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Annual Report

July 1, 1970

BROOKHAVEN NATIONAL LABORATORY

Upton, Long Island, New York 11973

Brookhaven National Laboratory is operated under a contract between the United States Atomic Energy Commission and Associated Universities, Inc. This, the twenty-first in a series of unclassified Annual Reports, gives an account of the progress of the Laboratory during the period July 1, 1969 – June 30, 1970, and its plans for the future. It is submitted under the terms of Contract No. AT-30-2-GEN-16 between Associated Universities, Inc., and the Atomic Energy Commission.

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BNL 246 (AS-7) July 1, 1953
BNL 303 (AS-8) July 1, 1954
BNL 364 (AS-9) July 1, 1955
BNL 426 (AS-10) July 1, 1956
BNL 462 (AS-11) July 1, 1957
BNL 523 (AS-12) July 1, 1958
BNL 560 (AS-13) July 1, 1959
BNL 632 (AS-14) July 1, 1960
BNL 682 (AS-15) July 1, 1961
BNL 742 (AS-16) July 1, 1962
BNL 806 (AS-17) July 1, 1963
BNL 867 (AS-18) July 1, 1964
BNL 929 (AS-19) July 1, 1965
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Brookhaven National Laboratory is operated by Associated Universities, Inc., under contract with the United States Atomic Energy Commission. Nine northeastern universities sponsor Associated Universities, Inc. The Board of Trustees consists of two individuals from each university, one a principal administrative or corporate officer and the other a scientist, and not more than six Trustees-at-Large selected by the Board. The purpose of the latter is to insure adequate representation of any scientific discipline in which the corporation may undertake work and to provide general flexibility in methods of operation. The composition of the Board as of July 1970 is given below. The officers of AUI are shown on the organization chart for the Laboratory. AUI has appointed five visiting committees to Brookhaven National Laboratory to provide a continuing independent evaluation of the research program. The committees cover the fields of applied science, biology, chemistry, medicine, and physics and report annually to the Board of Trustees.

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ASSOCIATED UNIVERSITIES, INC.

ORGANIZATION CHART

July 1, 1970

THE NUMBER OF EMPLOYEES IN EACH ORGANIZATIONAL UNIT ON JULY 1, 1970, IS SHOWN. TOTAL FOR THE LABORATORY, 2942.

BROOKHAVEN NATIONAL LABORATORY

* ACTING

On October 3 a 12-gram sample of lunar rock collected by the Apollo 11 astronauts arrived at the Laboratory. Before undergoing intensive analysis by Chemistry Department scientists, it was displayed to the public for two days and was viewed by some 8500 people.

Introduction

The program and activities of Brookhaven National Laboratory during the fiscal year 1970 are described in this annual report. The progress and trends of the research program are presented together with a description of the operational, service, and administrative activities of the Laboratory. The scientific and technical details of the many research and development activities are covered more fully in scientific and technical periodicals and special reports of the Laboratory. A list of all publications published or submitted for publication during the year may be found in Appendix A.

Technical publications.

RESEARCH PROGRAM

The Brookhaven research program, which covers a wide range of subjects in the physical and biological sciences and in engineering, has as its central

motif the development and exploitation of nuclear science and technology. It can be broadly described under five main headings:

1. FUNDAMENTAL STUDIES OF ATOMIC NUCLEI, THE PARTICLES THAT CONSTITUTE THEM, AND THE FORCES INVOLVED IN THEIR STRUCTURE. These studies, which are basic to all nuclear science and technology, involve the use of all the major machines of the Laboratory. They range from measurements of the properties of undisturbed nuclei to study of the violent disruptions resulting from nuclear fission or from bombardment with high energy protons from the Laboratory's 33-BeV Alternating Gradient Synchrotron (AGS).

2. STUDIES OF THE PHYSICAL, CHEMICAL, AND BIOLOGICAL EFFECTS OF NUCLEAR RADIATION. The effects of radiation are utilized to determine the characteristics of physical and chemical structures and to elucidate the more complex properties of living systems and the changes they undergo in their life and reproductive cycles. Of direct practical interest are the possible deleterious effects of radiation upon biological systems and upon various materials, for example, those involved in reactor construction. Of equal interest are the potentially beneficial effects of radiation in the treatment of diseases, in the induction of genetic changes in plants or animals, and in the improvement of manufacturing processes.

3. THE USE OF NUCLEAR TOOLS, SUCH AS NEUTRONS, CHARGED PARTICLES, GAMMA RAYS, AND ISOTOPIC TRACERS, IN ALL BRANCHES OF SCIENTIFIC RESEARCH. In this broad and diversified field, which overlaps the one just mentioned, nuclear particles and radiations are used as tools in studying physical, chemical, and biological systems in their undisturbed states. Neutrons and other particles are used as probes: by observing their penetration and scattering, minute details of physical and chemical structure can be studied. Wide use is made of isotopic tracers in many fields to yield information on such matters as the mechanisms and rates of chemical reactions and biological processes.

4. RESEARCH AND DEVELOPMENT, NOT NECESSARILY ITSELF OF A NUCLEAR NATURE, DIRECTED

Checking out one of the tanks for the new 200-MeV linear accelerator, which will replace the 50-MeV machine currently serving as injector for the AGS. The new injector represents one aspect of the AGS Conversion Project.

Three members of the staff of the Institute of Nuclear Research, Dubna, USSR (second, third, and fourth from the right), being shown counting equipment in the AGS East Experimental Area by BNL physicists.

TOWARD SOLVING THE PROBLEMS OF ATOMIC ENERGY DEVELOPMENT. The more basic aspects of this category include the chemistry of elements and compounds of special interest, isotope effects, the metallurgy of materials used in nuclear reactors and other devices of importance in the atomic energy program, the neutron scattering and absorbing properties of substances used in reactors and other nuclear devices, and similar subjects. Among its applications are the development of reactor components such as fuels, structures, and shields, the development of components and processes for the chemical processing and useful recovery of reactor products, and theoretical and experimental studies in the field of reactor physics.

5. THE DEVELOPMENT OF SPECIFIC DEVICES FOR USE AS RESEARCH TOOLS OR IN PRACTICAL APPLICATIONS OF ATOMIC ENERGY. This category includes both the design and development of special research tools, such as accelerators, reactors, and other technical equipment, and the development of devices for practical applications of atomic energy, such as the preparation of special isotopes, the development and packaging of high-intensity radiation sources, and basic development work on power reactor systems.

The involvement of the various scientific disciplines in these areas of study and development results in a coherence and mutuality of interest that enhance the entire program of the Laboratory in both tangible and intangible ways. Specific research projects are described in those sections of this report devoted to the particular discipline or organizational unit in which the work is being carried out. It will be noted that research interests overlap from one department to another, and similar problems are being attacked from different points of view.

In addition, the international aspects of the research program should be pointed out. Besides providing research opportunities for many scientists and students from other countries, Brookhaven has a general program of international cooperation which includes cooperative agreements with the nuclear centers in Greece, Italy, and Puerto Rico.

RESEARCH FACILITIES

Research at Brookhaven is centered on, although not confined to, the use of several large machines and other special facilities, some of which are described below.

Alternating Gradient Synchrotron

The AGS, Brookhaven's 33-GeV synchrotron, continues to be one of the major centers for research in high energy physics. During the first part of the year, however, it was inoperative because of the construction programs associated with the AGS conversion project. As part of the project, the new central radio-frequency drive system was commissioned. Operation was resumed in January, and since then the beam intensity has increased steadily. Other aspects of the conversion call for a 200-MeV linear accelerator to replace the present 50-MeV injector, additions to the Target, East Experimental, and Service Buildings, and various other improvements designed to meet the future research requirements of the AGS.

The number of experiments that can be run concurrently has expanded further during the year. This results mainly from a mode of operation in which an internal target intersects the circulating proton beam simultaneously with the operation of the slow external beam system. In order to make efficient use of the increased beam intensities now available at the AGS, the external beam system is being expanded into a beam "switchyard." A complete report on the AGS and the conversion project can be found in the section on High Energy Accelerators.

High Flux Beam Research Reactor

The High Flux Beam Research Reactor (HFBR), which achieved initial criticality in October 1965 and attained its full design power of 40 MW in February 1966, produced a total of 9056 MWd of energy during the year, bringing the total power accumulated to date to 39,106.36 MWd. In the course of the year eleven full operating cycles were completed. During scheduled shutdown periods, 168 used fuel elements were discharged from the reactor and replaced with new elements. All the horizontal beam holes have been occupied during the year by experiments, including many involving the irradiation of samples of lunar material from the Apollo 11 and 12 missions.

Medical Research Reactor

The Medical Research Reactor (MRR), which achieved criticality in March 1959, was designed for the purpose of exploring the possible applications of nuclear reactors to the study of man and his diseases. During fiscal 1970 it was operated on

Mouse with its leg in the center of a ^{252}Cf source array for neutron exposure of bone marrow. The Lucite holder contains an array of four ^{252}Cf needles. At BNL's Medical Research Center this radioisotope, with its unique characteristics as a neutron emitter, is being evaluated for use in cancer therapy.

165 days, and 1307.099 MWh of operation were accumulated. A total of 821 irradiations were made; 26 of these were for outside organizations. The original MTR-type fuel elements with which the MRR was loaded in 1959 are still in use, with no difficulties encountered.

Additional information on both the HFBR and the MRR is given in the section on Technical Operations and Services.

Critical Assembly Laboratory

The Critical Assembly Laboratory provides specialized facilities for research in reactor physics and for reactor development studies. These facilities include five assembly cells and their associated control areas, a counting room, two uranium storage vaults, and an analogue computer and two digital computers used for on-line processing as well as for standard data reduction. Two of the cells contain neutron source reactors, and a fast source reactor (FS-1) is available for experimental

Health physicist checking radiation levels at a fast source critical assembly (FS-1). This assembly, designed to investigate the general characteristics of fast reactors, contains 143 kg of ^{235}U . The core is built up of 29 layers of ^{235}U alternating with layers of graphite, surrounded by a minimum of 18 in. of steel on each side. The maximum power output of FS-1 is 1 kW, although it is often operated at 1 W to minimize residual radiation.

The control room of the HFBR. In the foreground is part of the console from which the various systems of the reactor are controlled. The operator in the background is recording data from one of the many instruments used to monitor and record the operation of the reactor and its supporting systems.

use in another cell. This latter assembly, containing ≈ 150 kg of ^{235}U , is being used in a series of studies of heterogeneity effects in fast breeder reactors.

High Intensity Radiation Development Laboratory

The primary functions of the High Intensity Radiation Development Laboratory (HIRDL) are to obtain engineering data on a variety of radiation sources in the million-curie range and to develop more efficient techniques for handling large-scale radiation sources. This information is essential for the design of future irradiation facilities needed for a wide range of applications of radiation energy. Operations included the processing of monomer-impregnated concrete specimens,

the field testing of accelerator safety devices and Medical Department phantoms, and the loading and modification of food, biological, and medical irradiators. One shipboard irradiator was returned from Iceland and reconditioned. Following interim use in Louisiana, it will be installed in Korea. A second unit was completed and shipped to India, and the third was installed in Chile late this year. A portable cesium irradiator, after a period of deactivation, was sent to California for short-term use and will go next to Louisiana.

80-in. Liquid Hydrogen Bubble Chamber

During the year the 80-in. bubble chamber, located in the North Experimental Area of the AGS, produced a total of 676,000 pictures, dis-

The Biology Department's research field, where various plants can be grown under controlled conditions in studies on plant genetics, plant ecology, and related research projects.

tributed among 7 separate experiments in which 12 experimental groups participated. The conversion program, which prevented the AGS from providing particles for eight months, was responsible for this relatively small number of pictures.

Most of the pictures were taken with the chamber filled with deuterium and with the new hydraulic-powered expansion system in operation. During the shutdown period the chamber was converted to a bright field illumination system. New lenses with a shorter focal length give a greater demagnification and permit the use of 35-mm instead of 70-mm film. More information on the 80-in. bubble chamber may be found in the section on Physics.

Central Scientific Computing Facility

The Central Scientific Computing Facility supplies large-scale, general-purpose computing service to the overall research program of the Laboratory. It is currently equipped with four computer systems. Two large-scale CDC 6600 computers, each with a 65,000-word internal memory and both sharing one million words of extended core storage, serve remote users through BROOKNET, a high-speed computer-to-computer digital communications network. A small-scale CDC 3200 system is coupled directly to the CDC 6600's for remote on-line editing and updating of files. The fourth computer system, a small CDC 924, provides off-line support to the CDC 6600's. Since the present equipment is fast approaching saturation, plans are under way to acquire an additional, very large-scale computer in order to meet the Laboratory's growing needs. Further details on the Brookhaven computer program are contained in the section on Applied Mathematics.

MAJOR RESEARCH FACILITIES UNDER DESIGN AND CONSTRUCTION

Tandem Van de Graaff

MP-7, the second of the two accelerators for the new three-stage Tandem Van de Graaff Facility, was assembled and in operation by July 1969, and both accelerators were completed and had undergone all but one of the acceptance tests by the end of August.

The one test not completed was that for beam modulation. The beam from the special duoplasmatron used for the accelerators turned out to

be modulated as much as 95% under the worst conditions and 40% under the best conditions. Since the specifications stipulated 20% or less, there was a serious problem with this ion source that required investigation at the factory.

The H^- ions that are accelerated are customarily produced from H^+ ions through a charge exchange process in a gas. After extensive testing, the High Voltage Engineering Company (HVEC) discovered that the source could be operated under special conditions that optimized the production of H_2^+ ions rather than H^+ ions and could meet the modulation specifications by this means. The only difficulty in producing H^- ions from H_2^+ ions by gas exchange is that the binding energy of the H_2^+ ions limits the minimum time compression by bunching techniques when the beam is used in the pulse mode. Unfortunately, the specification did not include the detail that the H^- ions had to be produced by H^+ ions in the exchange system; consequently this technique was adequate in terms of contractual requirements. However, HVEC felt a moral obligation to provide an H^- capability in the spirit, if not the actual language, of the contract and supplied to the Laboratory, free of charge, two direct extraction sources that adequately meet the modulation and current specifications. One of these sources is now in use on the MP-7 accelerator and is an improvement over the original gas exchange source because of its greater ease of operation.

Accelerator MP-6 was tested to 9.5 MV with a negative terminal and cycled through both positive and negative operation to demonstrate a lack of difficulties with the negative operational mode. It was then modified for installation of the terminal source, and control rods were installed for the control of the terminal ion source components. The accelerator was again tested to 9.5 MV to demonstrate that the control rods did not affect the electrostatic integrity of MP-6.

Toward the end of the fiscal year, the terminal source was being installed in final form in the terminal mock-up for alignment tests to demonstrate the performance of the source. The necessary beam transport equipment for the three-stage interconnection has now been installed, and three-stage operation was achieved shortly before the end of the year.

