In this case the linear correlation coefficient is about 0.5.

using the neutrons from the tailored-beam facility. Many of the nuclei near mass region $A \approx 100$, at which a p -wave neutron giant resonance is located, show a high correlation between neutron-capture radiative intensities and the cross section for direct neutron transfer from deuterons to the same final states. Examples of such correlations are seen for the even isotopes of molybdenum, including ^{92}Mo , ^{94}Mo , ^{96}Mo , and ^{98}Mo , and for niobium. The latter is a particularly interesting case, since from previous neutron resonance measurements it is known that the radiative intensities are independent of the resonance neutron strengths. A definite correlation (of about 0.5), however, is observed between radiative intensities and the strengths for producing in direct captures low-lying final states with the single-particle orbital $d_{5/2}$. The intensities are related as shown in Figure 4. These data for the molybdenum isotopes and niobium show the importance of two distinct capture mechanisms—one proceeding from single-particle motion of the captured neutron, and the other from a "doorway" state formed in the capture process. The former effect shows correlations between radiative strengths and both resonance neutron strengths and final-state direct capture strengths; the latter shows correlations only between radiative strengths and final-state direct capture strengths.

Figure 5. The concentration of ^{10}B atoms, implanted in silicon, shown as a function of depth (solid lines). The effect of annealing the sample is shown (dashed lines) for ions implanted at energies of 100 and 500 keV.

Neutron capture techniques have been put to a very different and interesting use. The question of the diffusion of boron in silicon when subjected to annealing cycles at various temperatures bears directly on techniques of solid-state device fabrication, as well as on our understanding of the physical process of diffusion rates. The usual method of determining diffusion rates, as shown in Figure 5, is to measure the spreading of a peaked distribution of the impurity resulting from annealing of the crystal. Boron, however, diffuses at a rate that depends on the amount of boron present locally; this concentration dependence of the diffusion constant complicates the interpretation of peak broadening measurements. In order to determine how rapidly a boron atom moves in a uniform sea of boron impurity, a series of experiments using special, uniquely prepared targets was begun several years ago. ^{10}B , the boron isotope with a very large (n, α) cross section, was implanted in silicon wafers in a Gaussian depth distribution. Then ^{11}B , which yields almost no α particles under neutron bombardment, was implanted in complementary fashion to give a uniform distribution of elemental boron. Measurements at the HFBR then determined the spreading of the ^{10}B "tracer" peak due to annealing; from these isoconcentration experiments, effective diffusion constants have been obtained with boron concentrations of 10^{19} cm^{-3} , $5 \times 10^{19} \text{ cm}^{-3}$, and 10^{20} cm^{-3} . The diffusion rate of boron in the presence of other impurities is also of importance; in particular, early experiments done at the HFBR and reported in the 1970-1972 *Brookhaven Highlights* showed marked anomalies in transistorlike structures doped with arsenic and boron. A determination of the diffusion constant of boron in arsenic-doped crystals shows that the arsenic impurity inhibits boron diffusion by a factor of ≈ 10 . This effect has been explained in terms of electrical interactions between the p-type boron and the n-type arsenic.

NUCLEAR THEORY

In the past two years there has been concentrated study of mechanisms entering into the nuclear reactions between heavy projectiles and a heavy target. Study has centered on the highly peripheral direct reactions, i.e., nuclear reactions involving only small changes in the energy, charge, or mass of either projectile or target. What has emerged is a rather general picture of these direct reactions that contains a certain element of sur-

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prise. It had been thought that the angular distribution of such direct reactions would be a rather featureless sharp peaking at the angle of the classical trajectory. Experiments carried out at Brookhaven, involving the transfer of two neutrons from an oxygen projectile to a nickel target, yielded unusual angular distributions rising strongly in the forward direction. Theoretical analysis indicated that an explanation could be found only if the average interaction between projectile and target nuclei was very weakly dissipative at grazing separation. The theoretical studies, however, strongly couple the forward-peaking cross section with an intensity oscillating rapidly with angle, both arising because of the interference between orbits penetrating on opposite sides of the nucleus. This interesting prediction of clearly quantum-mechanical behavior has been confirmed in subsequent experiments, e.g., the one-proton transfer reaction involving a ^{14}N projectile and a ^{48}Ca target, described earlier in this report. The very low threshold in energy at which quantum-mechanical behavior is observed (in retrospect, the greatest source of surprise) is a further strong indication of the ability of target and projectile to lightly touch without appreciable dissipation. The end result of these developments is an added richness in the heavy-ion reaction mechanism that can be exploited to yield detailed information on structure.

Moreover, the average interaction between heavy projectile and heavy target, which describes elastic scattering, is of considerable interest. Some success has been achieved in calculating the large-separation form of this interaction directly from the nucleon-nucleon interaction.

Study of the interaction of π mesons with nuclei is in the exploratory stage. The theoretical connection between the dynamics of the meson-single-nucleon system and the meson-many-body system is clearly fundamental. The development of ways of adapting the Chew-Low formalism, applied successfully in the meson-single-nucleon system, to the many-body system has opened the way to an explanation of the phenomenologically known features – for example, the shift in the energy at which (3,3) resonance is observed in nuclei as compared with the free single nucleon. These methods have also provided the basis for determining that the Pauli exclusion principle has only a small influence on the average interaction between a pion and the nucleus; this overcomes the difficulty posed by intuitive, lower-order calculations.

Experimenters in high-energy, or particle, physics usually expose electronic detector arrays or bubble chambers to beams of particles – protons, π or K mesons, or neutrinos produced by the primary circulating beam in an accelerator such as Brookhaven's 30-GeV Alternating Gradient Synchrotron (AGS). Interactions produced by beam particles in targets or directly in a bubble chamber are recorded and analyzed by means of complex data-processing equipment. The detectors determine the trajectories of the particles emerging from a reaction. Magnets are often used to determine the sign of charge and the momenta of the particles that are electrically charged; velocity can often be determined by measuring the density of ionization left behind by a fast-traveling particle, or by means of the light produced in a Čerenkov counter; and energy can often be measured by determining the total amount of ionization produced in a "calorimeter," which may be a sandwich of metal plates and scintillators. With these quantities determined for some of or all the particles from a reaction, and by applying conservation laws concerning energy, momentum, and charge and concerning quantum numbers such as spin, isotopic spin, strangeness, or parity, interactions can be studied with the help of large modern computers. Their meaning can be interpreted in terms of new, unexpected discoveries, confirmation of previously indicated experimental results, or agreement or disagreement with theoretical predictions based on accepted or new concepts concerning the structure of particles and the forces acting between them.

Although they often act simultaneously, the forces encountered in particle physics can be distinguished as strong, weak, and electromagnetic. All three forces are thought to act through exchange of particles such as photons (electromagnetic) or mesons (strong). For the weak force the postulated "intermediate vector boson" has not been observed so far. Perhaps it is so heavy that energies at existing accelerators are not yet sufficient. In contrast with the well-understood electromagnetic force, which can act over long distances between particles, the strong and weak forces act only over very short ranges and are not well understood. The probability for occurrence of an interaction between two particles is measured by the cross section, which depends on the kinds of

particles colliding, their relative energies, their quantum states, angles of observation, etc. Generally, the cross section for a weak interaction is only about 10^{-12} of that for a strong interaction at collision energies now available in laboratories.

Cross sections can be measured for the occurrence of any interaction in a given reaction (the total cross section), or for selected events (obtainable by triggering an electronic detector array) such as the distribution in angle of a scattered particle or in the associated momentum transfer. Events with large momentum transfer are likely to be caused by violent, head-on collisions and thus can be expected to reveal details about the internal structure of colliding particles. Cross sections can also be selected for production of strange particles such as hyperons or K mesons, which then decay by the weak force into other particles. Study of such decays offers many opportunities to investigate the properties of the weak force, including unexpected violation of conservation laws obeyed by the strong force. A complementary way to explore the weak force is to expose one of the target-detector combinations to a beam of neutrinos.