Bids have been received on a large magnetic spectrometer, the only experimental component still to be purchased under the construction con-

Inside the Tandem Van de Graaff Facility Building. Accelerator MP-7 is in the upper center, and MP-6 is in the background. The analyzing magnet (foreground) bends accelerated particles from the two machines at a 90° angle. The control slits on the beam line (lower left) control the energy of the particles. MP-7 is now being used on nuclear research problems, and MP-6 will be connected to it in the future for higher energy. In addition to being used for research with accelerated protons, this facility will be able to accelerate the ions of such elements as chlorine, sulfur, fluorine, oxygen, and carbon for special nuclear measurements.

tract. The spectrometer should be in operation in about two years.

MP-7 went into routine operation for research on a 3-days/week basis. A number of preliminary measurements have been made, but a large amount of diagnostic work remains to be done. An active summer program is planned, the work to be carried out principally with two 30-in. scattering chambers. One of these is already installed and in use.

General Construction Program

In the AGS conversion program, for which >\$43 million has been allocated to date, the building and facility construction work is essentially complete, except for the new North Experimental Facility. By the end of the fiscal year about 84% of the project funds had been committed. Detailed design of the accelerator components is nearing completion, and much of the equipment is now on site. The first section of the 200-MeV linac is accelerating protons to 10 MeV. Injection of 200-MeV protons into the AGS is expected to begin in the last quarter of 1971.

The East Experimental Building Addition, completed last year, is now housing that portion of the experimental program associated with the extension of the slow external beam. The main Power Supply Building and the Rf Building, both located inside the main ring, have been completed. The Linac Building complex, including the beam transport tunnel into the AGS, is complete.

The original conversion proposal called for a West Target Building inside the ring. However, as it became clear that all bubble chamber activity should be concentrated in the North Experimental Area, it was decided that the money allocated to the West Target Building should be reallocated to the North Experimental Area. A neutrino beam tunnel about 600 ft long will be built to transport a full-intensity beam (10^{13} protons/sec) to a heavily shielded target. This will be followed by a 30 to 40-ft steel neutrino filter, in front of which the 7-ft and 80-in. bubble chambers will be located. Design for this facility is essentially completed and the contract is about to be let.

PERSONNEL

The total number of employees at the Laboratory on June 30, 1970, excluding temporary ap-

pointees, Research Collaborators, and guests, was 2943, a net decrease of 318 from the 1969 figure. During the year the regular scientific staff (Ph.D. or equivalent) decreased from 464 to 457. Research associates decreased from 67 to 59, and salaried visitors* decreased from 29 to 27, for a net decrease in salaried staff of 17, from 560 to 543. The non-salaried scientific staff* decreased from 922 in 1969 to 886 in 1970, as of May 31 of these years. The latter visitors are not at Brookhaven on a full-time basis. About one-fourth to one-third of them are on site at any one time. A total of 628, as compared with 633 in 1969, visiting scientists and students worked at the Laboratory during the year; this number does not include Research Associates.

Summer visitors continue to play a significant role in the Laboratory's program. Arrangements have been made for 268 visiting scientists and students to work at Brookhaven during the summer of 1970. Of this number, 124 are staff members from various educational and research institutions, and 144 are students.

ADMINISTRATION

The organization of the Laboratory and the corporate structure, both as of July 1, 1970, are shown on the Organization Chart and in other material at the front of this report.

The principal changes in the corporate structure are the election of Mr. Lewis R. Burchill to the office of Treasurer as well as that of Controller, and the loss to AUI of the services of Mr. Charles F. Dunbar, who retired on December 31 after more than 23 years of service as Secretary and General Counsel.

Several changes in Laboratory administration took place during the course of the year. Dr. William J. Catacosinos resigned as Assistant Director on August 1 to join an industrial firm; on this date Mr. Vincent O'Leary assumed the title of Assistant Director for Financial Planning and Business Management, and on September 1 Mr. Henry C. Grahm was appointed Budget Officer. Dr. Werner Hirs, Chairman of the Biology Department, left the Laboratory on September 10 to accept the position of Director, Division of Biological Sciences, Indiana University; he was replaced by Dr. William Siegelman, who became Acting

*These categories include students. For further details, see the section on Administration and Operations.

BNL physicist with a group of students during their tour of the exhibits and demonstrations on High School Visitors' Day.

The third group of students to participate in the Brookhaven Semester Program, during an orientation tour at the HFBR.

Operating Cost Distribution by Programs								
Fiscal Year	Physical Sciences	Reactor Development	Life Sciences	Isotope Development	Training & Education	Special Nuclear Materials	Other (Net)	Total Cost
1970	34,817,424	4,319,738	8,043,871	1,274,269	196,441	749,987	2,166,430	51,568,160
1969	34,283,899	4,771,541	7,745,345	1,257,277	214,137	385,498	1,834,281	50,491,978
1968	33,737,789	5,098,856	7,605,319	1,209,620	227,390	—	1,553,662	49,432,636

Major Categories of Operating Expenditures				
Fiscal Year	Salaries & Wages	Materials & Supplies, Subcontracts, Travel, & Special Procurements	Power	Operating Total
1970	40,005,878	10,048,471	1,513,811	51,568,160
1969	38,666,941	10,111,892	1,713,145	50,491,978
1968	36,229,083	11,374,975	1,828,578	49,432,636

BROOKHAVEN NATIONAL LABORATORY COMPARATIVE BALANCE SHEET

Assets		June 30, 1970	June 30, 1969
Cash		\$ 653,999	\$ 74,070
Accounts receivable		280,182	186,514
Advances, deposits, and prepaid expenses		103,027	137,342
Property, plant, and equipment (less reserves of \$102,406,801 at June 30, 1970, and \$99,473,625 at June 30, 1969)		193,797,556	181,627,014
Research materials and supplies		9,043,305	12,961,990
Total assets		\$203,878,069	\$194,986,930
Liabilities			
Accounts payable		\$ 4,302,988	\$ 5,307,053
Accrued vacation		3,503,981	3,443,037
Accrued payroll		426,192	297,715
Atomic Energy Commission		195,644,908	185,939,125
Total liabilities		\$203,878,069	\$194,986,930

NOTE: Although the Laboratory has custody and use of the assets, title remains vested in the United States Government.

AUI Distinguished Lecturers at BNL during fiscal 1970. Professor Kenneth E. Moyer (top left), Professor of Psychology at Carnegie-Mellon University, delivered a lecture on "Some Implications of Recent Brain Research" on October 2. Former Secretary of the Interior Stewart L. Udall (left) spoke on November 12; the title of his lecture was "Agenda for Tomorrow." Dr. Alvin M. Weinberg (top center), Director of Oak Ridge National Laboratory, delivered a lecture on February 26 with the title "National Environmental Laboratories?" On April 2 Dr. Richard L. Garwin (top right), who is Director of Applied Research at the IBM Watson Laboratory, spoke on "Strategic Arms Limitations."

Chairman of the department on September 11 and Chairman on March 1. Mr. Gerald C. Kinne, Leader of the HFBR Operations Group, became Assistant to the Director on September 1. On January 26 Dr. J.B.H. Kuper, Chairman of the Instrumentation and Health Physics Department, was appointed Chairman of the newly established Environmental Sciences Study Group; Dr. Frederick P. Cowan is serving as Acting Chairman of the department, with Mr. Robert L. Chase as Deputy Chairman.

FINANCE

AEC-supported research continued to be financed by the AEC Divisions of Reactor Development and Technology, Research (Physical Sciences), Biology and Medicine (Life Sciences),

Nuclear Education and Training, and Isotopes Development. Operating costs for the work in each program and the major categories of operating expenditures are shown in the accompanying figure.

CONFERENCES

Six major scientific conferences were held at Brookhaven during fiscal 1970: Seminar on Irradiator Source Activity Standardization, July 8-9; Chemical and Physical Aspects of Neutron Diffraction, August 22-23; Third American Electromagnetic Isotope Separator Symposium, September 16-17; Atmospheric Diagnostics Program Information Meeting, October 16; Electrochemical Carbon Meter Meeting, March 23; and the Sixth Seminar on Medical Planning and Care in Radiation Accidents, April 26-29.

PHYSICAL
SCIENCES
AND
ENGINEERING

Physics

PARTICLE PHYSICS

The study of the particles from which all matter is built has three aspects: the investigation of intrinsic properties of the particles, the analysis of the interactions that lead to forces between them, and the correlation of particles and interactions into a unified description providing appropriately for each. Typical intrinsic properties are rest mass, electric charge, spin, isospin, strangeness, magnetic moment, and parity. Some of these are quantum numbers associated with the internal symmetry of the particle. Others are coupling constants that specify strengths of interactions. The behavior of elementary particles is, in a sense, complex, with many identifiably different particles and four types of interaction between them. Various schemes seek to arrange the particles in orderly families and to identify some as excited states of others.

Of the four types of force there are two whose investigation is closely linked with nuclear phenomena. The first is the weak interaction, which appears mainly in β decay and other relatively slow disintegration processes of unstable systems. Neutrino interactions represent a field of research into weak interactions that is still virtually unexplored. The second type is the strong interaction, which causes nuclear binding, nuclear reactions, and fast disintegration processes. The other two forces, gravitational and electromagnetic, were first understood from larger-scale phenomena. Gravitational interactions between elementary particles are too weak to be experimentally accessible. Electromagnetic interactions govern important aspects of particle behavior and are a major research tool, primarily at electron accelerators.

Historically, it was the discovery of light quanta that first indicated the wave-particle duality that pervades modern physics. This duality between interactions and particles means that particles are the sources of interactions and, since fields causing interactions can be described as composed of particles, interactions are the source of particles. The two are intimately related in a complementary way and must be taken together in any unified description. In the "bootstrap" theory the strongly

interacting particles and fields are all supposed to generate each other in such a way as to satisfy some basic consistency principle. There is no generally accepted unifying theory at present, but the growing wealth of experimental information provides the basis for eventual understanding.

At Brookhaven the Alternating Gradient Synchrotron (AGS) is the major experimental facility used for research in particle physics. The operation, maintenance, and improvement of the AGS is the responsibility of the Accelerator Department. This responsibility extends to the provision of secondary particle beams and other general support for the experimental high energy physics program. For the first half of fiscal 1970 the AGS was shut down to accomplish changes necessary for eventual operation at increased intensity. These activities are described in detail in the section on High Energy Accelerators.

The primary proton beam at the AGS has an energy of ≈ 30 GeV. Slightly higher values may be obtained when needed, and lower values are possible. About 2×10^{12} protons/pulse can be accelerated. The beam may strike internal targets within the AGS ring or be ejected to hit an external target. From such targets a wide variety of secondary beams of momenta up to ≈ 25 GeV/ c are available, including protons, neutrons, antiprotons, K^+ , K^0 , K^- , π^+ , and π^- mesons, and neutrinos. Some beams are separated to provide particles of a single mass, and some have the fraction of particles with the desired mass enhanced to a lesser degree. Either fast (short time duration) beams for bubble chambers or slow (up to 0.4-sec duration) beams for counters or spark chambers can be provided. Normal operation provides appropriate combinations from each machine pulse.

In addition, certain particle detection facilities are provided for groups performing experiments. A simple service is the provision of a pool of electronic equipment from which experimenters can draw standard circuits and subsystems. Hydrogen targets and cryogenic service are another form of experimental support. There are three bubble chambers, a round chamber 30 in. in diameter and two rectangular chambers, one 31 in. long and

the other 80 in. long. There are two operating crews so that the 80-in. chamber and either the 30-in. or the 31-in. chamber can be operated 24 hr/day, 7 days/week.

The On-Line Data-Processing Facility, in which a PDP-6 computer and a companion PDP-10 are the central elements, is available for on-line monitoring and analysis of as many as four electronic experiments at one time. Precision measurement of bubble-chamber photographs is performed by a flying spot digitizer for bubble-chamber groups at Brookhaven. Such measurements are also made on a limited basis for collaborating university groups. When circumstances require it, the Central Scientific Computing Facility is also made available to high energy physics groups doing experiments at the AGS.

Brookhaven staff members carry on an active research program in high energy physics, but most experimental work is done by groups from universities and other laboratories. During the year the number of guests scientists participating in the high energy physics program was 245. They represented 30 universities and laboratories, mainly, but not exclusively, in the United States, as follows.

Brandeis University
Brown University
Carnegie-Mellon University
Case Western Reserve University
CERN
City College of the City University of New York
Columbia University
Cornell University
Florida State University
Harvard University
Hunter College of the City University of New York
International Business Machines Corporation
Johns Hopkins University
Massachusetts Institute of Technology
Max-Planck Institut
McGill University
National Accelerator Laboratory
National Aeronautics and Space Administration
Northeastern University
Princeton University
Purdue University
Rockefeller University
Rutgers University
State University of New York at Stony Brook
Syracuse University
Tufts University
University of California at Berkeley
University of Cincinnati
University of Maryland
University of Massachusetts
University of Michigan

University of Pennsylvania
University of Rochester
University of Tennessee
University of Wisconsin
Vanderbilt University
Virginia Polytechnic Institute
Yale University
York College of the City University of New York

In the following summary no attempt has been made to include all the work in particle physics done at BNL during fiscal 1970. A list of publications is given in Appendix A from which more complete information can be obtained. This description presents the highlights and typical examples of the research activity for this period.

AGS Research Activity

Bubble-Chamber Experiments. Bubble-chamber research continues to be a profitable source of knowledge and understanding of the physical world. There are four forces of nature (strong, electromagnetic, weak, and gravitational), each responsible for a type of interaction which in general provides the "glue" for a given system. In particular, the strong interaction holds the nucleus together; the electromagnetic interaction, the atom; and the gravitational interaction, the planetary system. One way of looking at how the force is transmitted at a distance is to imagine that there is an exchange of some particle or particles, much like two boys interacting by throwing a baseball to each other. Large particles involve short-range interactions. Therefore particles and interactions are strongly interrelated. Each interaction obeys some set of conservation laws or symmetry principles, such as the conservation of charge.

Because it permits a close look at each interaction with little angular bias and with good spatial resolution, the bubble-chamber technique is particularly valuable for the discovery of new elementary particles and subsequent deduction of their properties, as well as the analysis of reactions with many particles in the final state. The three bubble chambers operating at BNL have provided data whose analysis in the past year has advanced our grasp of the basic forces of nature, their symmetries as well as their dynamical form. A partial summary is presented of results obtained in the past year from bubble-chamber experiments at BNL.

Parallel to the research effort at BNL, development of the bubble-chamber technique is being actively pursued by improvement of existing fa-

cilities, such as the chambers themselves, and development of new chambers and techniques, such as the 7-ft chamber, the track-sensitive target, and the minimum guidance program for data processing. The efforts of the BNL bubble chamber groups are also reviewed.

1. Strong Interactions. In broad terms, experiments in the area of strong interactions can be classified in three categories: the search for new particles and determination of their intrinsic properties such as mass and spin, two-body reactions ($a + b \rightarrow 1 + 2$), and multiparticle production ($a + b \rightarrow 1 + 2 + 3 \dots$). The first category is principally concerned with classification and symmetries of strong interactions, while the second and third are concerned with developing a theory of strong interactions which, while including the symmetries, treats of the dynamical nature of the interaction.

Symmetries and classification. The search for new particles (sometimes called resonances) and the determination of their properties are of interest because they often fit into families. This follows the example of looking at light spectra in the late nineteenth century. These families are often related by some symmetry or conservation law of nature. An example of this concept is the charge independence of strong interactions, which says, for instance, that the neutron (charge = 0) and the proton (charge = +1) have the same strong interactions. The symmetries are usually expressed mathematically in terms of group theory; thus

charge independence is equivalent to invariance of the strong interaction under rotations of the $SU(2)$ group. In recent years the search has been for higher symmetries, such as $SU(3)$ and $SU(6)$. The $SU(3)$ scheme has been used quite successfully in classifying the elementary particles.

About five years have elapsed since the discovery of the Ω^- hyperon and seven years since the introduction of the $SU(3)$ group by Gell-Mann

Figure 2. Chew-Frautschi plot for the baryon spin-parity series $\frac{1}{2}^+$, $\frac{3}{2}^-$, $\frac{5}{2}^+$.

Figure 1. Chew-Frautschi plot [J^P versus $(\text{mass})^2$] for the baryon spin-parity series $\frac{1}{2}^+$, $\frac{3}{2}^-$, $\frac{5}{2}^+$, $\frac{7}{2}^-$.

Figure 3. Chew-Frautschi plot for the known boson particle spectra.

Figure 4. Histogram of number of events for each 20-MeV/ c^2 $K_1^0 K_1^0$ effective-mass interval when the momentum transferred from the beam to the K_1^0 pair is $< (1.0 \text{ GeV}/c)^2$.

and Ne'eman for the classification of strongly interacting bosons and baryons. In the intervening time numerous additional resonances have been reported, and several $SU(3)$ families have been proposed in both the boson and baryon categories. In the former category, the existence of spin-parity (J^P) 0^- , 1^- , and 2^+ families is established, and the evidence for possible 0^+ and 1^+ multiplets is becoming compelling. Numerous baryon families are established, namely the $J^P = \frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{3}{2}^-$, $\frac{5}{2}^+$, $\frac{5}{2}^-$ and $\frac{7}{2}^+$ multiplets. The masses and spins of the constituent members of these families are shown in Figures 1, 2, and 3.

For boson families, only particles with isospins $I=0$, 1, and $\frac{1}{2}$ have been observed. New experimental information on $I=0$ particles has come from two experiments performed at BNL in the 80-in. bubble chamber. A $J^{PC}=0^{++}$ enhancement (C =particle-antiparticle number) was observed at a mass of $1030 \pm 10 \text{ MeV}/c^2$ with a width of $45_{-15}^{+35} \text{ MeV}/c^2$ by combining data from a K^-p experiment at 3.9, 4.6, and 5.0 GeV/ c and a K^-d experiment at 3.6 and 3.9 GeV/ c performed by groups from BNL. The resonance interpretation was favored over an s -wave scattering length effect. (See Figure 4.) Within experimental uncertainties, this enhancement was associated with the S^* observed in π^-p interactions. Another $I=0$ resonance was observed in an 8-GeV/ c π^+d experiment performed by groups from BNL, Oak Ridge National Laboratory, Union Carbide Corp., the University of Tennessee, and the University of Pennsylvania. The resonance has a mass of $1670 \pm 20 \text{ MeV}/c^2$ and a width of $100 \pm 40 \text{ MeV}/c^2$ and decays mainly into the $\rho\pi$ final state.

Much new information concerning $I=1$ bosons has come to light, including discoveries, confirmations, and clarifications of some old problems. Two new $I=1$ boson resonances were discovered. Evidence was presented for a resonance with mass $1695 \pm 20 \text{ MeV}/c^2$ and width $90 \pm 20 \text{ MeV}/c^2$, found in a K^-p experiment at 4.6 GeV/ c performed by a BNL group. It decays principally into $\omega\rho$ and $\omega\pi\pi$. This state can be interpreted either as new, further complicating the R region, or as an alternative decay of the $\pi(1640)$, sometimes called the A_3 ; the latter would require an $\omega\pi\pi/f\pi$ branching ratio >4 . Another $I=1$ resonance was found in a $\bar{p}p$ formation experiment performed by a BNL group. It has a mass of $2190 \text{ MeV}/c^2$ with a width of >20 but $<80 \text{ MeV}/c^2$, and decays into $\rho^0\rho^0\pi^0$. It may be associated with an enhancement in $\bar{p}-p$ and $\bar{p}-d$ total cross sections.

Two $I=1$ resonances were confirmed. In a K^-p experiment at 3.9, 4.6, and 5.0 GeV/ c performed by a BNL group in collaboration with a group from Syracuse University, the δ meson found in missing-mass experiments was confirmed. Its mass was $970 \pm 15 \text{ MeV}/c^2$, with a width consistent with 0 and a dominant $\eta\pi$ decay mode. (In a K^-d experiment at 3.6 and 3.9 GeV/ c performed by a BNL-CCNY collaboration, a previous confirmation of the δ meson in other experiments was not supported; a kinematic effect was proposed to explain the data.) The g meson [or $\pi(1700)$] was confirmed in its 2π decay mode in an 8-GeV/ c π^-p experiment performed by groups from the Universities of Pennsylvania, Notre Dame, and Rochester, and in its 4π decay mode in an 18.5-GeV/ c π^+p experiment by Notre Dame.

The old problems of the A_1 and A_2 resonances were investigated by various groups. The A_2 has generally been observed in π^-N experiments and decaying in $\rho\pi$, $K\bar{K}$, and $\eta\pi$ modes. The $\rho\pi$ decay mode has clearly indicated a split in the A_2 to yield two narrow resonances instead of one wide one. A BNL group reported the observation of one narrow resonance in the A_2 region produced in K^-d interactions at 3.6 and 3.9 GeV/ c and decaying into $K\bar{K}$. Its spin-parity analysis favored $J^{PC} = 1^-+$. The $K\bar{K}$ decay mode may or may not be split; this controversial point still needs clarification, since it can play a large role in the determination of the spin-parity of the A_2 's.

The A_1 [or $\pi(1090)$] resonance was observed in an 18.5-GeV/ c π^+p experiment by a Notre Dame group, a 16-GeV/ c π^-p experiment by a group

from the Stanford Linear Accelerator Center (SLAC), and a 12.7-GeV/ c K^+p experiment by a Rochester group. SLAC found a large d -wave contribution to the A_1 . Rochester found a relatively narrow A_1 (width $\Gamma = 120 \pm 30$ MeV/ c^2) in the first clear observation of the A_1 in a nondiffractive region. The A_3 [or $\pi(1640)$] resonance was observed in a 13-GeV/ c π^-p experiment by a Harvard group in the 3π and $f\pi$ decay modes. Both the A_1 and A_3 were observed in a 6-GeV/ c π^-p experiment by a BNL group as s -wave threshold enhancements in $\rho\pi$ and $f\pi$, respectively, which indicated 1^+ as the J^P for the A_1 and 2^- for the A_3 .

A new $I = \frac{1}{2}$ resonance was discovered, the $K(1160)$, in a 3.9-GeV/ c K^-d experiment performed by a BNL group. Its mass is 1160 ± 10 MeV/ c^2 , and its width is 90 ± 30 MeV/ c^2 . (See Figure 5.)

In K^+p interactions at 9 GeV/ c (Berkeley) and at 12.7 GeV/ c (Rochester), low-mass $K\pi\pi$ enhancements are observed in the so-called Q region. At a $K\pi\pi$ mass of 1260 MeV/ c^2 , a narrow peak ($\Gamma = 40 \pm 10$ MeV/ c^2) is observed at 9 GeV/ c but a wide one ($\Gamma = 180 \pm 70$ MeV/ c^2) at 12.7 GeV/ c .

For baryon families, only particles with strangeness $S = 0, -1, -2$, and -3 have been definitely observed. New information on the $S = 0$ baryons (or nucleon resonances) has come from one bubble-chamber experiment, the K^-p experiment at 3.9, 4.6, and 7.3 GeV/ c performed by a BNL group, which established the existence of an $N(1710)$ with a mass 1712 ± 6 MeV/ c^2 and a width of 70 ± 15 MeV/ c^2 , decaying into $p\pi^+\pi^-$ but not $\Delta^+\pi^-$. There is some evidence of a ΛK decay mode indicating $I = \frac{1}{2}$. Whether this resonance is to be associated with the plethora of nucleon resonances of mass about 1700 MeV/ c^2 deduced from phase-shift analyses remains to be seen.

Results concerning $S = -1$ baryon resonances come from various experiments. Among the many results of a K^-p formation experiment covering the center-of-mass energies between 1605 and 1710 MeV, performed by a BNL group, is the confirmation of the $\Lambda(1690)$ resonance with spin-parity $J^P = \frac{3}{2}^-$, which is coupled strongly to the $\Sigma\pi$ channel and even more strongly to the $\Lambda\eta$ channel. The $\Sigma\pi\pi$ channels show no resonant behavior; in particular, the $\frac{3}{2}^-$ $I = 1$ channel shows no resonant behavior in the $\Lambda(1405)\pi$ channel. This experiment places an upper limit on the $\bar{K}N$ coupling of the $\Sigma(1660)$ found in production experiments and dis-

Figure 5. Histogram of number of events for each 20-MeV/ c^2 $K_1^0\pi^-$ mass interval.

agrees somewhat with a European experiment in interpretation of this resonance. In a K^-p experiment at 3.9, 4.6, and 5.0 GeV/ c performed by groups from BNL and Syracuse, the $\Sigma(1660)$ was observed and its branching ratios $\Lambda\pi$, $\Sigma\pi$, and $\Sigma(1385)\pi$ and $\bar{K}N$ channels were determined. These ratios are consistent with the $\Sigma(1660)$ being in an $SU(3)$ octet:

$$\begin{aligned}\Sigma(1660) &\rightarrow \frac{\Lambda\pi}{\Sigma\pi} = 0.9 \pm 0.3 \\ &\rightarrow \frac{\Sigma(1385)\pi}{\Sigma\pi} = 0.4 \pm 0.1 \\ &\rightarrow \frac{\bar{K}N}{\Sigma\pi} < 0.26.\end{aligned}$$

Another $S = -1$, $I = 1$ resonance, the $\Sigma(1616)$, has been confirmed in a K^-d experiment at 3.9 GeV/ c by groups from BNL and CCNY. Figure 6 shows the $\Lambda\pi^+\pi^-\pi^-$ final state. A clear enhancement is apparent at a mass of 1619 ± 8 MeV/ c^2 and width 72^{+22}_{-15} MeV/ c^2 . There is no clear evidence for any other decay mode.

Considerable advance has been made in understanding $S = -2$ resonances in the past two years. A new Ξ resonance, the $\Xi(1630)$, was discovered in a 2.87-GeV/ c K^-p experiment by four groups from the University of Maryland and Brandeis,

Figure 6. Histogram of number of events for each 20-MeV/ c^2 $\Lambda\pi^\pm$ mass interval, with the peripheral $\rho(765)$ and $\Upsilon_1^*(1385)$ reflections taken out.

Syracuse, and Tufts Universities (see Figure 7). In addition, the $\Xi(1820)$ and $\Xi(1930)$ were observed, with masses 1820 ± 7 MeV/ c^2 and 1963 ± 8 MeV/ c^2 ; widths, 64 ± 23 MeV/ c^2 and 89 ± 33 MeV/ c^2 ; and $\Xi\pi/\Xi(1350)\pi$ branching ratios, $1.5^{+0.6}_{-0.4}$ and $2.8^{+0.7}_{-0.6}$, respectively. The $\Xi(1830)$ was also found in a K^-d experiment at 3.6 and 3.9 GeV/ c by a BNL group. In this experiment, the mass was 1830 ± 10 MeV/ c^2 with a width of 103^{+38}_{-24} MeV/ c^2 , wider than that found in the 2.87-GeV/ c experiment.

Exotic baryon and boson states, those with quantum numbers not fitting into a simple quark model, have been looked for but not found in two experiments. In the K^-d experiment at 3.6 and 3.9 GeV/ c just mentioned, Ξ resonances with isospin $I = \frac{3}{2}$ were sought. A $\rho\pi\pi$ boson resonance ($I = 2$) previously reported by a European group was not found in a 7-GeV/ c π^-d experiment by a Rochester group.

Dynamics: Two-body and multiparticle production. The study of the overall characteristics, e.g., differential cross sections and polarizations, of the distribution of particles from a high energy collision is usually put in a separate category called dynamics in which a search is made for a theory of strong interactions. Since an overall theory is still far off, use is made of models of strong interactions in which parameters are adjusted to fit the data. In a future theory the number of parameters should be very small, with the successful model parameters derivable from "first principles." In model build-

ing a distinction is usually made between multiple-particle production and two-body production, since the latter is the easier to study experimentally and interpret mathematically. Multiparticle production involving many final-state particles is much more complicated because of the large number of variables needed to describe adequately such a process. Such processes should be studied, however, because multiparticle production occurs more frequently. Bubble chambers are useful for such studies. For example, Figure 8 gives the cross section of charged particles in $p\text{-}p$ interactions for beam momenta ranging from 13 to 28.5 GeV/ c , as analyzed by a Berkeley group (80-in. bubble chamber).

One of the many models describing high energy phenomena is the one-particle exchange model; in particular the lowest mass particle, consistent with the conservation laws, is assumed to be exchanged, since low masses imply large impact parameters and it has been found that high energy collisions tend to be peripheral. An experiment performed by a BNL group studied the reactions $p + p \rightarrow$

Figure 7. The combined spectra of $M(\Xi^-\pi^+)$ from $K^- + p \rightarrow \Xi^- + \pi^+ + K^0$ and $M[\Xi(1530)\pi]$ from $K^- + p \rightarrow \Xi + \pi + \pi + K$ (crosshatched).

$\Delta^{++} + M$ at 28.5 GeV/c, where M was any aggregate of particles, including a nucleon and many pions. Since one-pion exchange is permitted, a comparison was made between real $\pi + p \rightarrow M$ reactions and virtual $\pi + p \rightarrow M$ for the same M . This comparison was successful (see Figure 9).