A large number of strongly (rapidly) decaying excited states or resonances are produced in high-energy collisions, and by studying these, theoreticians have been able to correlate many of the observed particles by means of mathematical methods [SU(3) group, the Regge calculus, etc.]. Such correlations must precede a final, perhaps all-encompassing, theory expressing the observed phenomena in terms of the underlying dynamics. Much work remains to be done on studies of excited states and their spectroscopy to obtain a

complete picture, but it is not likely that the particles (or forces) encountered in high-energy physics can finally be understood without the discovery of further facts: particles previously considered to be basic building blocks of matter may themselves have a structure. Thus, "even more elementary" particles may exist and must be discovered. Since these may be very massive, accelerators with still higher energies are needed¹, as recently proposed.

Examples of accomplishments at BNL in particle physics research during the past two years are given below.

TOTAL CROSS SECTION MEASUREMENTS

During the past decade a Brookhaven counter-spark-chamber group has systematically measured total cross sections of π mesons, K mesons, and antiprotons on protons and deuterons at the various energies that became available at the AGS. If the incident particle interacts with the protons, it is either absorbed or suffers deflection. As stated above, a total cross section experiment detects the total of all such interactions between the incident particle and the target particle. Variations in the value of the total cross section as the energy of the incoming particle is varied appear as structure in the plot of cross section versus energy. Such structure may indicate the existence of a very short-lived particle or resonance. Precision measurements of total cross sections have resulted in the discovery of a large number of resonances at Brookhaven. Recently, a new low-energy separated beam was designed and built at the AGS to provide high fluxes of particles in the momentum range from 400 to 1050 MeV/c. In one experiment carried out in this beam, K^- -meson total cross sections on protons and deuterons were measured in a search for hyperon resonances. A major improvement in the method of measuring total cross sections by transmission was effected by using proportional wire chambers in the incident K^- -meson beam to select only particles that were directed toward the final focus. This technique eliminates beam "halos," which could give erroneous results. The proportional chambers also eliminated fluctuations due to accidentals, and this greatly improved the reproducibility of the data. The total cross sections of K^- mesons on protons and deuterons were used to extract the cross sections of K mesons on neutrons. These results are shown in Figure 6. A new and previously unobserved structure seen at a laboratory momentum of 540 MeV/c

Figure 6. Total cross sections of K^- mesons on neutrons. Evidence is presented for a previously unobserved structure with a mass of 1580 MeV/ c^2 .

Figure 7. Total cross sections of antiprotons on protons and deuterons. A new structure is observed at a laboratory momentum of 475 MeV/c.

is interpreted as a hyperon resonance with a mass of $1580 \text{ MeV}/c^2$ and a width of $\leq \approx 50 \text{ MeV}/c^2$. Measurements of the total cross sections of K^+ mesons on protons and deuterons confirmed a very broad structure that had been pointed out previously by the same group. A new structure was also disclosed by the results of the antiproton-proton total cross section measurements. After unfolding the experimental resolution, the structure was found to have a mass of $1932 \text{ MeV}/c^2$, a width of $\approx 5 \text{ MeV}/c^2$, and a height of 18 mb. This effect, shown in Figure 7, is by far the narrowest structure yet observed in total cross section measurements in high-energy physics.

The same group, in collaboration with physicists from the Fermi National Accelerator Laboratory (FNAL) and Rockefeller University, have used these techniques to measure total cross sections of π mesons, K mesons, protons, and antiprotons on protons and deuterons at the very high energies available at FNAL. These precise measurements (accurate to ≈ 1 part in 500) reveal that the effective sizes of the proton, shown in Figure 8, increase

Figure 8. Total cross sections of antiprotons, protons, π mesons, and K mesons on protons. Five of the six cross sections are observed to increase at high energies.

for five of the six probes when their energy is increased from 50 to 200 GeV. The similarities and the intercomparisons of the behavior of the cross sections with the six probing particle beams indicate that a new simplicity of nature may be revealing itself at very high energies – a situation predicted by some physicists. Since the proton and neutron are the basic building blocks of all atomic nuclei, these experiments are a significant advance toward an understanding of the constitution of matter.

INELASTIC PROTON-PROTON SCATTERING OBSERVED BY THE MULTIPARTICLE ARGO SPECTROMETER SYSTEM

Gaining an understanding of strong interactions has proved to be more difficult than was originally anticipated, possibly because hadronic (strong interaction) physics with non-pointlike objects is involved. Since it is not known what aspects of hadron scattering experiments will yield the key observations for eventual understanding, it seems clear that the scattering process must be measured as completely as possible, a minimum being to detect and momentum-analyze all charged particles

Figure 9. Schematic floor layout of MASS. $H1$ to $H4$ and $L2$ to $L4$ indicate the positions of scintillation counters triggering the high-momentum spectrometer and the low-momentum spectrometer, respectively.

in the final state. The instrument used to carry out such investigations during the past decade was the bubble chamber; unfortunately, the very nature of strong interactions put limits to its usefulness. Hadronic interactions happen most frequently when the target and projectile do not really come very close together; this is called peripheral or glancing collision. The closer or more central the collision, the greater the improbability of an interaction. The rare nature of such central collisions made them elusive in bubble-chamber observation, and the fact that the two incident, or leading, particles could not be recognized in the final state constituted a further limitation.

To observe rare, central hadron-hadron scattering processes in a bubble-chamber-type instrument and recognize the leading particles in the final state seemed to be a necessity in the quest for a better understanding of strong interactions. To achieve that end construction of a magnetic multiparticle spectrometer with fully automatic track recognition, the Multiparticle Argo Spectrometer System (MASS), was started in 1969 and was brought to a successful conclusion in 1974. Although one or two conventional magnetic spectrometers detected and identified one or both leading particles (see Figure 9), the novel magnetic vertex spectrometer (VS) detected all charged decay particles, and a data bank of $>3 \times 10^6$ rare events has been built up at BNL. The VS consists of a nested set of 9 cylindrical wire spark chambers surrounding a liquid hydrogen target located in a 10-kG magnetic field (Figure 10). The field volume measures $1.5 \times 1 \times 1 \text{ m}^3$. The axes of the cylinders are perpendicular to the beam. Dip angles of

Figure 10. Five full-round and two half-round cylindrical chambers located inside the support structure ("can") of the vertex spectrometer. The fifth full-round chamber is shown sitting in its cradle, above the can. In the background part of the Argo magnet can be seen.

$\pm 50^\circ$ with respect to the median plane are covered. High multitrack efficiency is accomplished by pulsing the chambers in a transmission line mode. Digitization is obtained by means of magnetostrictive lines located inside the magnet and shielded from the 10-kG field. A computer code (PITRACK) has been developed to provide automatic pattern recognition capability. Written in FORTRAN IV, it requires 72,000 octal words on a CDC 6600 computer. Reconstruction time depends strongly on prong number N . Central processor time is equal to $(0.4 + 0.04 N^2) \text{ sec}$. A typical 10-prong event, as found by PITRACK, is displayed in Figure 11. The reliability of PITRACK was evaluated by scanning a sample of events and also by comparing its findings with the bubble chamber in an overlapping data region. It was found, when observing 28.5-GeV/c pp collisions, that losses totaled 17% and could be corrected by using charge conservation. A corrected sample agreed well with the bubble chamber with respect to average charged multiplicity, as well as multiplicity distribution.

So far measurements have been made of the dependence of the mean charged-particle multiplicity $\bar{n}_c$ on the four-momentum transfer $|t|$ to the

forward-going proton in the reaction $p + p \rightarrow p + MM$ at 28.5-GeV/c incident proton momentum for several intervals of missing (not directly measured but inferred from momentum and energy conservation) mass MM . The data show that the distributions for high $|t|$ differ from those at lower $|t|$, with a higher $\bar{n}_c$ at high $|t|$. In Figure 12 the variation of $\bar{n}_c$ with $|t|$ is shown for five values of MM . While $\bar{n}_c$ shows little or no variation for $|t|$ values up to 2 (GeV/c)², it rises rapidly for values > 2 (GeV/c)² and then slows down for values of $|t| > 3$ (GeV/c)². Additional information was extracted from the data by studying the particles' directions, momenta, and higher moments of the multiplicity distributions. Shrinkage of multiplicity scaling curves with $|t|$ and the tendency of produced particles to part company with the fast forward protons at large $|t|$ have led to proposals of a new picture of strong interaction dynamics: while nature obscures its simplicity in the region of large cross section, by having the leading proton radiate off neutral pions, the situation simplifies on going to large transverse momentum, where the leading proton undergoes a quasi-elastic scattering process only and mesons are produced quite far away from the nucleons. Such a picture has been anticipated by the theorists working on the hypothesis that protons consist of smaller units called partons.