Another model for multiparticle production is the multiperipheral model wherein the basic assumption is that the production can be described as shown in Figure 10. The dotted lines represent exchanges of particles so that the reaction is just a chain of two-body reactions. Thus two-body processes are assumed to determine multiparticle processes. For the reaction $p + p \rightarrow p + p + \pi^+ + \pi^+ + \pi^- + \pi^-$ studied by the same BNL group, the multiperipheral model works well. A Florida State University experiment studying the $\pi^+ + p \rightarrow 4\pi^+ + 3\pi^- + \pi^0 + p$ reaction at 11 GeV/c needed some resonance formation to describe adequately the data.

Figure 8. Cross sections for multiple charged-prong final states in pp collisions from 13 to 28.5 GeV/c.

The exchange of families of particles rather than single particles is described by the "Regge-pole exchange" model. Double Regge-pole exchanges were investigated by many groups, with partial success: $K^+ + p \rightarrow K^{*0} + \pi^+ + p$ at 7.3 GeV/c, by a UCLA group; $K^- + p \rightarrow K^- + \pi^- + \Delta^{++}$ at 7.3 GeV/c, by a BNL group; $K^+ + p \rightarrow K^+ + p + \pi^+ + \pi^-$ at 12.7 GeV/c, by a Rochester group; and $K^- + p \rightarrow K^- + p + \pi^+ + \pi^-$ by a Yale-Berkeley collaboration.

The "exchange-degeneracy" model holds that whatever mechanism produces the exchange, single-particle or Regge-pole, for certain reactions the resulting differential cross sections should be the same. For example, the reactions $K^- + p \rightarrow \bar{K}^0 + n$ and $K^+ + n \rightarrow \bar{K}^0 + n$ and $K^+ + n \rightarrow K^0 + p$ (ρ and A_2 exchange permitted) should have the same momentum transfer distributions, i.e., the same slope and intercept. A test of this model was made by a BNL group for various reaction pairs. With the exception of one reaction pair at only one energy, the slopes, intercepts, and cross sections were not simultaneously equal; this cast doubt on the model.

New results have been obtained on low energy $K + N$ reactions which have implications for a dynamical theory of strong interactions. A Carnegie-Mellon-BNL collaboration has studied $K^+ - d$ interactions at 600 MeV/c and has determined from the charge exchange reaction that the Yang solu-

Figure 9. Diagram showing the reaction $p + p \rightarrow \Delta^{++} + M$ with pion exchange.

Figure 10. Schematic diagram showing the multiperipheral mechanism for the reaction $p + p \rightarrow p + p + \pi^+ + \pi^+ + \pi^- + \pi^-$.

tion is favored over the Fermi one for the $T=0$ phase shifts. A University of Massachusetts-BNL collaboration has looked at Σ^-p inelastic interactions and determined their s -wave character for Σ 's between 0 and 500 MeV/c. The Σ^0n and Λ^0n final states have about the same cross sections. A University of Rome-BNL group has studied the $K^- + d \rightarrow \Sigma^- + \eta + p$ reaction near threshold and has shown that the impulse model for the deuterium is not adequate for this reaction. A Columbia University experiment using stopping K^- and $\bar{p}$ has searched for tachyons (t), faster than light particles with imaginary mass allowed by the special theory of relativity. Upper limits for production compared with pion production (e.g., $K^- + p \rightarrow \Lambda + t$ vs $K^- + p \rightarrow \Lambda + \pi$) are about 10^{-3} .

2. Weak Interactions. The theory of weak interactions is well advanced, with definite predictions that have in the main been verified. When it is considered that the theory explains the gross (and many of the fine) details of a basic force of nature over 13 orders of magnitude, from neutron decay (10^3 sec) to hyperon decay (10^{-10} sec), its power is evident. The theory says that the weak interaction is of the current-current type, with the current having vector-axial-vector space-time properties and being composed of three parts, a purely lep-

tonic current, a strangeness = 0 hadron current, and a strangeness = +1 hadron current. The strangeness = 0 hadron current has isovector properties, while the strangeness = 1 current has isospinor properties. The Cabbibo theory places the two hadron currents in two $SU(3)$ octets, one for the vector parts and one for the axial-vector parts, and thus relates many reactions. The μ meson (muon) and electron are considered to be identical except for their different masses and different lepton number.

Weak interactions were investigated in a few bubble-chamber experiments in the past year. The Cabbibo theory makes definite predictions as to rates and the proportion of vector (g_V) to axial-vector (g_A) parts in hyperon decays. A group from Columbia and the State University of New York at Stony Brook studied the $\Sigma^\pm$ semileptonic decays in a stopping K^- beam in the 30-in. chamber. The results are in agreement with the Cabbibo predictions:

$$\frac{\Sigma^- \rightarrow \Lambda + e^- + \nu}{\Sigma^- \rightarrow \text{all}} = (0.52 \pm 0.09) \times 10^{-4},$$

$$\frac{\Sigma^+ \rightarrow \Lambda + e^+ + \nu}{\Sigma^+ \rightarrow \text{all}} = (0.16 \pm 0.07) \times 10^{-4},$$

$$g_V/g_A = -0.7 \pm 0.4,$$

with similar results for $\Sigma^- \rightarrow n + e^- + \nu$ and $\Sigma^- \rightarrow n + \mu^- + \nu$. A University of Maryland experiment on stopping K^- mesons in the 30-in. hydrogen bubble chamber also confirmed the Cabbibo theory in the $\Sigma^- \rightarrow n + e^- + \nu$ decay with $|g_A/g_V| = 0.23 \pm 0.16$. The ratio

$$(\Sigma^- \rightarrow n + \mu^- + \nu) / (\Sigma^- \rightarrow n + e^- + \nu) = 0.39 \pm 0.08$$

agrees with the universal (i.e., $\mu \equiv e$) $V-A$ prediction of 0.45. In the same experiment, the Cabbibo theory was confirmed in the $\Lambda \rightarrow p e^- \nu$ decay with a branching ratio of $(0.80 \pm 0.08) 10^{-3}$ and $g_A/g_V = 0.72^{+0.19}_{-0.14}$.

Counter-Spark-Chamber Experiments. In most experiments carried out during fiscal 1970 spark chambers were used to give accurate measurement of position and momentum of the particles observed. Use of electronic data-recording tends to result in better statistical accuracy than is obtainable in bubble-chamber experiments, and in some cases makes it possible to select rare processes that would be difficult to study by the less selective bubble-chamber technique.

Figure 11. Missing-mass plots of the reaction $\pi^- + p \rightarrow \pi^- + X$, where X stands for a final state whose missing mass is plotted. Curves for incident π^- energies of 8 and 16 GeV/c are shown and, for comparison, the corresponding missing-mass curves for the reaction $p + p \rightarrow p + X$.

As for bubble-chamber experiments, it is useful to divide experiments into those dealing with the strong interactions on one hand and the weak interactions on the other. The effort was about equally divided between these two fields.

1. Strong Interactions. Data obtained from a previous wire spark-chamber spectrometer run at the AGS have continued to yield fruitful information. The experiment was a collaboration of a BNL group and one from Carnegie-Mellon University.

An example of the results obtained is shown in Figure 11. The plot shows the variation in cross section with missing mass from the reaction $\pi^- + p \rightarrow \pi^- + X$, where X represents the final state whose missing mass is plotted in the figure. The results for two incident π^- energies (8 and 16 GeV/c) are shown, and these plots are compared with the corresponding missing-mass spectra for proton-proton interactions obtained from an earlier experiment. The peaks indicate the production of isobars, and the similarity in shape can be seen. This means that in the process of exciting nuclear isobars, at these energies, a π meson (pion) and a proton interact in a very similar manner. Figure 12 is an example of how the production of an isobar by these pions varies with scattering angle (the abscissa $-t$ is roughly proportional to $\sin^2\theta$, where

Figure 12. Variation of cross section with $-t$ ($-t \approx \sin^2\theta$, where θ is scattering angle) for the reaction $\pi^- + p \rightarrow \pi^- + N^*(1500 \text{ MeV})$. Data at incident π^- momenta of 8 and 16 GeV/c are shown.

θ is the scattering angle). Two interesting and significant features are noted. The cross section for the production of the isobar $N^*(1500 \text{ MeV})$ falls off at very small angles, and there is a minimum in the 8-GeV/c data at larger angles ($-t \approx 1.0 \text{ GeV/c}^2$).

The effectiveness of wire spark-chamber spectrometers is due not only to the profusion of accurate data produced but also to the ease with which these data can be analyzed. Since the data are wholly on tape, they can be reproduced and used by anyone having access to a standard computer. A large number of physicists can work effectively at their own institutions, and thus a large array of talent is brought to bear on an extensive store of data. This is a main reason for the high productivity of this type of counter experiment.

In an experiment recently carried out in the slow extracted proton beam at the AGS, a Columbia group found a significant muon-pair signal extending in dimuon mass as high as 6 GeV/c^2 . These muon pairs were found in 30-GeV proton collisions with a thick uranium target. All strongly interacting particles were absorbed by a thick iron shield, and the emerging muons were vector-momentum analyzed by recording their respective angles and ranges in iron. The true dimuon signal was "buried" in a large accidental rate and was extracted by simultaneously recording "in-time" and "delayed" events and carefully subtracting them. Numerous tests demonstrated that the muon pairs originating in the uranium target did not come from pions and that any contamination from beam time-structure and biases in the subtraction process was negligible.

While a better understanding of the detection efficiency furnished by Monte Carlo calculations is required to produce final cross sections, some definite statements about the data can be made. The cross section $d\sigma/dm^2$ falls exponentially from $\approx 10^{-33} \text{ cm}^2/(\text{GeV/c}^2)$ at 1 GeV/c^2 to $\approx 10^{-38} \text{ cm}^2/(\text{GeV/c}^2)$ at a mass of 4 to 5 GeV/c^2 . No structure in the data betrays the presence of a new vector meson. Indeed, any such resonances must be produced with cross-section branching-ratio products $< \approx 4 \times 10^{-35} \text{ cm}^2$.

Two models have been considered in an attempt to explain the dimuon continuum. One-pion exchange from pions produced in the target, using a ρ -dominated pion form factor, agrees with the data within a factor of 2 to 4. However, a comparable fit is realized by a calculation of Berman et al.,

using the incident protons to produce massive photons via a "parton" model. A more sophisticated analysis in progress may permit some discrimination between these two processes.

On April 30, 1969, a Cornell group completed an experiment on backward π^-p charge-exchange scattering at high energies. In the proposal it had been estimated that 400 hr of data-taking would be required for runs at 6 and 10 GeV/c. In the actual 442 hr of running, a run at 14 GeV/c was done as well. Virtually all γ rays from 45° to 180° were detected by lead-plate shower chambers. The forward neutrons were detected by nuclear interaction in downstream spark chambers.

So far all the 6-GeV/c and part of the 10-GeV/c film have been analyzed for single backward π^0 's ($\pi^- + p \rightarrow n + \pi^0$). About 2500 good events at 6 GeV/c, an estimated 2000 at 10 GeV/c, and 1500 for 14 GeV/c were found. Detailed structure is seen in the angular distributions at both 6 and 10 GeV/c. Preliminary 6-GeV/c results have been obtained. There is a deep dip at $u \approx -0.2$ GeV/c², similar to that seen in the π^+p backward peak. In addition, the backward peaks in the reactions $\pi^- + p \rightarrow n + \omega^0$ and $\pi^- + p \rightarrow n + \eta^0$ are being analyzed. These are of special interest because only the $I = \frac{1}{2}$ baryon exchange can contribute, and if the Regge-pole theory explanation of the dip is correct, it should also appear in these reactions.

The University of Bari (Italy), Brown University, and the Massachusetts Institute of Technology have collaborated in an attempt to determine the absolute differential cross sections for the two processes $\pi^- + p \rightarrow n + \pi^0$ and $\pi^- + p \rightarrow n + \eta^0$ in the far backward direction for the emitted meson at a large number of incident momenta in the region 2 to 8 GeV/c for the incident π^- .

These reactions are of great interest as a tool in baryon spectroscopy through the study of the appearance of possible resonant states above a background amplitude. In the backward direction it may be hoped that the background amplitude is not grossly dominant over any single resonant partial-wave contribution, as is certainly the case in the forward direction in the energy region. This energy region is abundantly supplied with resonant states, and it is planned to study their partial widths and quantum numbers. In addition, this energy region allows study of the transition between low and high energy phenomena and is an important region for testing the Regge phenom-

nology. In these reactions the exchanged objects are baryon trajectories, and again there exists, from a different point of view than above, an opportunity for an insight into baryon spectroscopy.

The experiment is performed with use of scintillation counters and visual spark chambers as detectors. The method is to require a π^- to disappear in a liquid hydrogen target unaccompanied by any π^0 decay γ rays in most of the forward hemisphere via a combination of scintillation counters and lead-scintillator shower counters. In addition, a neutron detector is located in the forward direction and a detected neutron is required to complete the trigger requirements for the spark chambers. The spark chambers are γ -ray detecting devices and detect the π^0 and η^0 via two γ decay modes.

Data-taking began near the end of fiscal 1969. The results at this point are encouraging. The electronic rates were about as predicted. In the film, the first scan and measurement have been completed of some 600 two- γ -ray events as a check on possible difficulties in the analysis. So far none has developed, and the yield of two- γ -ray events is also

Figure 13. $d\sigma/dt$ versus $-t$ for

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

15-GeV/c incident π^- mesons were run for ≈ 10 hr.

as expected at $3.5 \text{ GeV}/c$. The remainder of the data runs were completed during fiscal 1970, and measurement and analysis of the data on film are now in progress.

During fiscal 1970 an experiment by a Yale group has been in progress at the AGS to measure the asymmetry and differential cross section for the elastic scattering of K^+ mesons by polarized protons in the K -meson momentum range of 1.2 to $2.4 \text{ GeV}/c$. The specific motivation for this experiment is to contribute to the important search for the existence of a baryon with strangeness $S = +1$, a Z^* particle, which is not included in a three-quark model of the baryons. More generally, these measurements will aid in the determination of phase-shift parameters which characterize phenomenologically the K^+-p interaction. The principal new technical feature of this experiment is the use of wire spark chambers to detect the scattered particles, which results in excellent separation of elastic scattering from background, even with a lanthanum-neodymium-magnesium nitrate polarized proton target. This experiment is the first high energy experiment to be done at Brookhaven with a polarized target.