This experiment with MASS may well turn out to be an important step in understanding the dynamics of particles or their possible substructure.

The work described above was a collaboration between members of the BNL staff and the staffs of Virginia Polytechnic Institute and State University, the University of Wisconsin, Purdue University, and the University of Pennsylvania.

A SEARCH FOR QUARKS

One of the most exciting ideas in physics in the last decade has been that of quarks. The number of "elementary" particles has increased to the point where the idea that they are the fundamental building blocks of which all matter is made is becoming difficult to accept. Indeed, if these particles are the building blocks, the concept of fundamental becomes difficult to understand. As knowledge of these particles' properties expands, a pattern has developed that points to three really fundamental entities from which all the others can be constructed. Although imperfect, the theories based upon this concept have been very successful

Figure 11. 10-Prong event, as seen by the vertex spectrometer of MASS.

Figure 12. Variation of the average charged-particle multiplicity, $\bar{n}_c$, with four-momentum transfer, $|t|$, for four values of missing mass, MM : 5.2 ($\circ$), 4.5 ($\blacktriangle$), 3.6 ($\square$), and 2.7 ($\bullet$).

in explaining many of the properties of particles. The possibility exists that these entities are really fundamental particles that have not yet been discovered. The not-yet-found particles have been named quarks.

These hypothetical (to date) particles would have a charge one-third or two-thirds that of the electron. If they exist and have this unusual property, they should already have been discovered, unless they are very massive. The new accelerator at FNAL, Batavia, Illinois, provides energy much greater than has been available to date (except at CERN's colliding-beam ISR). It was thought that with this great energy it might be possible to produce these particles.

A group of scientists from BNL and Yale University have conducted a search for these particles at the FNAL accelerator. Eight counters were placed in a beam from this machine in such a way that single particles traversed them all. Signals from these counters would be proportional to the square of the charge of the particles. A $\frac{1}{3}$ quark would give a signal $(\frac{1}{3})^2$, or one-ninth as large as that of an electron. A $\frac{2}{3}$ quark would give a signal four-ninths as large as that of an electron or of any other normal particle with the charge of an electron. All particles discovered to date have charges equal to or an integer multiple of that of the electron or have no charge at all. One-ninth or four-ninths signals simultaneously registered in all eight detectors would have indicated the existence of quarks with very high probability.

No such signals were registered, and it must be concluded that these particles are not produced at 300 GeV, the highest incident proton laboratory energy available. It is possible that they were produced but decayed before reaching the detector. If so, it is difficult to imagine what they decayed into, since charge is conserved. They could, of course, be so massive that there was not enough energy to produce them. If they weigh more than about 12.5 times the weight of a proton, this would be the case. Higher energies at the Batavia accelerator or elsewhere might resolve this question.

WORK WITH A DOUBLE-VEE SPECTROMETER

A large spectrometer (double-vee spectrometer, Figure 13), designed for detecting decays of strange particles produced in interactions, was in continued operation by members of the staffs of BNL and City College of the City University of New York. Several improvements, including deployment of a

Figure 13. View of the double-vee spectrometer as it was used in the experiment described in the text. A liquid hydrogen target in which interactions took place is located in a box structure to the right of and below center. Two high-resolution spark-chamber modules right behind the target and additional modules of three spark chambers each farther downstream (upper part of picture) detect secondary particles from an interaction. A magnet, 48 in. wide and 48 in. deep, provides momentum analysis of these secondary particles, and a large, atmospheric-pressure Čerenkov counter hodoscope in the background (at top) provides identification.

proportional wire chamber to obtain better trigger selection, were incorporated. The reaction $\pi^- + p \rightarrow A_2^- + p$, with subsequent fast decay of $A_2^- \rightarrow K^0 + K^-$, was reinvestigated at an incident π^- momentum of 24 GeV/c. Earlier results had demonstrated that the mass spectrum of the A_2^- meson, contrary to some of the original results, did not show a split peak. The existence of the split peak would have caused grave difficulties in the interpretation of the resonance scheme, since it has not been found anywhere else. The new result, with a factor of 5 improvement in the data statistics, confirms this conclusion even when the data are divided into several momentum transfer regions to study the finer details. The total and differential cross sections for this process are being derived from these data. This will provide the highest momentum point in the evaluation of momentum dependence of the cross section. Furthermore, a density matrix analysis will be completed soon and is expected to demonstrate again, with much better statistics, that spin-parity $J^P = 2^+$ for the A_2^- meson. A limit on g -meson production in the $K^0 K^-$ channel is also to be determined.

The reaction $\pi^- p \rightarrow K_S^0 K_S^0 + n$ was also studied. The effective mass spectra of the $K_S K_S$ system from the reaction showed peaks in the A_2 and f^0 -meson regions. Further results of the data analysis will include preliminary studies of the Q and R regions (the existence of Q and R as *bona fide* narrow resonances has been in doubt for some time). About 1000 events of the Q type - $K^0 \pi^+ \pi^-$ - were obtained from 24-GeV $\pi^- p$ interactions. The effective mass spectrum so far shows a broad peak around a mass of 1.3 GeV/ c^2 . In the reaction $\pi^- p \rightarrow K^+ K^- \pi^- p$, a search for a possible $\phi^* \rightarrow \phi + \pi$ resonance is being made. In this reaction an enhancement is also seen in the $K^+ K^-$ mass at the ϕ peak, which is associated with the recoil mass > 2 GeV/ c^2 .

Associated production,

$$\pi^- + p \rightarrow K^0 + \left(\begin{matrix} \Lambda \\ \Sigma \end{matrix} \right),$$

at 8, 10.7, and 15.7 GeV was studied as a function of four-momentum transfer t . A total of 22,600 events obtained with the spectrometer were analyzed with the Λ and Σ^0 separated by missing mass techniques. It was concluded that the Σ^0 has a narrower forward exponential shape than the Λ and that the t -dependences flatten out beyond $t = -0.4$ (GeV/ c^2). Regge shrinkage effects can be

deduced by combining these with lower energy data. The ratio of the forward differential cross sections for the two reactions is smaller than at lower energies. The combined total cross sections are falling at a rate proportional to $P^{-3/2}$ ($P =$ momentum), with Σ^0 production falling somewhat less rapidly than Λ production.

As a natural extension of the double-vee spectrometer, this group has been engaged for two years in the design, construction, and testing of a multiparticle spectrometer (MPS, described in the Accelerator Department section) in a joint project with the Particle Detector Division of the Accelerator Department. The goal is to build a major magnetic spectrometer facility that can be used for a large class of investigations of high-energy particle physics phenomena. This will allow efficient and effective use of the AGS for the quantitative investigation of complex reactions, which was much less feasible with the existing devices.

MESON AND BARYON SPECTROSCOPY

In efforts to understand the properties of short-lived particles or resonances and, ultimately, the interactions among them, several experiments, most of them with bubble chambers, have been performed to uncover new particles in measurements of the quantum numbers (spin and parity, in particular) of meson resonances and the dynamical relationship among resonant states.

Based on the novel technique of employing mass-dependent angular distributions, a study has been made, without recourse to the poorly understood production dynamics, of the behavior of 0^+ , 1^- , and 2^+ spin-parity states in the $K\pi$ system from the reaction $K^- p \rightarrow K^- \pi^+ n$ at 3.9 and 4.6 GeV/ c . From this study it has been determined that a substantial 0^+ resonance, if it exists, cannot be in the $K^*(890)$ region (890 is the mass in MeV/ c^2) but instead must be in the region just below the $K^*(1420)$. In a continuing study of $K^- p$ interactions at 7.3 GeV/ c , two K^* resonances, hitherto poorly established, have been detected at high statistical significance. They are the $K\pi$ resonance at mass 1760 MeV/ c^2 and the $K\omega$ resonance at 1710 MeV/ c^2 . It is as yet unclear how these resonances should be classified in the SU(3) families, mainly because of lack of information on the spin and parity.

In a concurrent development, an exhaustive partial-wave analysis has been performed of the $\pi\omega$ system based on high-statistics data of the re-

action $\pi^+p \rightarrow \pi^+\omega p$ at 7.1 GeV/c (data from Group A at Lawrence Berkeley Laboratory). This work establishes, with a high degree of confidence, the existence of a 1^+ resonant $\pi\omega$ state at mass 1250 MeV/c², and this conclusion has been confirmed by a recent, similar analysis at CERN based on π^-p data at slightly different energies.

A persistent question in the field of low-mass boson spectroscopy is that of whether any $J^P=0^+$ mesons exist. The possibility of one such state, an $I=1$, $\delta(980)$ decaying into a $\pi\eta(550)$ final state, has been reported in a variety of experiments. A counter experiment designed to study the excitation of such a δ meson via the reactions $\pi^\pm p \rightarrow pX^\pm$ near the threshold, with mass of $X^\pm$ in the region of 900 to 1020 MeV/c², was made in collaboration with a Rutgers University group. No evidence was found for narrow structure, of width <12 MeV/c², as had been previously reported for the $\delta(965)$ meson. A narrow neutral X^0 has been observed in $\pi^-p \rightarrow nX^0$ near 957 MeV/c² in an experiment at the Rutherford Laboratory. The absence of $X^\pm$ at 957 MeV/c² establishes that this $X^0(957)$ is the $\eta'(958)$ meson: this is crucial to any study of η' in the reaction $\pi^-p \rightarrow nX^0$, accessible to counter experiments; bubble chamber studies with the $\eta'(958)$ are made with the $K^-p \rightarrow \Lambda\eta'$ reaction.

A low-mass ωp enhancement at a mass of ≈ 1.8 GeV/c² and width ≈ 120 MeV/c² was observed in the reaction $\pi^-p \rightarrow \omega p\pi^-$ at 4.5, 6.0, and 14.0 GeV/c. The analysis was done by BNL, the California Institute of Technology, and Lawrence Berkeley Laboratory on bubble-chamber film taken at BNL and the Stanford Linear Accelerator Center. The decay angles of the ωp and ω in their respective rest frames are isotropic and uncorrelated, which suggests s -wave decay. The cross section for this enhancement was fitted to the form s^n (here s is the square of the interaction energy in the center-of-mass system), to give $n = -0.66 \pm 0.06$, a value consistent with the intercept of "Reggeon exchanges." This is to be contrasted with known diffractive $N^*_{1/2}$ production with little or no energy dependence for the small- t region. A search for other decay modes yielded upper limits for the branching ratios: $(\pi N)/(\omega p) < 30\%$, $(\rho^0 p)/(\omega p) < 14\%$ at the 90% confidence level.

An analysis of the production mechanism in A_2 production was carried out. Use was made of bubble-chamber film analyzed at BNL in the following reactions: $\pi^-p \rightarrow A_2^-p$ at 4.5 and 6.0 GeV/c, and

$\pi^+p \rightarrow A_2^+p$ at 6.0, 10.5, and 23 GeV/c. The $I=0$ and $I=1$ exchange contributions to A_2 production were determined as a function of s and at 6 GeV/c as a function of the four-momentum transfer t . There is good evidence for f^0 exchange dominating the $I=0$ exchange, as well as the natural-parity contribution. The dip observed in $(d\sigma/dt)$ ($\pi^\pm p \rightarrow A_2^\pm p$) at $|t| \approx 1.2$ (GeV/c)² is associated with $I=0$ natural-parity exchange (f^0). Unnatural-parity exchange (B) dominates the $I=1$ exchange as a function both of s and of t . These results are surprising in that, since the A_2 has such a large $\rho\pi$ decay mode, the ρ contribution to production was naively expected to be large.

There has been much theoretical interest in the studies of K^-p interactions at 3.9 and 4.6 GeV/c. Systematic analyses have been made at BNL of reactions such as $K^-p \rightarrow \Lambda, \Sigma^0, Y^*(1385) + \text{meson}$, and $K^-p \rightarrow K^*(890), K^{**}(1420) + \text{nucleons}$. In the investigation of the former reaction, detailed amplitude analyses were performed for the first time. The results of this work have now been confirmed by groups working at CERN. One of the most interesting results was, in agreement with simple theoretical ideas [i.e., SU(3) and quark models], that all the observables for the reaction $K^-p \rightarrow \Lambda\phi$ are equal to those of the reaction $K^-p \rightarrow \Lambda K^*(890)$.

In the same area, a systematic study of the reactions $\pi^+p \rightarrow \rho p$, $\pi^-p \rightarrow \rho^0 n$, and $\pi^-p \rightarrow \rho^- p$ at 6 GeV/c was concluded. Comparison of these reactions at a fixed energy allowed separation of the $I=0$ and $I=1$ contributions to the t -channel exchanges. Differential cross sections and full density-matrix elements were shown to be reasonably well described by π and ω exchanges alone. Several of the s -channel helicity amplitudes show evidence of a certain structure expected from the geometrical picture of peripheral production processes.

SOME WEAK INTERACTION EXPERIMENTS

In the weak interaction realm, a precise measurement of the $K_S^0 \rightarrow \pi^+\pi^-/\pi^0\pi^0$ branching ratio was completed by a group from BNL and Carnegie-Mellon University. This number is of interest in searching for possible deviations from the value 2.0 expected from the phenomenological $\Delta I=1/2$ rule. The strong points of this bubble-chamber experiment are the firm control and understanding of systematic errors and a yield of events comparable to that in any previously reported experiment. From a total sample of 30,000 events, 15,000 re-

main after the imposition of geometrical and other criteria yielding a ratio with an error of $\leq 4\%$, which clearly indicates the requirement for $I=3/2$ and/or $I=5/2$ amplitudes in this decay process.

In a collaboration with a large group at CERN, data on the interactions of electronic neutrinos (ν_e) with nucleons were obtained in the CERN Gargamelle heavy-liquid bubble chamber and were published. Some 52 events from the first half-million pictures revealed that a "multiplicative" type of conservation law, which allows the decay mode $\mu^+ \rightarrow e^+ \bar{\nu}_e \nu_\mu$ in addition to the "normal" mode, $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$, appears to be ruled out. The ratio R of the two modes has been determined to be < 0.5 at the 90% confidence level, whereas a value of 1 is expected. In addition, the universality of the interactions of electronic and muonic neutrinos with nucleons was found to be true to the 30% level (since the ratio of the cross sections of the two types of neutrino is near unity, the measured value being 1.3 ± 0.3). Also, a limit on the mass of a new type of heavy muonic lepton (M^+) (if it exists) with charge opposite to that of the muon (μ^-), was set as $> 2.4 \text{ GeV}/c^2$ at the 90% confidence level. These data also imply that electron and muon lepton numbers are conserved to better than 1 part in 200.

An effort was made to improve the accuracy of the decay branching ratio $\Gamma(K_L^0 \rightarrow \mu^+ \mu^-)/\Gamma(K_L^0 \rightarrow \text{all})$. A Berkeley experiment in which no such two- μ events were found gave an upper limit for the branching ratio of 3.3×10^{-9} , which violated the primitive unitarity (lower) limit of 5.3×10^{-9} . The Columbia-NYU-CERN experiment at the AGS found six events, but with half the sensitivity of the Berkeley experiment. A new Columbia-BNL-CERN collaboration was formed to search further for this extremely rare decay mode. A new hodoscope was constructed to aid in muon identification and reduce background from $K_{\mu 3}$ decays. Three additional events were found in this search which, when combined with the original Columbia-NYU-CERN results, gave $\Gamma(K_L^0 \rightarrow \mu^+ \mu^-)/\Gamma(K_L^0 \rightarrow \text{all}) = 12^{+8}_{-4} \times 10^{-9}$ (the errors represent the 90% confidence level). This value is in excellent agreement with the theoretical lower limit.