During a brief run last spring before the AGS shutdown, data were obtained with K -meson momenta $p_K = 1.5$ and $1.7 \text{ GeV}/c$. A phase-shift analysis of these data, together with all other relevant data on K^+-p scattering, indicated an interesting resonance-like behavior of the $P_{3/2}$ wave. More data on the asymmetry and differential cross section for elastic scattering of K^+ mesons by polarized protons, particularly in the momentum range above $p_K = 1.5 \text{ GeV}/c$, have been taken to verify whether a Z^* particle has been found. With

Figure 14. An overhead view of the forward vee detecting leg of the double-vee magnetic spectrometer. The beam is incident from the right foreground. The 2-ft hydrogen target is contained in the canvas tent with the vent pipe on top. Three sets of $2x$, $2y$, $1w$ digitized spark-chamber combinations are shown before the 4-ft-wide by 4-ft-long by $1\frac{1}{2}$ -ft-aperture magnet. An anticounter, downstream of the hydrogen target, is used in the K^0 trigger selection. The last spark chamber shown behind the hydrogen target is 13 ft wide and is followed by a 13-ft-wide counter hodoscope. A K^0 trigger requires a coincidence of the appropriate incident particle, lack of a count in the anticounter downstream of the hydrogen target, and two charged particles striking the 13-ft-wide counter hodoscope at the extreme downstream end of the apparatus.

these additional points the range from 1.2 to 2.4 GeV/c has been covered. Analysis of the data is continuing.

A BNL group is continuing completion and testing of the double-vee magnetic spectrometer system referred to in last year's annual report. The multiple scattering of the forward vee detecting set of digitized spark chambers has been reduced by using aluminum wires, after life tests last year demonstrated that these wires have satisfactory lifetime characteristics.

Preliminary data test runs have been completed on the reactions

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

and various other double-vee reactions. Typical data, obtained in a few hours' run, are shown in Figure 13. The experimental arrangement used in these tests is shown in Figure 14. The data rates correspond to some several thousand particles per μb , which is about 2 to 3 orders of magnitude higher than typical rates for prior visual (nonelectronic) techniques.

The K^0 momentum resolution of the forward vee detecting leg is ≈ 0.25 to 0.50% (half-width at half-height), depending on whether one or two 48D48 magnets are employed. The wide-angle baryon recoil vee detecting system is being installed, and tests and results with the full system should be forthcoming this year.

Up to 13-ft-wide chambers have been successfully tested in the forward leg and found to have a space resolution of ± 0.25 mm. Up to 23-ft-wide chambers will be used in the wide-angle leg. The entire system is capable of collecting one million trigger-selected events per day and has a complete automatic system for recording the data and analyzing a sample on line, with use of the Brookhaven On-line Data-Processing Facility computers.

2. Weak Interactions. Analysis of a search for the vector boson (W particle), postulated as the mediator of the weak interaction, was completed by a BNL-Yale group, using a technique based on determining the intensity and polarization of muons originating very near the point of interaction of 28-GeV protons with nucleons. Bosons were not observed, and the upper limit on the production cross section for W 's with masses between 2.0 and 4.5 GeV/c² is $B\sigma \leq 6 \times 10^{-36}$ cm², where B is the branching ratio for the W decay to a muon and a neutrino.

If the conventional description of the weak interaction is used, it is possible to calculate the characteristics of the decay process $K \rightarrow \mu\pi\nu$ with only one parameter (a ratio of form factors) unknown. Since the energy distribution and the polarization of the muon both involve this same parameter, either one can be used to determine it. There is a serious discrepancy in the values obtained by these two methods.

A group of people from BNL, Yale, NAL, and LASL has performed an experiment at ANL designed to measure both the polarization and the distribution of events over the Dalitz plot for the decay of stopped K^+ into $\pi^0\mu^+\nu$. The π^0 's are detected by measuring their decay γ rays. The direction and energy of the γ rays is determined by the position and total ionization of their conversion products. The position is measured in spark chambers and the ionization in scintillation counters. The energy of the muon is determined by range, and its polarization is determined by the direction of its decay electron. All the data are recorded on magnetic tape by a PDP-8 computer, which also monitors the equipment and samples the data.

A group from Princeton University completed in March 1969 the data-taking on their experiment on the decay of K^+ and K^- mesons into the tau mode ($K^\pm \rightarrow \pi^\pm \pi^\pm \pi^\mp$). The main purpose of this experiment was to check CP (charge conjugation, parity) invariance, to a degree of accuracy never achieved before, by searching for an asymmetry between the Dalitz plots of the τ^+ and τ^- decays. About 2 million events (i.e., ≈ 50 times the current world supply) for each charge of the K meson were detected.

The experimental method consisted of detecting τ decays in flight and recording, in a system of eleven 1×1 -m X - Y wire spark chambers with magnetostrictive readouts, the paths of the three decay pions through a magnetic spectrometer. The information, digitized in scalars, was fed to a PDP-9 computer (8000 18-bit word memory + 4000 write only) belonging to the experimenters. The PDP-9, programmed in assembly language, made continuous checks on the apparatus, transferred the raw data to magnetic tape, and sent it to the PDP-6 computer of the Brookhaven On-Line Data-Processing Facility for complete reconstruction and analysis of a fraction of the events (20 to 40%, depending on the processor time available). The PDP-6 computer was time-shared with another on-line experiment as well as with off-line

Figure 15. Wire spark-chamber spectrometer and γ -ray detector for studying the decay modes $K^{\pm} \rightarrow \pi^{\pm} \pi^0 \gamma$.

users. The event rate was $\approx 15/\text{AGS}$ pulse, or $\approx 20,000/\text{hr}$. Analysis of the data is progressing satisfactorily and is nearing completion.

A Brookhaven group has completed data-taking for an experiment to study K^+ and K^- -meson decay into $\pi^\pm\pi^0\gamma$. The object of the experiment is to observe and compare the two decay modes in order to test for a possible difference which would indicate a violation of CP symmetry. The asymmetry could come about because of interference between the contribution to the decay of inner bremsstrahlung and possible direct emission. Theoretical studies indicate that the contribution from direct emission could be quite significant and could lead to a substantial symmetry in the $\pi^\pm\pi^0\gamma$ decay. It would be exciting if CP violation were to be observed in this decay mode.

The equipment (see Figure 15) includes a wire spark-chamber spectrometer that is used to locate the incoming $K^\pm$ mesons and $\pi^\pm$ mesons emitted in the forward direction. The two photons from the π^0 -meson decay and the third photon are detected in a shower detector consisting of eight layers, each composed of lead, scintillator, and an optical chamber, and subtending an angular interval $14^\circ \leq \theta \leq 45^\circ$.

Information from the on-line wire spark-chamber spectrometer has been used to prescan data and indicate the likely events for which the photon showers, photographed in the optical chambers, have been hand-measured. Preliminary tests were carried out on $K_{\pi 2}$ decays by requiring in the fast logic only two photons and a charged particle. The kinematically reconstructed events were in excellent agreement with the predicted Monte Carlo distribution. Subsequently, analysis of the $\pi\pi\gamma$ candidates between the τ' peak and the $K_{\pi 2}$ peak was started. They are being scanned, measured, and fitted to the $\pi\pi\gamma$ decay. The successfully fitted events have a reasonable decay rate and Dalitz decay distribution. The $\pi\pi\gamma$ event rate is about 10/hr.

In the same experiment some short runs have been taken to optimize the conditions for taking data on $K_{\mu 3}^+$ decay and polarization. As a result of these improvements, an event rate of 100 stopping $K_{\mu 3}$ decays with a visible muon decay electron per hour has been obtained. The forward-to-backward ratio of muon decay is close to unity, which indicates that there are no serious biases in the stopping-muon chambers. It would be reasonable to expect about 20,000 $K_{\mu 3}$ polarization events from this experiment.

In taking the $\pi^\pm\pi^0\gamma$ data, the trigger requirement is that there be one charged particle emitted forward through the wire spark-chamber spectrometer and at least three neutral showers in the γ hodoscope and optical chamber detector. As a result a number of other interesting decay modes would be recorded. About 20,000 τ' decays would be obtained; these could be used to study the τ' decay matrix element.

An experiment being carried out by a Princeton group to measure η_{00} has run very well but with a low event rate. About one $K_L \rightarrow \pi^0 + \pi^0$ event per hour of AGS time is counted. The rate is limited because the magnet borrowed from the Princeton-Pennsylvania Accelerator is too small. It was, however, the only one available.

In the first run in the spring of 1969 data were taken which were useful in making essential improvements in the apparatus. There was no trouble seeing $K_L \rightarrow \pi^0 + \pi^0$ events, but some difficulty was encountered in seeing regenerated $K_S \rightarrow \pi^0 + \pi^0$ events because of high neutron backgrounds. The situation has been improved by adding an additional spark chamber to increase the precision of the measurements (narrow the K_S mass peak). The rate of triggers from spurious sources has also been decreased by a factor of 5, so that event losses due to dead time are minimized.

By the end of the fiscal year data had been obtained to complete the measurement $|\eta_{00}|$. Measurement of ϕ_{00} is also essentially complete for a measurement in which precision to within $\pm 20^\circ$ is expected.

High Energy Theory

The research activities of the Particle Theory Group ranged from the formulation and study of dynamical models for the interactions between elementary particles to phenomenological analyses of data which are expected to yield model-independent information.

Work continued on the multiperipheral model, a formalism for including effects of multiparticle states at high energies. An integral equation for forward elastic scattering in this scheme, due to Chew and de Tar, was diagonalized with use of group-theoretical techniques. This reduced the original multidimensional integral equation to coupled one-dimensional equations, which are tractable numerically. The equation was generalized to deal with nonforward scattering, and an analogous diagonalization procedure was found.

Over the past few years the Regge-pole formalism, or complex angular-momentum description of interaction processes, has proved a useful tool. In scattering from a nonrelativistic potential the only observable complex angular-momentum singularities are Regge poles, whose position varies with energy. In relativistic theories with crossing symmetry, "fixed" poles, whose position is independent of energy, can in principle occur in some cases. It was shown that certain models of electromagnetic processes require such fixed poles, e.g., the vector dominance model of Sakurai, or any model for electroproduction in which the s -channel helicities are conserved.

For some years it has been hoped that the general constraints imposed on the interaction amplitudes of elementary particles by such general considerations as relativistic invariance, conservation laws, and crossing symmetry might be enough to determine the behavior of those amplitudes without the need to know any detailed underlying dynamics. It is already clear that some additional constraint (such as specifying the high energy behavior) would be needed for such "bootstrap" calculations to give a unique answer. In most previous work on this question the constraints have been imposed analytically and exactly and then approximate methods used to solve the resulting equations. A new approach is that of using a computer search to look for solutions satisfying the constraints numerically.

A study of π - π scattering was performed with use of a simplified numerical approximation to the low energy behavior. The model was crossing symmetric by construction, unitarity was enforced as a numerical approximate constraint on the model, and finite-energy sum rules were used to relate the low energy behavior to assumed Regge behavior at high energies. The model was found to favor a solution similar to those currently favored from phenomenological analyses of pion production.

Vector dominance, or the close relation between processes involving ρ mesons and corresponding ones involving photons, has proved a powerful qualitative tool. For quantitative comparisons, however, there is the somewhat ambiguous question of exactly what to compare, since the ρ -meson mass is far from zero and hence its polarization properties are not exactly those of the photon. The comparison between pion photoproduction and ρ -meson production by pions is a particular example.

One phenomenologically successful suggestion, that of using the eigenvalues of the ρ -meson spin-density matrix, was shown to be unacceptable, as it implied a discontinuous extrapolation in vector-meson mass between the photon and the ρ meson.

The assumption of $SU(3)$ symmetry has had many outstanding successes in predicting relations between reaction rates involving different particles. In the currently accepted scheme of assignments, however, the relative decay rates for the η meson and π^0 meson to decay into two photons, $\pi(\eta \rightarrow 2\gamma)/\Gamma(\pi^0 \rightarrow 2\gamma)$, is predicted to be smaller than the experimental value by a factor of 6. Another puzzling feature of both these processes is that the assumptions of current algebra, partial conservation of the axial vector current, and smoothness of extrapolation in mass, which give excellent results elsewhere, would predict that both these rates vanish.

A way to understand these difficulties has been suggested within the chiral Lagrangian model of Gasiorowicz and Geffen. A PCAC*-violating term was introduced into this Lagrangian model. This term was chosen to be the simplest possible, such that (1) it contributes to processes like $\pi^0 \rightarrow 2\gamma$, $\eta \rightarrow 2\gamma$, $\omega \rightarrow \pi^0\gamma$, etc., (2) it satisfies nonet symmetry, (3) it transforms like a member of the $(3,3^*) \oplus (3^*,3)$ representation of $SU(3) \oplus SU(3)$, and (4) it preserves the algebra of fields.

By using as input the experimental value for $\Gamma(\pi^0 \rightarrow 2\gamma)$ as well as the results of the authors mentioned above, the values for $\Gamma(\eta \rightarrow 2\gamma)$, $\Gamma(\omega \rightarrow 2\gamma)$, $\Gamma(\omega \rightarrow \pi^0\gamma)$, etc. can be predicted.

With use of the recently measured value (11.7 ± 1.1) eV for the $\Gamma(\pi^0 \rightarrow 2\gamma)$, the predicted value for $\Gamma(\eta \rightarrow 2\gamma)$ is (0.9 ± 0.1) keV while the experimental value is (1.00 ± 0.25) keV. This satisfactory agreement suggests that both the discrepancies mentioned can be adequately explained. Other predictions, for $\Gamma(\omega \rightarrow \pi^0\gamma)$ and $\Gamma(\omega \rightarrow 2\gamma)$, are equally consistent with observations.

Detailed calculations are being carried out in connection with the possible search for the intermediate vector boson W in neutrino experiments at NAL. These calculations involve standard quantum electrodynamics but become quite complex. Estimates are being made of both total production cross sections and the angular and energy spectra of associated μ mesons. The energy range considered is 1 to 1000 GeV and W masses up to

*Partially conserved axial vector currents.

30 GeV. Extensive use is made of the speed and capacity of the CDC 6600 computer for both some of the algebraic trace computations and multi-dimensional numerical integrations.

To date, in the energy-mass range above, the total cross sections for the reaction

have been calculated for assorted targets (hydrogen to uranium). The angular and energy spectra for the primary (directly produced) muon have been determined. Work on those for the secondary muon in the fast decay $W \rightarrow \mu\nu$ is in progress. The correlated spectra of these two muons are important for a meaningful interpretation of the experiment, which looks for the appearance of both of these "signature" muons.

The reaction $\nu + Z \rightarrow Z + \mu + \mu + \nu$, where the W enters virtually, is also being considered.

In deep inelastic electron-scattering experiments it has been observed that the structure function, or form factor, seems to depend essentially only on the ratio of invariant momentum transfer to energy loss. While certain theoretical arguments suggest this as a behavior for the asymptotic region, they are far from watertight and the observed region is far from asymptotic. An attempt is being made to relate this phenomenologically to the behavior of the elastic and quasi-elastic form factors, with the assertion that these are due entirely to the spatial distribution of the interacting system, which absorbs the photons in a pointlike manner. The model does not assume a detailed dynamics for the hadron structure.

During the summer of 1969 a theoretical summer school was organized on the topic "Strong Interactions at High Energies." For six weeks 20 graduate students from universities throughout the country and overseas were given two lectures per day by lecturers from various universities in a series of courses designed to cover different approaches to the same field of physics. The lectures have been published as BNL 50212 (C-58) (see Appendix A).