Finally, a program has been started to study the details of neutral exchange currents and cross sections (form factors) in neutrino interactions in the 7-ft low-temperature bubble chamber described in the Accelerator Department's contribution to the 1970-1972 issue of *Brookhaven Highlights*.

FLYING IMAGE DIGITIZER

More rapid and efficient extraction of the data from track-chamber photographs is achieved with the computer-controlled flying image digitizer (FID), which provides 32 simultaneous scan lines. The previous flying spot digitizer, which provided one scan line, and its dedicated IBM 7094 computer were retired at the end of June 1973 after having provided highly accurate data for more than two million bubble-chamber events. During May 1974 the FID reached operational status when data were obtained from film of its first bubble-chamber experiment.

The FID is expected to digitize films from larger new chambers like the BNL 7-ft chamber, as well as films from conventional bubble chambers like the BNL 80-in. chamber. The locations of images are digitized to an accuracy of a few microns on the film. Moving mechanical parts are supported by air bearings to achieve the desired accuracy and minimize maintenance costs. New engineering concepts use two computer-controlled stepping motors to transport the film from frame to frame between measurement cycles.

A mini-computer, PDP-11, is dedicated to the control of the FID. Two other existing computers are time-shared with many other users to achieve the most economical computing services for the FID. The XDS Sigma Seven computer in the Physics Department is linked to the PDP-11 and to the CDC 6600 at the Central Scientific Computing Facility, which is also linked to the PDP-11. Upon command from the Sigma Seven, the PDP-11 causes the FID to send digitizings from the scan of one image through the PDP-11 to the CDC 6600. As many as 150 events can be digitized per hour by the FID, depending on the details of the film format and the requirements of the experiment.

THEORETICAL HIGH-ENERGY PHYSICS

The high-energy theorists at Brookhaven work on a wide variety of problems ranging from direct analysis of experimental data, through the analysis of models that make detailed predictions about high-energy phenomena, to the study and construction of fundamental theories of elementary particle interactions.

The aim of the work in the first category is to extract from experimental data the quantities of primary interest for theoretical studies, the scattering amplitudes. Much of this work has been done

in collaboration with experimentalists. In order to extract the scattering amplitudes, various polarization measurements, in addition to cross section measurements, are needed. Methods for parametrizing the data that bring out the implications of these measurements most clearly have been developed. Extensive amplitude analysis of specific processes such as $K^-p \rightarrow \omega\Lambda$, $\pi^-p \rightarrow K^*\Lambda$, and $K^-p \rightarrow \pi^-Y^{*+}$ have been performed and the results used to put constraints on models for the dynamics of these processes. More efficient numerical methods for performing the multidimensional integrations often encountered in studying complicated multiparticle final states have been developed.

In the second category, considerable effort has been devoted to the study of multiparticle final

states produced in strong interactions. The recently observed rise in the total cross section for elementary particle reactions has a variety of possible explanations. One such, in which a large number of particles is produced in a "fireball," has been shown to account for part of the rise, but it cannot account for all of it. Another mechanism that can account for part of the rise is the "Regge cut." Detailed properties of the final states – multiplicities and correlation functions – predicted by this

Figure 14. Apparatus for neutron scattering studies of magnetic materials subjected to high magnetic fields at low temperatures. A special double Dewar, the lower portion to house and cool the superconducting coils of the magnet and the upper to provide cooling for the sample, is mounted on a triple-axis neutron spectrometer. A "tail" containing the sample projects down from inside the upper Dewar to neutron beam level inside and along the axis of the lower Dewar.

model have been worked out. A complementary mechanism for producing many particles is the formation of a single cluster, the analogue of the compound nucleus in nuclear physics. Several experimental tests of this model in annihilation processes, $e^+e^- \rightarrow \text{hadrons}$ and $N\bar{N} \rightarrow \text{hadrons}$, have been suggested on the basis of a statistical analysis of this model. The process in which a particle is produced with a large component of momentum transverse to the incoming beam direction is expected to shed light on the structure deep inside the proton. A number of simple models for this process have been suggested by various workers around the world and some of them give a rather good qualitative account of the data. It is therefore important to study the foundations of these models and the assumptions implicitly contained in them. Such a critical study of one of the successful models has been carried out by a group from BNL and the University of Virginia, and criteria for the validity of the model's assumptions have been given.

One of the most interesting questions in the third category is why the "quarks," the supposed constituents of the proton, have not been observed in collisions of elementary particles. A group at MIT has suggested that the proton is a "bag" full of quarks. This novel and unfamiliar idea has been shown here to be the limit of a certain ordinary quantum field theory. Other work, done in collaboration with the State University of New York at Stony Brook and the Institute for Advanced Study, Princeton, N. J., showed that, in the new unified theories of weak and electromagnetic interactions, an external gravitational field can be consistently coupled to the fundamental fields of the theory without modifying the intrinsic structure of the theory. This is an important question of principle.

SOLID STATE PHYSICS

The program in solid state physics emphasizes research in which the special facilities at Brookhaven can be used to advantage in advancing our basic understanding of condensed matter. The properties of materials are governed ultimately by fundamental interatomic interactions, by collective mechanisms involving many atoms, and by the effects of lattice imperfections and impurities. The intense beams of thermal neutrons available at the HFBR provide a powerful experimental tool

for investigating the structure and dynamics of condensed matter. The wide range of radiation facilities at the Laboratory permits use of a variety of techniques for the study of defects in crystalline solids. Theoretical work is closely related to the experimental activities. The program is also strengthened by cooperation with materials research groups in other departments, especially on energy-related projects and in the interdepartmental program in superconductivity.

NEUTRON SCATTERING

The techniques of neutron scattering have been employed at Brookhaven to study an extensive range of solid state phenomena. The principal lines of investigation during the past two years have been concerned with phase transformation mechanisms and critical phenomena, the structure and dynamics of magnetic materials, the lattice dynamics of solidified rare gases, and studies on disordered and partially ordered systems. The type of information obtainable is illustrated in part by the two examples that follow.

Lattice dynamical concepts have been widely applied in the study of phase transformations in recent years, and neutron scattering has played a leading experimental role in this important area. Structural phase transformations are usually classified as either order-disorder or displacive. In the first class the atomic positions available in a change from a disordered to an ordered structural arrangement involve discrete choices similar to the + and - possibilities for spin orientations in magnetic materials. Indeed, this similarity has led to "pseudospin" descriptions of order-disorder transformations. In displacive transformations, structural changes often result from instabilities in particular normal vibrational modes. The frequency of a phonon mode can decrease to zero as the transformation temperature is approached, with condensation of the mode into an ordered array of static displacements. In one interesting case studied recently at Brookhaven, ND_4Br , both types of ordering occur simultaneously in the same crystal.

In ND_4Br the ordering of the tetrahedral ND_4 units in discrete orientations is accompanied by deformation of the sublattice of bromine ions. The condensation of a phonon mode, associated with the bromine displacements, and the long-range pseudospin ordering, identified with the ND_4 orientations, take place at the same temperature

Figure 15. Wave vector dependence of the bromine sublattice motion in ND_4Br , showing phonon-like sidebands, plus an additional quasi-elastic peak due to coupling with the relaxational flipping of the ND_4 ions.

because of the strong coupling between these two structural features. The kind of experimental data used in analyzing this dynamical transformation mechanism is illustrated in Figure 15. A simple lattice instability would be characterized by a peak in the inelastic neutron scattering at an unusually small energy at the critical wave vector 0.5. Observed instead is a normal phonon sideband accompanied by an additional strong quasi-elastic peak. This latter central component can be explained in terms of relaxational motion of the bromine sublattice due to coupling with the flipping of ND_4 from one orientation to another. Other examples of such phonon response have been observed recently in other materials with structural phase transformations, but this is the first system in which the underlying cause can be so thoroughly explained.