Particle Physics Apparatus

80-in. Bubble-Chamber Operations. From March 1, 1969, to Feb. 28, 1970, the 80-in. bubble chamber took 676,000 pictures. These were distrib-

uted among 7 separate experiments, with 12 experimental groups participating. The number of pictures was small because the AGS provided no particles to the chamber for 8 months as a result of the conversion program, and to a smaller extent because of difficulties associated with start-up of the 80-in. chamber.

Most of the pictures were taken with the chamber filled with deuterium and with the new hydraulic expansion system. Use of this system reduced the rate of deuterium loss by a factor of ≈ 3 compared with the rate experienced with the old pneumatic expansion system.

During the AGS conversion shutdown, the 80-in. chamber was converted to a bright-field illumination system using Scotchlite. New lenses of shorter focal length give greater demagnification and permit the use of 35-mm instead of 70-mm films, with considerable savings in film cost. The film cassettes were modified to use 35-mm film and to permit taking >1 picture/AGS pulse. A new heat exchanger was designed and built for the top region of the chamber, and an insulator made of a sandwich of balsa wood between layers of epoxy-fiber glass was installed on the surface of the piston. These changes effected a great improvement in the chamber thermodynamics, and the chamber can now double-pulse with a deuterium filling. A new data box was built for multipulsing and to provide a standardized data format for the BNL 80, 30, and 31-in. chambers and the SLAC 82-in. chamber.

30 and 31-in. Bubble-Chamber Operations.

During the period that the AGS was scheduled for the high energy physics research program, the 30 and 31-in. bubble chambers were operated alternately.

A total of 430,000 pictures was taken for two experiments in the 30-in. bubble chamber using hydrogen and deuterium. When not being operated for high energy physics research, the bubble chamber was used for tests of a bellows-expanded, cylindrical, Plexiglas track-sensitive target. The chamber expansion system was modified to allow it to be driven either by the existing helium gas system or by the 31-in.-chamber hydraulic system. Redesign and reworking of the 30-in. chamber optical system and electronic controls to permit use of 35-mm film with the 31-in. chamber multipulse cameras was also begun.

A total of 680,000 pictures for three experiments was taken in hydrogen, deuterium, and hydrogen-

Figure 16. The piston motion trace and corresponding chamber pressure trace for the 31-in. bubble chamber when it was being double-pulsed with a 125-msec interval between pulses.

Figure 17. Pictures taken in a neon-hydrogen mixture on the first and second pulses while the 31-in. bubble chamber was being operated with a 125-msec interval between pulses, with an assembly of leaded glass and tantalum plates mounted in the chamber.

neon mixtures in the 31-in. bubble chamber. Modifications of the bubble-chamber cameras, data-box system, and illumination system for multipulse operation with the new 35-mm film format were completed. The chamber was operated routinely with the AGS, whenever beam intensity permitted, in the double-pulse mode, and during several periods picture production rates of over 40,000 pictures/day were achieved. Figure 16 shows the piston motion trace and the corresponding chamber pressure trace for the 31-in. chamber when it was being double-pulsed with a 125-msec interval between pulses. Figure 17 shows pictures taken in a hydrogen-neon mixture on the first and second pulses while the chamber was being operated in the double-pulse mode, with an assembly of leaded glass and tantalum plates mounted in the chamber.

7-ft Chamber Operations and Conversion. An experimental cryogenic bubble chamber of 9400-liter volume was operated successfully for the first time in October 1969. This chamber consists of a cylinder 7 ft in diameter and about 9 ft high and is provided with a superconducting magnet to produce a field of 30 kG in the chamber. The chamber was originally built as a test facility for a larger chamber that was proposed in four successive years but has not been funded.

Stereo photographs taken of tracks produced by cosmic-ray particles showed uniform sensitivity and bubble images of high quality throughout the chamber volume. The chamber is located in neutrino and charged-particle beams to be obtained from the AGS, but the latter was not in operation when the chamber was first operated. The quality of the pictures eliminates uncertainties about optical difficulties which might have prevented bubble images of high quality in large-volume bubble chambers. What has so far been demonstrated is that (1) good track quality can be obtained throughout the chamber under normal operating conditions, (2) measurement precision should approach that of smaller chambers, such as the 80-in., and (3) the superconducting magnet can be operated steadily with gas cooling at a field of 10 kG or perhaps more. (Previously a field of 16.5 kG had been obtained for a short time with gas cooling.)

Improvements and additional tests scheduled for the immediate future include a reduction in the generation of spurious bubbles from various areas in the chamber, achievement of operation at a repetition rate of 1 sec (the previous run took place

at a 10-sec repetition rate), and an increase in the capacity of the available helium refrigerator, to allow the magnet Dewar to be filled with liquid helium for production of a 30-kG magnetic field.

Although the 7-ft chamber can be used for studies of neutrino interactions, its size for this purpose is marginal, and a larger size would also be desirable for future studies of strong interactions, especially when a track-sensitive target is operated inside the chamber. Design studies have been made on conversion of the 7-ft chamber to a much larger chamber with a volume of 20,000 to 30,000 liters and a maximum magnetic field of 30 kG, the exact magnitudes depending on available funds. This conversion will make use of >80% of the materials and effort already expended in construction of the 7-ft chamber. It is hoped that funds will be available to enlarge the chamber concurrently with its move to a new experimental area off the H-10 straight section of the AGS. Hydrogen and helium refrigerators of sufficient capacity to operate the chamber on a regular basis as a complete users' facility are being purchased.

Until the fall of 1969, design studies were continued on a joint NAL-BNL cryogenic bubble-chamber project to construct a 25-ft, 100,000-liter chamber for use at NAL's 200-GeV accelerator. A design report was published.

Superconducting Magnets. The investigation of different normal conductor-superconductor configurations for magnets for large bubble chambers was continued. A computer program was developed which calculates the temperature and pressure distribution along a length of hollow normal conductor-superconductor composite conductor, cooled internally by a flow of supercritical helium. Tests of the 7-ft bubble-chamber magnet indicated the existence of persistent eddy currents, and the effect was investigated with use of ANL's 2-ft-bore magnet. The duration of the eddy currents and their effect can be reduced by twisting the superconducting filaments in the composite conductors. Several methods of fabricating these so-called twisted conductors in various configurations were explored. In Figure 18 are shown samples of a twisted strip conductor and twisted hollow superconductors. These samples were made by wrapping and soldering superconducting wires and copper wires around hollow copper tubing and then forming the tubing to the final shapes. A small helium refrigerator has been installed for tests of these types of conductor and other conductor configurations.

Figure 18. Samples of (top) a twisted strip superconducting conductor and (bottom) twisted hollow superconducting conductors, made by wrapping and soldering superconducting wires and copper wires around hollow copper tubing and forming the tubing to the final shapes.

Track-Sensitive Targets for Bubble Chambers.

After the successful test of a diaphragm-expanded track-sensitive target (TST), a cylindrical, Plexiglas target was constructed with a system of bellows for the expansion mechanism to permit more independent control of the target pressure and temperature relative to the bubble-chamber pressure and temperature. Such control is required when the target contains hydrogen or deuterium and the chamber fluid has a high concentration of neon. The bellows-expanded target was operated successfully with hydrogen in both the target (Figure 19) and the chamber. Subsequent tests of

the target with deuterium and with neon-hydrogen mixtures were unsuccessful because of leakage past flange seals. An effort was begun to develop reliable seals for the model TST and for the TST being designed and constructed for the 80-in. bubble chamber.

Beams for Bubble Chambers. Because of the AGS shutdown for the conversion project and other minor shutdowns, the bubble-chamber beams operated during only five months of fiscal 1970.

In the 80-in. area the high energy rf separated beam from the AGS was used exclusively.

In the southwest area of the AGS, where the 7-ft bubble chamber will take neutrino pictures, work continued on the neutrino beam. In particular, the power supply was doubled so that the repetition rate of the magnetic finger would match the new repetition rate of the AGS (1 pulse/sec). A test of the complete beam was performed and the beam is ready.

A PDP-8L computer was installed in the 80-in. bubble-chamber beam area. Interfacing and programming were the main activities this year. The computer should be in full operation in the summer of 1970.

Design of the new H-10 bubble-chamber beam area was finished, and next year construction will be done. This area will be extremely versatile and will eventually provide any beam to either the converted 7-ft chamber or the 80-in. chamber.

Spark-Chamber Spectrometers. The two-arm spectrometer of large size described in the section on AGS Research Activity is being tested for use in an initial experiment. Each arm has large aperture and magnetic momentum measurement. This double vertex spectrometer could be used as a general research facility if sufficient funds for operations and manpower were made available.

A serious limitation of wire spark-chamber spectrometers, up to now, has been the inability to de-

Figure 19. Test model of a bellows-expanded, cylindrical, Plexiglas track-sensitive target.

fect all charged particles emitted from an interaction in the manner of bubble chambers. The important and difficult step of extending wire spark-chamber technology to a nearly 4π solid-angle system, so that multiparticle events can be studied, has been undertaken by a BNL group in collaboration with a group from the Virginia Polytechnic Institute. The key to such a spectrometer is a set of cylindrical chambers whose curvature is accurately maintained by a very light honeycomb construction. This 4π solid-angle spectrometer presents other new technical problems besides the construction of cylindrical chambers. The readout of the wire chamber must be accomplished in a magnetic field, the cylindrical chambers must be sensitive to high-multiplicity events, and a program must be developed to convert the information provided by the cylindrical chambers (spark coordinates) into the particle trajectories. These and other problems have been investigated and solutions are being obtained. There remains the task of constructing a complete working system and using it to carry out the first objective – the study of close proton-proton interactions during fiscal 1971.

Progress in Bubble-Chamber Data Processing. During calendar 1969, 415,000 events were mea-

sured for experiments by members of the Bubble Chamber and Nuclear Interaction Groups at Brookhaven and collaborating groups at universities. The measurement rate reached 10,000 to 11,000 events/week.

The Data Terminal Network (DTN), a general input-output and control system for bubble-chamber data processing, was completed. A Sigma-7 computer, the principal hardware element in the DTN, was interconnected during fiscal 1970 with a CDC 6600 at the Central Scientific Computing Facility. Basic software for the complete DTN time-sharing system was finished, including provision for time-shared communication with the CDC 6600 and for up to 32 remote terminals. Currently 18 of the 32 terminals are assigned: 13 to scan tables; 2 (with CRT) to real-time physics analysis (histogramming, curve-fitting, hypothesis testing, etc.); 1 (with CRT) to the minimum-guidance analysis system (described below); 1 (with CRT) to control of the production chain by computing aides; and 1 (with CRT) to the Sigma-7 console for program development and computer operation. The DTN has increased the event output per scanner by about 50%. It has also allowed a decrease in computing aide staff from 8 to 6, with a further decrease to 3 expected shortly.

The minimum guidance (MG) system for bubble-chamber data analysis has been completed and is being tested. The system uses the present flying spot digitizers (FSD) but requires scanners to digitize only the vertices of an event at the scan table and not 3 points per track. An increase of up to a factor of 2 in output per scanner is expected, in addition to the factor of 1.5 mentioned above. The basic recognition program for MG was taken from CERN, but a new procedure for human rescue of incomplete or incorrect computer recognition, using the DTN display, was incorporated. The system is designed to measure 3000 events/day, with a $<5\%$ rejection ratio. To date only a few hundred events have been measured, but the required rejection ratio has been obtained.

With MG in operation, output from the analysis system will be limited by the digitizing rate of the present FSD's. Accordingly, development work has begun on a faster digitizer called the flying image digitizer (FID). Whereas the present FSD's pass a small-area spot of light across a photograph, the FID passes a projected image of the photograph across a small-area photodetector. It is possible then to use multiple photodetectors and so obtain an almost arbitrary increase in speed. The maximum possible measuring rate of the FID is $\approx 50,000$ events/hr. However, practical problems in advancing film will certainly limit the rate to a few thousand events per hour for the next few years. Tests on a skeleton machine are expected to be made soon.

Two scan tables at City College of the City University of New York were placed on line to the Sigma-7 at Brookhaven as a test of remote collection and control of remote scanning. The purpose was to evaluate some of the problems associated with service measurement of bubble-chamber film at Brookhaven for university groups. No special difficulties were encountered, and the effectiveness of the system for a university group will be evaluated over a period of a few months.

During fiscal 1970 the Mark II (70-mm) FSD at Brookhaven was converted to handle 35 and 70-mm sprocketed film interchangeably. The Mark II machine has higher resolution (i.e., smaller spot size) and higher precision than the Mark I FSD and will be used to measure 35-mm film from the Brookhaven 80-in. and the SLAC 82-in. chambers.

The data analysis system of the Nuclear Interaction Group, consisting of image plane digitizers (IPD), produced $\approx 150,000$ events during the year,

compared with 100,000 events the previous year. This increase was due solely to the different mix of experiments, the present complement consisting entirely of experiments with one event every two pictures, whereas previously half the experiments undergoing measurement consisted of one event every 100 pictures.

The prototype measuring device called SICKLE was built and tested. This device, when placed on the vertex of an event of interest, measures the curvatures and angles of all tracks by essentially placing a template of varying curvature and angle over each track until a match is obtained, a procedure requiring 3 sec/view. The incorporation of such devices could increase the measuring rate by a factor of 2.

On-Line Data-Processing Facility for Spark Chambers. As reported last year, the rapid growth in user demand for On-Line Data-Processing Facility (OLDF) services required the purchase of a PDP-10 system in order to double user services capability. The OLDF can now handle up to four users on line simultaneously, while 4 to 5 off-line users prepare to rotate with the four on-line users. This rotation of two sets of 4 to 5 users fits the AGS scheduling capabilities and user time-absorption capabilities rather well. The PDP-10 arrived last summer and was successfully employed in user research activities immediately after the AGS shutdown.

Figure 20 shows the arrangement of the combined PDP-6 and PDP-10 computer complex with the associated local user satellite computers and digital data handlers that are, or will shortly be, in experimental use until the next scheduled AGS shutdown. The individual groups are also shown on the diagram. At present some rented core and temporarily borrowed (from Digital Equipment Corp.) magnetic tape transports are being utilized to meet user commitments, and these will have to be returned soon. It is expected, if additional funds permit, that these items will soon be replaced and more PDP-15 satellite computers and other necessary input/output for users will be added.

In addition, a high-resolution remote scope display system for all on-line users has been developed. A TV system and job status notification display is being completed, and this will provide each user with all relevant information in his own trailer.

The facility is accommodating the user load smoothly, with a high degree of operational uptime ($>90\%$), and cooperation between users and staff members is excellent.