The physics of surfaces and thin films has long been of interest since it plays a prominent role in many important chemical processes. While the macroscopic properties of surfaces and films can be studied by techniques similar to those employed for bulk materials, their microscopic properties (by far the more important) are much less accessible to direct investigation. At present, aside from the information obtained from low-energy electron diffraction studies, knowledge of microscopic surface physics is limited to what can be inferred from bulk measurements. Recently it was demonstrated at Brookhaven that neutron scattering can be applied in the study of surface films and that the

Figure 16. Neutron diffraction patterns observed from nitrogen films adsorbed on Grafoil, a basal-plane-oriented graphite, at 20 K. The amount of nitrogen adsorbed decreases from top to bottom.

technique can be used to considerable advantage in certain cases. A particularly favorable case is that of nitrogen adsorbed on Grafoil, a basal-plane-oriented graphite that duplicates to a remarkable degree the properties of an idealized crystalline surface.

Figure 16 shows typical neutron diffraction patterns observed when varying amounts of nitrogen are adsorbed on Grafoil at a temperature of 20 K.

At the lowest coverages (bottom of Figure 16), a sharp diffraction peak at a scattering angle of 69.4° indicates that the film exists as a two-dimensional triangular lattice in which each nitrogen molecule sits in registry in the center of a basal-plane graphite hexagon. As the coverage is increased, the diffraction peak is observed to shift to larger angles; i.e., the effect of adding molecules is to decrease the intermolecular distance and force the film out of registry, although it retains its triangular structure. A detailed study of the line shape at the highest coverage (top of Figure 16) reveals the existence of a second layer in registry with the first layer and forming a hexagonal close-packed structure. There are also indications that the interaction of the film with the underlying graphite lattice is weak enough so that in the dense phase the film behaves in many ways like an idealized two-dimensional structure.

DEFECTS IN SOLIDS

The study of imperfections in crystals is another major experimental activity in solid state physics. Two main avenues of research are emphasized. One involves the use of energetic particles and ionizing radiation to create defects in crystalline solids. The resulting effects on the physical proper-

ties of the solids are then studied. The other component of the research effort uses particles as probes in solids to furnish basic information of physical interest. Both avenues have as their goal an increase in our fundamental understanding of real solids, i.e., solids containing defects. In addition to its scientific merits, this objective is important from an applications viewpoint. A thorough knowledge of the factors controlling their properties and behavior is the basis for creating new materials whose characteristics satisfy the steadily developing needs of a highly technological society.

One of the most powerful tools for studying radiation damage effects in insulators is based on measurements of radiation-induced absorption, i.e., color center formation. Until recently, such measurements were made by irradiating the sample in an accelerator, reactor, or x-ray or γ -ray source and then transferring it to an optical spectrophotometer where the absorption was measured at some interval after irradiation. Four years ago, the first optical absorption measurements were made at Brookhaven on samples during γ -ray irradiation. Such measurements have since provided a greatly improved understanding of γ -ray-induced radiation effects. Very recently, initial measurements were carried out with a new facility for studying optical properties of samples during irradiation with high-energy electrons. Because the electron-imparted doses are very much larger than those obtained with γ rays, the radiation-induced absorption increases much faster and the radioluminescence is much more intense than that measured previously.

Figure 17 shows the initial measurements made in the new system. The sample is a crystal of LiF. The upper curve shows the growth of F-centers during irradiation and indicates that these centers remain at a relatively fixed level after irradiation. The lower curve shows the radioluminescence emitted during irradiation and the absence of luminescence as soon as the beam is interrupted. Other measurements (on, e.g., KCl, NaCl, and glasses) indicate that copious radioluminescence is emitted during irradiation and that a large fraction of it is absorbed by the radiation-induced color centers. These appear to be the first simultaneous measurements of optical absorption and radioluminescence on a sample undergoing electron bombardment, and a much improved understanding of radiation damage processes in nonmetals can be expected to result from such experiments.

Figure 17. Top: Optical absorption in LiF showing increase in F-center concentration during electron irradiation and stability of centers after irradiation. Bottom: Radioluminescence of LiF during electron irradiation and absence of luminescence after irradiation.

Figure 18. Behavior of positrons in aluminum containing helium atoms. Top: Rate at which positrons are trapped by helium atoms as a function of annealing temperature. Bottom: Lifetime of positrons in helium-atom traps as a function of annealing temperature.

In the past two years, positron annihilation has been developing into a useful tool for studying defects in solids. At Brookhaven it has been confirmed that such fundamental parameters as the energy required to create a vacant lattice site and the energy with which an impurity atom is bound to a vacant site can be determined by studies of positron lifetimes in metals as a function of temperature. Because vacancies play a major role in the diffusion processes that control metallurgical reactions, it is important that their properties be understood in detail.

A vacancy is an example of an intrinsic defect. Impurity atoms are examples of extrinsic defects, always present and sometimes deliberately added to solids. Interactions between intrinsic and extrinsic defects govern many properties of solids. The Brookhaven experiments have also demonstrated that positrons are sensitive to extrinsic defects. A good example is the study of helium-im-

planted aluminum. Helium is one of the transmutation products created in the structural materials of nuclear reactors. It is believed to play a key role in the nucleation of gas bubbles and voids, which produce macroscopic swellings of fuel cladding, and is known to cause embrittlement of metals.

In the Brookhaven studies, positron lifetimes in aluminum previously injected with α particles (helium nuclei) were measured at room temperature following heat treatment of the samples. With increasing temperature the rate at which positrons are trapped decreases (Figure 18, top). This behavior can be explained in terms of a decrease in the number of trapping sites, due to the migration and agglomeration of helium atoms. This provides a means of studying the migration behavior of the gas.

The positron lifetime in the trap increases as the trap enlarges (Figure 18, bottom). Efforts are continuing to quantify this change and relate it to average sizes of bubbles and voids. The approach is especially well suited to low-dose or initial-phase irradiations. Electron microscopy is an effective tool for studying voids with diameters $> \approx 20 \text{ \AA}$, but techniques for investigating small voids have been sorely needed. It appears that positron annihilation can fulfill this need and thus augment the electron-microscopy work in developing a proper understanding of this important research area.

LOW-TEMPERATURE PHYSICS AND SUPERCONDUCTIVITY

The properties of matter at low temperatures are investigated at Brookhaven along two distinct lines of research. In the first, interest is centered on the properties of the condensed phases of helium at ultralow temperatures, although some attention is given to other cryogenic experiments made possible by the specialized facilities available. The other is concentrated on the phenomenon of superconductivity, and the program is carried out in cooperation with the Accelerator Department and the Department of Applied Science (see that section of this report).

The experiments at ultralow temperatures employ a variety of refrigerators that cool to temperatures as low as $1/100$ of a kelvin (degrees above absolute zero) and are currently being modified to produce $1/1000$ of a kelvin. At such temperatures the effects of quantum mechanics can be seen on a macroscopic scale. Main attention is focused on the liquid and solid isotopes of helium, ^3He and

^4He , which show the most striking effects because of their low mass and weak binding. Superfluidity in liquid ^3He , an exciting recent discovery, is currently of principal interest in the experimental program.

Low-temperature techniques can also be used to bring about an alignment of the spins of atomic nuclei and thus make possible certain nuclear physics experiments. One question of fundamental interest is whether nuclear reactions involving the fundamental nuclear force called the weak interaction are symmetrical under time reversal. Obviously time cannot be reversed in the laboratory. However, it can be deduced that the rates at which the γ rays and electrons are emitted in different directions depend in a known way on the degree to which the force that determines the nuclear reaction would not be the same if time were to flow in the opposite direction. A test was carried out at Brookhaven by cooling radioactive cobalt nuclei to $1/100$ of a degree above absolute zero and measuring these rates of emission in different directions relative to the axis of nuclear alignment. Within experimental accuracy, the weak interaction was found to be unchanged by time reversal.

The solid state physics component of the cooperative program in superconductivity has emphasized work on ultrathin films, surface effects, and properties of small particles of superconducting materials. Although the research is fundamental in nature, particular attention is given to problems of underlying importance in the development of materials useful for energy-related applications.

The superconducting properties of crystalline ultrathin films were investigated for the first time in samples well characterized by low-energy electron diffraction techniques. These investigations were also extended to the properties of ultrathin metal films on small-gap semiconductors to determine whether excitons in the semiconductor substrates have any effect on superconductivity in ultrathin films. Experiments with lead films on PbTe have disclosed surprising superconducting properties due to involvement of the semiconductor surface, but no evidence has yet been obtained that would permit an excitonic mechanism to be established.

By evaporating metals in a helium atmosphere, it is possible to make small metallic particles, about 1000 Å in size, which are then pressed together to form an array of Josephson junctions. In

the region of the superconducting transition these arrays are extremely sensitive to rf radiation, and a dc voltage appears across the array in the presence of radiation. The possibilities of using these arrays to generate coherent radiation are being investigated.

Investigations have been made to achieve a better understanding of some superconducting properties, such as the penetration depth, that are known to be surface sensitive. By using Auger spectroscopy and ion-sputtering techniques, it was possible to study impurity distributions at and near the surface of heat-treated samples of niobium and tantalum. A model that includes the surface impurity distribution has been developed within the framework of the Ginzburg-Landau theory of superconductors. With this model, many problems that had not been resolved on the assumption of an ideal surface can now be approached on the basis of a better picture of real metal surfaces.

THEORETICAL RESEARCH

The theoretical work in solid state physics emphasizes areas in close correspondence with the principal experimental programs: neutron scattering, crystal imperfections, and low-temperature physics. The broad topics of continuing interest include the theory of phase transformations, magnetism, properties of the condensed phases of helium, electronic structure of metals and alloys, and lattice defects. The close relationship between theory and experiment is apparent in the example that follows.

In a ferromagnetic material, such as iron, all the magnetic moments of the individual atoms are aligned parallel to one another below the Curie point, which produces a net magnetic moment in the sample. Many substances possess the property of antiferromagnetism, in which the individual magnetic moments are aligned antiparallel to one another below a characteristic temperature called the Néel point. To produce such an arrangement above the Néel point, it would be necessary to apply a magnetic field that changes its direction from one atom to the next, and thus align the magnetic moments. Such "staggered" magnetic fields have been regarded as theoretical constructs, analogous to uniform magnetic fields in ferromagnets. The theoretical interpretation of unusual experimental results obtained by neutron scattering in the case of the antiferromagnet dysprosium aluminum garnet

net has shown, however, that it is actually possible to produce such fields in the laboratory. The differing environments of moments result in a different effect of an external magnetic field on the moments, i.e., in a staggering of that field.

This effect is important because it makes possible the creation of single-domain antiferromagnetic crystals. In addition, exploration of the phase diagrams of antiferromagnets can be carried out in the presence of staggered, as well as uniform, fields.

GENERAL AND ADMINISTRATIVE

PERSONNEL

The accompanying tables show the makeup of the scientific and visiting staffs by rank and degree, the extent to which consultants' services have been used, and some statistics on overall Laboratory employment. Table 1 reflects an increase in regular staff and nonsalaried visitors, and Table 2 shows a trend toward increased use of consultants. Total employment (Table 3) has increased slightly, after four years of reductions in personnel.

The large number of visiting scientists and students (Table 1) function at the Laboratory in various ways. The majority are faculty visitors who, with post- and predoctoral university students, form groups to carry out experiments at the Alternating Gradient Synchrotron and other BNL research facilities. These groups are in residence for some months while preparing for and then performing their experiments. Often groups from several institutions join in conducting an experiment. The ≈ 1000 nonsalaried visitors (Table 1) represent between 150 and 180 different universities or colleges.

Many visitors also take advantage of the academic summer recess. The demand for space is so great that the summer program at BNL is divided into two halves. The ratio of salaried to nonsalaried faculty visitors is roughly one to three. In addition, the summer student program, which runs for 10 weeks and offers a modest stipend, supports about 80 undergraduates selected from an application list of ≈ 500 .

In addition to academic visitors, between 50 and 100 scientists come for varying lengths of time from other national laboratories, industrial companies, foreign research institutes, and medical facilities. Some individuals find it most valuable to visit on an intermittent basis; thus, the ≈ 1000 visitors represent a total of 300 to 400 man-years, or a research effort about equal to that of the resident staff.

Postdoctoral research associates are treated as visitors in these statistics inasmuch as their terms are limited to a two-year stay at the Laboratory. Here again, however, the nonsalaried appointees greatly outnumber those on salary at Brookhaven.

AFFIRMATIVE ACTION

During fiscal 1972-1974, despite a 4% reduction in the total work force, minority representation at the Laboratory rose from 10 to 11.3%, and employment of women rose from 16.7 to 17.6%.

Currently, 49.5% of all minorities and 52% of all women hold positions in the top three Federal Equal Employment Opportunity job categories.

Two Black management interns have graduated into permanent administrative positions. In addition, two women have been promoted to positions as buyer, and two others have joined the ranks of police officers; formerly both jobs were traditionally filled by men.

Successful training contracts were negotiated between the Laboratory and the National Alliance of Businessmen's JOBS program; to date, this has resulted in training opportunities for eight minority individuals. On-the-job training, job-related basic education, and special counseling in the technical and drafting fields are being provided. Contract provisions dictate that special emphasis be given to minorities, women, veterans, and the "hard-core unemployed." All participants at BNL are individuals who represent these categories.

ADMINISTRATIVE

Dr. George H. Vineyard became the fourth Director of Brookhaven National Laboratory in January 1973. He replaced Dr. Maurice Goldhaber, who served as Director for 11 years. Dr. Vineyard had served as Chairman of the Physics Department from 1961 to 1966, and as Deputy Director of the Laboratory from August 1967. Dr. Goldhaber has become AUI Distinguished Scientist and is engaged full time in physics research at BNL.

Table 1
Scientific Staff and Students on May 31

	Visitors								
	Regular staff			Salaried			Nonsalaried		
	1974	1973	1972	1974	1973	1972	74	1973	1972
By appointment category									
Staff									
Senior Scientist	98	97	92	1	1	1	92	94	71
Scientist	182	182	188	3	2	2	216	183	198
Associate Scientist	95	91	97	4	2	2	228	250	211
Assistant Scientist	42	39	24	1	3	1	82	93	105
Senior Research Associate	-	-	-	6	7	10	1	2	3
Research Associate	-	-	-	54	57	52	112	115	119
Research Intern	-	-	-	0	7	18	-	-	-
Students									
Junior Research Associate	-	-	-	4	3	3	151	150	174
Research Assistant	-	-	-	0	0	0	133	116	113
Total	417	409	401	73	82	89	1015^a	1003^b	994^c
By academic degree									
Ph.D. or M.D.	307	299	285	66	76	81	-	-	-
Master	42	45	47	4	4	4	-	-	-
Bachelor	62	59	63	3	2	4	-	-	-
No degree	6	6	6	0	0	0	-	-	-

^a 70 of these appointees were at BNL on a full-time basis as of May 31, 1974.

^b 65 of these appointees were at BNL on a full-time basis as of May 31, 1973.

^c 76 of these appointees were at BNL on a full-time basis as of May 31, 1972.

Table 2
Consultants' Services

	Fiscal year			
	1974	1973	1972	1971
Total contracts in effect	149	105	108	116
Number of consultants used	91	58	70	57
Number of man-days of service	828	652.95	673.85	616.5

In November 1973 Dr. John P. Blewett was appointed Special Assistant to the Director for Energy. With the increased interest in energy problems, pertinent projects have been undertaken throughout the Laboratory. These range from programs related to fusion reactors, through studies of a hydrogen economy, to a program for developing an ac superconducting line for transmitting large blocks of electric power. Dr. Blewett will coordinate these various efforts and advise the Director on their status and on possible future programs.