Figure 20. The arrangement for the combined PDP-6 and PDP-10 facility. Each computer system is shown in a 40-ft-long by 10-ft-wide trailer with the average minimum memory and input/output equipment usually committed to its use. The trailer in the middle contains a common pool of memory and input/output equipment, which can be easily switched to either computer. The solid-line boxes indicate equipment in use now. The dotted-line boxes indicate the major additional items expected to be incorporated shortly.

MEDIUM ENERGY PHYSICS

The Brookhaven Medium Energy Physics Group, with the cooperation of Rice University and Vassar College, completed a series of p - d measurements at the Bevatron early in fiscal 1970. The data were recorded on magnetic tape and analyzed later at Brookhaven. Three distinct experimental studies were carried out.

(1) Elastic p - d forward scattering as a function of incident proton momentum from 1.7 to 6.4 GeV/ c .

(2) Backward p - d elastic scattering over the range 1.7 to 5.2 GeV/ c .

(3) $p + d \rightarrow d + p^*$ at 1.7-GeV/ c incident protons.

The interest in all these measurements was primarily related to nuclear physics. Phase (1) was concerned with an experimental study of the breakdown of the Glauber theory, the principal framework for extracting correlation data from high energy p -nucleus scattering data. However, the limits of the theory are not well understood. The Brookhaven results indicate that the theory is in agreement with experiment (within experimental error, $\approx 10\%$) out to momentum transfers of 1.0 (GeV/ c)² over the entire range of measurement (1.7 to 6.4 GeV/ c). The effects of pair correlations are most dominant in the momentum region of 0.25 to 0.50 (GeV/ c)² and therefore it is suspected that the theory will be applicable for nuclear physics measurements to be carried out at the Los Alamos Meson Physics Facility (LAMPF).

In the backward p - d measurements interest was in the nature of the hard core in the nuclear force. Kerman and Kisslinger have suggested that when the neutron and proton are close together in the deuteron a virtual d^* state is formed in which one of the nucleons is excited to the 1688- d $\frac{1}{2}$ nucleon resonant state. On the basis of this model Kerman and Kisslinger have calculated the variation in magnitude of the backward p - d scattering as a function of incident proton momentum. The present results are in good agreement with the predictions of this model.

Another aspect of the role of excited nucleon states in the nucleus was studied in the third phase of measurements. Here the inelastic spectrum of the forward scattered deuteron was measured. A broad peak in the missing mass spectrum centered on the $p^*(\frac{3}{2}, \frac{3}{2})$ state was observed. In first order the position and shape of this peak could be accounted for by assuming that the $(\frac{3}{2}, \frac{3}{2})$ excited

proton state in the deuteron was formed at the same energy as the free N^* . The width of the peak is a reflection of the internal momentum distribution of the proton in the deuteron. This is not too surprising because the deuteron is such a loosely bound system.

During the latter half of the fiscal year a bare PDP-9 computer was acquired to be instrumented for on-line spark chamber experiments. The Group also started on a program of building Charpak proportional counter-type wire spark chambers. The published characteristics of these planes have been reproduced, and a prototype is under development for the focal plane detectors of the high resolution spectrometer being built at LAMPF.

NUCLEAR STRUCTURE

Experimental study of nuclear ground and excited states plays an essential role in providing the accurate information from which fundamental understanding of nuclear physics evolves. Low energy accelerators and neutron beams from the High Flux Beam Research Reactor (HFBR) are used to excite nuclei and to produce nuclear reactions. The energies of excited states, their spins, parities, electric and magnetic moments, lifetimes, transition probabilities, and other relevant properties are determined for excited nuclei. In nuclear reactions, the types of reaction products observed, and their distributions in energy and angle, give basic information on nuclear structure and forces. Accelerators and reactors also are used to produce unstable nuclei from which information similar to that obtained from investigations of excited nuclei can be extracted from observations on the decay products. Direct measurements are made of nuclear spins and magnetic moments with highly sensitive atomic beam equipment. Detailed knowledge of all such properties often makes possible tests of principles and ideas of broad significance in physics, not merely in nuclear physics. Some representative examples of recent research are described briefly below.

Several of the neutron capture γ -ray studies at the HFBR have been concerned with nuclei at or near closed shells. Knowledge of the properties of nuclei with one or two particles or holes outside the $N=82$ closed shell has been very limited. Information on the electromagnetic decay of levels in $N=83$ nuclei is almost nonexistent. Recent

Figure 22. Partial level schemes of ^{110}Ag , showing evidence for the $2-$ first-excited state of ^{110}Ag obtained in studies of the $^{109}\text{Ag}(n,\gamma)^{110}\text{Ag}$ reaction. (a) Evidence presented in the thesis of H. U. Freund; (b) evidence obtained in the present work. Relative intensities of transitions in thermal neutron capture are shown in parentheses. Because of the large number of available levels the primary transitions shown represent only a small fraction of the total transition intensity. A large black dot indicates a coincidence relationship. For clarity the splittings of close-level multi-

plets are not to scale. The energies for levels populated by primary transitions now agree with energies obtained from low energy singles and coincidence measurements within 0.5 keV, on the average. Discrepancies are nowhere >1 keV. Of the six transitions assumed by Freund to terminate in the first-excited state, two (118.64 and 236.75 keV) have been confirmed and the third (338.6 keV) has not been definitely located but probably ends at the ground state; the ≈ 359 -keV transition, now known to be 360.3 keV, definitely terminates at the ground

state. The 380.5-keV transition was found to be a doublet with a splitting fitting the ground-state–first-excited state level spacing. The 431.0-keV energy fits the 432.0 first-excited state energy difference. Further support for the placement of the first-excited state at 1.28 keV in ^{110}Ag is obtained from four additional transitions, the 265.60-keV transition (see Figure 23), and transitions of 484.1, 613.7, and 748.2 keV [not shown in Figure 22(b)], which fit in energy between the 1.28-keV state and well-established levels at 485.2, 614.7, and 749.4 keV, respectively.

studies on γ rays from the $^{138}\text{Ba}(n,\gamma)^{139}\text{Ba}$, $^{140}\text{Ce}(n,\gamma)^{141}\text{Ce}$, and $^{142}\text{Nd}(n,\gamma)^{143}\text{Nd}$ reactions have revealed evidence of single neutron particle states and of single particle states coupled to the excited states of the semimagic core at low energies in these $N=83$ nuclei (Figure 21). One striking feature of the level schemes obtained from these experiments is the intense feeding of the first and second-excited states from the neutron capture states. These states are also strongly excited in the (d,p) reaction. It was found that the strengths of excitation of levels in these nuclei in the (n,γ) and (d,p) reactions are strongly correlated. It can be shown that this correlation is consistent with the common unique parent assumption of Lane and Wilkinson and with the predominance of direct neutron capture in these nuclei.

Another experiment was carried out to elucidate the structure of the doubly closed shell nucleus ^{208}Pb , which is of particular interest because of the remarkable success of the shell model in describing energy levels of nuclei in this region of the periodic table. Prior to this study only the ≈ 7.37 -MeV ground-state transition and the 2.617-MeV $3- \rightarrow 0+$ transition had been discovered following neutron capture in ^{207}Pb . Besides the well-known intense primary transition to the ground state, two weak two-step γ -ray cascades from the capture state to the ground state were observed. These cascades, with intensities $<0.1\%$ that of the ground-state transition, proceed via the first-excited $3-$ state at 2614 keV and the $2+$ state at 4086.0 keV. These results will represent a valuable test for transition probabilities to be computed from the wave functions of the states of ^{208}Pb , as recently calculated by Brown, Kuo, and Blomqvist in the random phase approximation.

One unfavorable feature of the neutron capture reaction is that the nuclear levels are not observed directly but must be inferred from the observation of the transitions between levels. This disadvantage is largely offset by the energy resolution of the Ge(Li) detector, which is superior to that of the current generation of charged-particle spectrometers. In certain classes of experiments (e.g., the study of odd-odd nuclei where the energy level density is high), this higher resolution provides a decided advantage. In a recent Brookhaven study of the $^{109}\text{Ag}(n,\gamma)^{110}\text{Ag}$ reaction it was possible to show the existence of the postulated low energy $2-$ state, for which many investigators had searched in vain, by studying the

decay of 253-day ^{110m}Ag . Some indication of a level at ≈ 1.6 keV had been obtained from the $^{109}\text{Ag}(n,\gamma)^{110}\text{Ag}$ reaction by H.U. Freund (thesis, Technische Hochschule, Munich, 1967). Definite proof for the existence of the level energy was found at (1.28 ± 0.10) keV. Figure 22 compares the part of Freund's level scheme relevant for the discovery of the $2-$ level with the corresponding part deduced from the present high-precision work. Direct proof of the existence of the level was obtained by showing that a 235.47–236.75-keV doublet, found in a high-resolution γ -ray singles spectrum (Figure 23), is in coincidence with the γ ray feeding the 236.75-keV level. There is also some less convincing evidence for the coincidence of another doublet (266.86–265.60 keV) with the 93.27-keV transition populating its 266.86-keV initial state (Figure 24). Earlier studies at Brookhaven showed that for a level of this energy $\tau_{1/2} \geq 10^{-7}$ sec, which prevents the detection of conversion electrons from the transition in coincidence with preceding radiations. Figure 23 compares the information on the energy levels of ^{110}Ag resulting from this work with the present knowledge of the low-lying states in other odd-odd gold isotopes. In particular, the position of the $2-$ and $6+$ states relative to the $1+$ state as a function of neutron number is of interest.

The results of a detailed investigation of the decay characteristics of the high spin isomer $^{194m2}\text{Ir}$ were given in the 1968 Annual Report. This isomer of high spin ($I=10$ or 11) was formed from ^{191}Ir by triple neutron capture in a high flux reactor. Following β decay of the isomer, two high spin states are populated in the ^{194}Pt nucleus at excitation energies of 2438 and 2423 keV. The 2438-keV state was shown to decay by two parallel γ -ray cascades to the ground state of ^{194}Pt . The 2423-keV state was observed to be only weakly populated. It decays by emitting either a 324-keV γ ray to the presumed $8+$ member of the "ground-state band" of ^{194}Pt or by a crossover γ ray of 1011.8-keV to the presumed $6+$ member of this band. The combination of low source intensity and low specific activity then available made measurement of the β -ray end-point energy in the isomeric decay impossible and precluded definite establishment of β - γ coincidences and determination of the multipolarity of the weak 1011.8-keV γ ray. The multipolarity of this transition is important in that it can be used to fix the spin and parity of the 2423-keV state and

thus provide a clue to the configurational character of this state.

A new $^{194m_2}\text{Ir}$ source of high specific activity was made by bombardment of ^{191}Ir in the High Flux Isotope Reactor at Oak Ridge National Laboratory for a time calculated to maximize the ratio of the $^{194m_2}\text{Ir}$ intensity to the obscuring 74-day ^{194}Ir intensity. With use of a $\text{Si}(\text{Li})$ electron

detector and a $\text{Ge}(\text{Li})$ γ -ray detector, a series of two-parameter high-resolution β - γ coincidence studies yielded a β -ray end-point energy of (231 ± 10) keV. An upper limit of 10^{-7} sec was found for the half-life of the 2438-keV state. In addition, the internal conversion coefficient of the 1011.8-keV transition was measured as $(4.0 \pm 0.4) \times 10^{-3}$, a value that fixes its multipolarity as $E2$.

Figure 23. Singles and coincidence results showing the structure of (b) the 235.47–236.75-keV and (c) 265.60–266.86-keV transition doublets. For comparison, corresponding results for (a) the 198.39-keV transition (a single peak) are shown. Since one channel in the coincidence results corresponds to eight channels in the singles spectra, histograms have been constructed by summing over eight channel segments of the singles peaks to indicate the coincidence results expected from the structure of the

singles peaks. The transition used as a coincidence gate is indicated (see Figure 22). The individual sections are not drawn to a common scale. In (b), the structure of the 235.47–236.75-keV doublet appears clearly in the coincidence results. In (c), because of the limited statistical accuracy of the coincidence results and the low intensity of the 265.70-keV satellite peak, the results are consistent with the presence of either one or two peaks in coincidence with the 93.27-keV transitions.

6+ — 8.4 d ~ 300

Figure 24. Present knowledge on low-lying states in odd-odd gold isotopes. Level energies are indicated in keV. No 6+ state has yet been observed in ^{112}Ag .

The configuration of the 1+ and 6+ states is probably $p(1g_{9/2})^{-1}n(2d_{5/2})^{-1}$, and that for the 2- states, $p(2p_{1/2})^{-1}n(2d_{5/2})^{-1}$.

Figure 25. Proposed decay scheme of $^{194m_2}\text{Ir}$. The level energies are given in keV. The numbers in parentheses are intensities, given in percent per disintegration.

The spin and parity of the 2423-keV state is thereby determined to be $8+$. A detailed series of γ - γ angular correlation measurements using a combination of Ge(Li) and NaI detectors was carried out. The spin assignments to ^{194}Pt states shown in Figure 25 are consistent with these angular correlation measurements and with the results of improved internal conversion coefficient measurements. In particular, the spin and parity of the 2438-keV state is $10+$. The mode of population of the 2423-keV state (i.e., by a β branch or by a low energy transition from the 2438-keV state) is still under investigation.

The ability to extract meaningful information from observations of "in-beam" γ rays produced in nuclear reactions has been enormously amplified by the use of high-resolution Li-drifted germanium detectors. This has led to a series of new experiments examining γ rays produced in 30 to 40-MeV α -particle induced reactions at the 60-in. cyclotron. It is well known from heavy-ion induced reactions on heavy nuclei that such reactions involve large angular momentum transfers. Typically, spin distributions of the compound system can extend to 10, 15, or even 20 units of $\hbar$ when α particles in the 40-MeV region react with a medium-to-heavy nucleus. The compound system formed evaporates a few nucleons of low average energy. The resulting nucleus, still highly

excited, is left in high angular momentum states normally populated in other ways. An important feature of the reaction is that these states are highly aligned perpendicular to the beam direction. These highly aligned states of high spin tend to decay via "stretched cascades" in which the alignment is preserved down the γ -ray cascade. These cascades generally exhibit high anisotropic angular distributions with respect to the beam direction, a circumstance that opens several interesting experimental possibilities in nuclear structure studies, especially when combined with another advantageous feature of such cyclotron-produced reactions. The latter arises from beam-bunching characteristics of the cyclotron. The arrival of α particles at the target in bursts, well defined in time, permits timing measurements on the emitted γ rays relative to time zero defined by the burst. Thus, "prompt" and "delayed" γ -ray cascades can be separated in coincidence experiments in which time comparison is between the cyclotron radio frequency and the signals from the high-resolution γ -ray detector. Time relationships between different γ rays in the cascades are also examined by conventional γ - γ coincidence techniques. Populations of high spin states in these reactions often lead to observable "isomeric" states which decay with lifetimes ranging from a few nanoseconds to much longer times.