In June 1973 Vincent R. O'Leary, Associate Director for Administration, assumed the additional responsibilities of the Fiscal Division and the Technical Information Division. In February 1974 the Management Information Systems office was established under Mr. O'Leary. This reflected the shift in responsibility for the operation of the ADP computer from the Associate Director for Administration to the Applied Mathematics Department.

Dr. Mark Q. Barton was appointed Chairman of the Accelerator Department, effective February 1974.

Table 3
Employment Statistics^a

	June 30, 1974		June 30, 1973		June 30, 1972	
Scientific staff ^b	480		480		485	
Scientific professional staff	282		283		283	
Nonscientific staff	1711		1674		1853	
Total	2473		2437		2621	

	1974		1973		1972	
Turnover data	Number	Annual rate (%)	Number	Annual rate (%)	Number	Annual rate (%)
<u>Accessions</u>						
Scientific staff ^b	85	18	82	17	85	18
Scientific professional staff	26	9	36	13	23	8
Nonscientific staff	156	9	108	6	140	8
Total	267	11	226	9	248	9
<u>Separations</u>						
Scientific staff ^b	85	18	87	18	57	12
Scientific professional staff	27	10	36	13	30	11
Nonscientific staff	119	7	287	17	163	9
Total	231	9	410	17	250	10
<u>Net Accessions</u>						
Scientific staff ^b	0	0	-5	-1	28	6
Scientific professional staff	-1	-1	0	0	-7	-3
Nonscientific staff	37	2	-179	-11	-23	-1
Total	36	2	-184	-8	-2	-1

^a Figures do not include temporary summer nonstudent employees. Guests and temporary student employees are included in Table 1.

^b Includes Research Associates, Research Interns, and Visitors.

In May 1973 the Laboratory's programs to provide information to the news media, arrange conferences and group visits, provide speakers for outside groups, establish liaison with public officials, and create publications, films, tapes, and exhibits describing the activities of the Laboratory were consolidated in an Office of Public Relations. Dr. R.C. Anderson is in charge of this office and carries overall responsibility for public relations.

An Office of Academic Relations was established in April 1973 to coordinate educational and related activities of the Laboratory. Dr. G.A. Price heads this office, while retaining his titles and responsibilities as Laboratory Security Officer and Foreign Scientist Advisor. Dr. Price is responsible for educational activities such as the Summer Stu-

dent Program, the Brookhaven Semester Program, in-service teacher institutes, and cooperative education. Appointments of visiting scientists and of students are made through this office, as well as all working visits of foreign scientists, whether of short or long duration.

The Office of Technology Transfer was created in April 1974, under the direction of William L. Graves, to promote the practical application in industry and government of technological developments made at Brookhaven.

Charles Meinhold, Head, Health Physics and Safety Division, assumed responsibility for the Plant Protection and Security Division on March 1, 1973, in recognition of the increased role of safety in the planning and functioning of the emergency forces on site.

The Department of Applied Science formed the Office of Regulatory Assistance (ORA) in October 1973 to expand the scope of technical support to the regulatory directorates of the AEC. The ORA provides technical support in the areas of safety analysis for thermal power reactors, nuclear materials, fast breeder reactors, and in other areas where appropriate.

Early in 1974 the Department of Applied Science experienced significant growth in the area of energy research and development, i.e., energy storage, systems analysis, environmental research, and technology assessment. New programs have been initiated, and increased emphasis has been placed on existing programs. The AEC's interest in the siting of power plants on off-shore stations has led to increased emphasis on meteorological research and to the initiation of programs in oceanography. The Division of Reactor Safety Research has funded new programs designed to update and revise, in preparation for the future, analytical models and computer codes for safety analysis with respect to light-water, gas-cooled, and breeder reactors.

Late in 1972 Associated Universities, Inc., reviewed AUI-BNL personnel policies and concluded that on the whole they have served the Laboratory well. The up-or-out policy and the high barriers to promotion, especially to positions with permanent tenure, have contributed greatly to the building of a high-quality scientific staff and have permitted a large throughput of younger staff. The latter, together with the research associates and the numerous visitors, have greatly enhanced the vigor of the Laboratory and have provided prolific sources of stimulating ideas. Administrative management of selection, promotion, and salary review processes was considered generally excellent in both the scientific and the administrative-service areas; reductions forced by inflation have been well handled from the standpoints of both productivity and morale. However, it would be desirable to accelerate the flow of younger staff and Ph.D. scientists in certain parts of the Laboratory where financial stringencies have forced a slowing down in this respect.

An organization chart as of February 1, 1974, appears on the inside back cover.

SERVICE ORGANIZATIONS

Cost reductions involving major computing facilities were implemented in fiscal 1974. After extensive review, the Digital Equipment Corporation

PDP-10 systems in the Accelerator Department and the Control Data Corporation 6600 complex in the Applied Mathematics Department were switched from contract maintenance by the manufacturers to maintenance by Laboratory personnel. The resultant savings amount to \$207,000 per year.

A Payroll System Committee, composed of representatives of the scientific and administrative organizations, was formed. Recommendations made by the committee were adopted, and, through the combined efforts of the Administrative Systems and Data Processing Division and the Fiscal Division, a redesigned payroll system became operational in June 1974. The new system provides management with significantly improved reporting and employees with additional data.

The Staff Services Division has assumed responsibility for coordination of record management and issuance of identification cards to operators of U.S. Government motor vehicles. These functions were formerly assigned to the Plant Protection and Security Division.

The Personnel Division instituted a supervisory development program for supervisory personnel in which management techniques, self-appraisal, and concepts of organizational development are stressed.

The Photography and Graphic Arts Division has consolidated by reducing the number of buildings housing it from four to three and relocating the illustration, photomicrography, optics, and standards functions.

The video tape capability of the Photography Group has been expanded from black and white to color. At present the color operation is limited to playback of programs from various sources, including the extensive library assembled by the AEC. Future plans for video tape include color recording within a program designed to provide the Laboratory with more effective communication.

The magnetic tape typewriter service of the Graphic Arts Group has been expanded into a word processing center with additional personnel and more sophisticated equipment. The center has also added dial dictation to its services.

ENERGY CONSERVATION

A number of steps were taken during the spring and summer of fiscal 1973 to reduce the consumption of electricity. The temperature settings of air conditioners were increased during working hours

and the equipment was turned off during non-working hours. Lighting level standards were reduced and lights were turned off in nonessential areas.

At the beginning of fiscal 1974 the gravity of the energy crisis became apparent and the effort to reduce all forms of energy consumption was put into high gear. In addition to the changes noted above, preparations for fall and winter conservation were begun. The maximum permissible temperature in occupied space was established as 68°F. Temperatures in unoccupied spaces were reduced to 55°F or lower, and several buildings were drained and the heat was turned off completely. Installation of automatic temperature setback controls in buildings was initiated when a cost/benefit analysis showed that a savings in fuel consumption would result. Departments were requested to consolidate their functions into fewer buildings so that power and heat could be saved in the vacated buildings.

The program of power reduction was intensified, and almost half of the fluorescent tubes were removed wherever health and safety considera-

tions would permit. A minimum of light was maintained in hallways and none in unoccupied spaces. Experimental equipment not in use was turned off when neither the equipment nor the research would be adversely affected.

"Waste oil" was procured and blended with virgin oil at the Central Steam Plant. Almost a million gallons of virgin oil has been conserved by the substitution of 1.2 million gallons of scavenger oil.

Participation in car-pooling (long a tradition at BNL) was increased by a voluntary computerized information system that provided interested employees with the names and addresses of employees residing in the same general area who also wished to join a car pool. The employees then made their own commuting arrangements.

Energy savings resulting from the above actions are difficult to assess; however, they are believed to be significant. Comparison of general power consumption in fiscal 1974 with that in fiscal 1973 indicates a 13% reduction, and steam production was reduced by 12% despite a colder winter.

ASSOCIATED UNIVERSITIES, INC.

ORGANIZATION CHART

February 1, 1974