The combination of highly anisotropic γ -ray distributions, together with the measurable lifetimes of excited states, makes it feasible to measure the gyromagnetic ratios of delayed states. A magnetic field applied perpendicular to the plane defined by the beam and the line from the target to the γ -ray counter will precess the angular momentum vector of the excited state around the field direction at twice the Larmor frequency, $\omega_L = g\mu_0 B/\hbar$. This frequency is detected by observing the modulation of the time distribution of delayed γ -ray events, since the angular distribution of the delayed γ ray is "locked" to the precessing spin. From the angular distributions, the spins of levels involved in the γ -ray cascades to low-lying and ground states of the product nuclei may be deduced. Information concerning parity changes in the γ -ray transitions must be derived in other ways. This type of information is reflected in the linear polarization of the γ rays relative to the plane defined by the beam direction and the

Figure 26. Angular distributions of prominent γ rays observed in the $^{60}\text{Ni}(\alpha, np)^{62}\text{Cu}$ reaction. The metallic ^{60}Ni target was magnetically not aligned in these measurements. γ Rays either totally delayed (348.2 keV) or partially fed (242.8 keV) through the 11.5×10^{-9} -sec state suffer severe perturbations of time-integrated angular distributions. For the 242.8-keV γ ray, A_2' represents the measured angular distribution, while A_2 represents the value obtained by correcting A_2' for the partial feeding of the state through the delayed state. The 348.2-keV time-integrated angular distribution is severely perturbed by the randomly oriented static magnetic hyperfine interaction.

outgoing γ -ray direction. This polarization is measured by using the polarization sensitivity of the Compton scattering process. The Compton "polarimeter" consists of two high-resolution Ge-Li γ -ray detectors, one serving as a Compton scatterer while the other detects the Compton-scattered γ ray. The probability of the scattering process for a particular γ ray is then measured as a function of the angle of scattering relative to the plane defined above. The complexity of the reaction γ -ray spectrum demands that good resolution be preserved in these measurements. This is achieved by summing the two detector signals after coincidence requirements are established.

A number of nuclei were investigated by these techniques. The dominant reaction on ^{60}Ni with ≈ 39 -MeV α 's, for example, is the (α, np) reaction, which leads to excited states in ^{62}Cu , an odd-odd nucleus. Very little is known about the distribution of higher spin states in the excitation spectrum of such nuclei. It was found that a large fraction of the measured total cross section (600 mb) for this reaction appears in γ rays that decay via a "stretched" γ -ray cascade. Angular distributions relative to the beam direction of the strong γ rays observed in this reaction are shown in Figure 26. Coincidence studies and γ -ray intensity measurements show that the excited state at which significant entry is made after the reaction nucleons have boiled off is a state near 2.9 MeV. The spin and parity of this state are found to be $6+$, and the γ -ray cascade proceeds to the ^{62}Cu ground state via an $M1$ cascade (determined by linear polarization measurements of the type described above). A $3+$ isomeric state with a half-life of about 11.5×10^{-9} sec is observed at 390-keV excitation (see Figure 27). The g -factor for this particular state was measured ($g = +0.63$) by a spin-precession measurement of the type described above. Here the isotopically enriched ^{60}Ni metallic target was aligned magnetically by being placed across the pole tips of a magnet. The magnet field that precesses the spin is the aligned internal field at the ^{62}Cu impurity site in a nickel lattice (known to be -47.2 kG). The results of the g -factor measurement are shown in Figure 28. The states in ^{62}Cu observed in the (α, np) reaction are shown in Figure 29.

In the 3.5-MeV Van de Graaff program the triton beam was used in 80% of the total research work. Radioactive elements made with this beam for the purpose of studying their decay schemes

include ^{11}Be , ^{21}F , ^{25}Na , ^{32}Si , ^{38}S , and ^{50}Ca . The investigation of ^{25}Na was part of a study of mirror symmetry in the β decay of the $A = 20$ and 25 systems. On simple grounds it is expected that mirror β decays should have identical comparative half-lives (ft values), although it is known that in the β decays of ^{12}N and ^{12}B to the ^{12}C ground state $(ft)^+/(ft)^- = 1.11 \pm 0.01$. If this failure of mirror symmetry by about 10% for $A = 12$ were due to an induced tensor interaction, then for the

Figure 27. Time distributions of coincidences between the cyclotron radio frequency and 348-keV γ rays observed in the $^{60}\text{Ni}(\alpha, np)^{62}\text{Cu}$ reaction.

Figure 28. The ratio $R = 2(N_{135} - N_{45}) / (N_{135} + N_{45})$. Here N_{135} and N_{45} represent the normalized time distribution of coincidences between the cyclotron radio frequency and 348-keV γ rays obtained at 135° and 45° , respectively, to the α -particle beam direction. The metallic ^{60}Ni target was magnetized perpendicular to the plane defined by the beam direction and the direction from the target to the γ -ray counter. Two fits to the observed Larmor precession are shown. The solid line is the least-squares fit in which no time-dependent attenuation of the angular distribution is assumed. The dotted line is the best fit to these data in which an attenuation of the form $e^{-\lambda t}$ is assumed, with $\lambda = (0.011 \pm 0.005) \times 10^9/\text{sec}$. The Larmor frequency is unaffected by the possible small attenuation to the accuracy of the measurement.

$A = 20$ and 25 systems the corresponding ratio would be 1.06. Experimentally it is found that $(ft)^+/(ft)^- = 0.93 \pm 0.03$ for $A = 20$ and 1.19 ± 0.08 for $A = 25$. Thus, the two cases show significant departures from mirror symmetry, they are in opposite senses, and neither example falls systematically in line with the $A = 12$ case. Present theories are therefore not able to account for these departures from mirror symmetry.

The triton beam from the 3.5-MeV Van de Graaff was also used for a number of spectroscopic investigations. One of the more interesting was a detailed study of the energy levels of ^{36}S formed in the $^{34}\text{S}(t, p)^{36}\text{S}$ reaction with use of targets enriched in ^{34}S . The ^{36}S nucleus is of particular interest because it is a double-closed shell and according to theory its energy level structure should be analogous to that of ^{16}O and ^{40}Ca ; these latter nuclei are known to have related properties. Previous work had indicated ^{36}S excited states at 2.00 MeV (0^+), 2.88 MeV (2^+), 3.30 MeV ($2^+, 3^-$) and 3.36 MeV (0^+); information on higher states was rather sparse. The Brookhaven experiments indicated that the 2.00- and 2.88-MeV

Figure 29. States of ^{62}Cu observed in the $^{60}\text{Ni}(\alpha, np)^{62}\text{Cu}$ reaction. Excitation energies (E) and γ -ray energies are given in keV. Transition intensities are given in terms of 100 populations of the ^{62}Cu ground state. Multipolarities and mixing ratios are deduced from angular distribution and polarization measurements. Spins and parities are based on a 1^+ assignment to the ^{62}Cu ground state.

Figure 30. The upper curve is the spectrum of γ rays from a 5×6 -in. NaI(Tl) scintillation detector in coincidence with protons from the reaction $^{10}\text{B}(^3\text{He}, p)^{12}\text{C}$ leading to the 15.11-MeV $T=1$ state of ^{12}C . New transi-

tions of 2.40 and 7.46 MeV are observed. An instrumental effect accounts for the large amplitude of the 4.44-MeV lines. The lower curve is the yield in adjacent proton channels and represents background.

Figure 31. Summary of γ -ray branches, in percent, from the 15.11 and 12.71-MeV states of ^{12}C . The known α -particle branches from these two states are included in the figure.

levels probably do not exist. Nine energy levels were measured in ^{36}S up to an excitation energy of 7.5 MeV. The states at 3.30 and 3.36 MeV have $J^\pi = 2^+$ and 0^+ , respectively, where the latter assignment was established by pair spectrometer and lifetime measurements. Much more additional information was obtained on the higher states with use of angular correlation techniques.

According to theories of light nuclei, the transition rates for $\Delta T=1$ β decay should be closely related to the rates for the corresponding magnetic dipole γ -ray transitions. A test of this can be made in the $A=12$ system by comparing the $\log ft$ values of the various β -ray branches from the $T=1$ nuclei ^{12}B and ^{12}N with the γ -ray transition rates from the 15.11-MeV $T=1$, $J^\pi = 0^+$, 1^+ , or 2^+ . Only the γ -ray transitions $15.11 \rightarrow 0$ and $15.11 \rightarrow 4.44$ had been observed previously. By means of a ^3He beam from the Van de Graaff, the reaction $^{10}\text{B}(^3\text{He}, p)^{12}\text{C}$ was used to excite the 15.11-MeV state. The γ -ray spectrum in coincidence with protons leading to the 15.11-MeV state of ^{12}C is shown in Figure 30. Observation of the new transitions of 2.40 and 7.66 MeV completes the list of all γ -ray transitions from the 15.11-MeV state that can be measured experimentally. Figure 31 shows the branches and their intensities, not only from the 15.11-MeV state, but from the 12.71-MeV state obtained in the same experiment. The branches given in Figure 31 for transition between the 15.11-MeV state and those at 4.44, 7.65, and 12.71 MeV compare with expected branches of 3.2%, 7.4% and 1.2%, respectively, based on simple calculations using the $\log ft$ values for β decay. The difference by as much as a factor of 3 between the β transitions and analogue $M1$ γ -ray transitions will have to be explained by higher-order corrections in the theory.

The Nuclear Moments Group continued a program of studying hyperfine structure of stable and radioactive nuclei, with use of atomic beam magnetic resonance. With the Brookhaven equipment, transitions may be studied with relative precision of the order of 10^{-8} to 10^{-9} , which permits separation of the interaction of the nuclear magnetic moment with an external magnetic field in the presence of the normal hyperfine interaction. Measurement of moments in this manner is not subject to perturbations due to molecular or lattice environments, nor need it be analyzed by atomic wave function calculations. The determination of nuclear moments is of particular interest if made to a precision of 10^{-3} or better, since this permits evaluation of the nuclear hyperfine anomaly. The latter is an effect resulting from penetration of valence electrons into the nuclear volume and interaction with the magnetic field due to the particular configuration of intrinsic particle and orbital magnetization. In the principal experiment completed during the past year, the hyperfine interval for the ground state $\Delta\nu$ of ^{39}K has been measured as 461,719,720.1 Hz, with a probable error of $<\pm 2$ Hz.

NEUTRON PHYSICS

Neutron physics research at Brookhaven is concerned with the properties of the neutron and its interaction with nuclear matter. The neutron ex-

periments, carried out at the HFBR, employ both time-of-flight and crystal spectrometer techniques. The excitation of nuclei by neutrons and study of the subsequent decay of the excited levels yield fundamental information on the neutron capture reaction mechanism and on the spin, parity, and other parameters of the excited states. Precise measurements of neutron cross sections give data that are significant for basic nuclear physics, as well as for technological applications involving neutrons. Additional data are obtained from studies of interactions of polarized neutrons with nuclei oriented in magnetic fields at ultralow temperatures.

Much of the work at the fast-neutron chopper facility is centered on the reaction mechanism of slow-neutron capture. A reaction is studied by recording the probability of radiative decay of the compound system formed by neutron capture as a function of incident neutron energy. Several simple reaction mechanisms are of current interest. In compound nucleus formation, which is usually the dominant process, the incident neutron's energy is shared among the target nucleons, and the resulting system subsequently decays by γ -ray emission after a relatively long time. Other mechanisms can, in favorable cases, compete with compound nucleus formation of single-particle states and 2-particle-1-hole states.

Recent experiments carried out on the capture of P -wave neutrons in ^{93}Nb resonances suggest

Figure 32. Comparison of γ -ray spectra following S and P -wave capture in ^{93}Nb . The transitions are averaged over 300-keV intervals and summed over 4 P -wave and 3 S -wave resonances. The enhanced strength near 7 MeV for P -wave capture is attributed to transitions across the major shell closure at $Z=50$.

Figure 33. Distribution of transition probabilities for $^{175}\text{Lu}(n, \gamma)^{176}\text{Lu}$. The curve best fitting the distribution is intermediate between the $\nu=1$ and $\nu=2$ curves of the χ^2 distribution family.

strongly that the intense electric dipole γ rays following such capture are due to 2-particle-1-hole components in the capturing states. These states, formed by the elevation of a $p_{1/2}$, $p_{3/2}$, or $f_{5/2}$ proton across the shell closure at $Z=50$, decay by proton-hole annihilation, leaving the incident neutron in a low-lying S or D state. The presence of these strong transitions is indicated in Figure 32, which shows the energy reduced transition probabilities, averaged over 300-keV intervals and summed over resonances, for both S - and P -wave capture. The enhancement of $E1$ transition strength in the P -wave case as compared with the S -wave spectrum is clearly evident. This enhancement is accompanied by a correlation of radiative widths with the cross sections for (d, p) excitations of the same final states. These correlations are evidence of failure of compound nucleus formation.

Extensive studies of the distribution of radiative transition probabilities have been carried out. The most recent evidence for the failure of the Porter-Thomas distribution of widths is exhibited by the reaction $^{175}\text{Lu}(n, \gamma)^{176}\text{Lu}$. The distribution of widths is best fitted by a χ^2 distribution of $1.62^{+0.42}_{-0.30}$ degrees of freedom, as indicated in Figure 33. This departure from the $\nu=1$ (Porter-Thomas) distribution is also indicative of the failure of the assumption of a purely statistical decay of a compound nucleus.

It has been demonstrated that spin assignments for neutron resonances can be made on the basis of observed regularities in the low energy γ rays in the resonance spectra. The final states that are nearer in angular momentum value to the initial (resonance) state tend to be populated more

strongly than those farther away. The ratio of γ rays from the decay of these states is thus a sensitive indicator of spin. A case in point is the study of resonances in the reaction $^{121}\text{Sb}(n, \gamma)^{122}\text{Sb}$, in which the ratio of two low energy γ rays is seen to exhibit such a dependence (Figure 34). The method provides a quick and reliable means for determination of resonance spins.

Studies of the radiative decay of resonances in fissile nuclei are complicated by the presence of fission γ rays. For the first time, it has been possible to observe direct high energy transitions to low-lying states of the residual nucleus, where the

Figure 34. Ratio of the 121 and 114.5-keV γ rays from ^{121}Sb resonances. A marked difference between spin 2 and spin 3 resonances is observed.

Figure 35. Capture γ -ray spectra from the 7.8 and 11.9-eV resonances in ^{239}Pu . The strong transition in the 7.8-eV resonance (top) populates a 1^- level in ^{240}Pu at 597 keV.

Figure 36. Portions of the spectra of delayed γ rays following fission of ^{239}Pu and ^{235}U from 4 to 4.5 MeV.

target nucleus is fissile. This has been accomplished by studying resonance capture in the reaction $^{239}\text{Pu}(n,\gamma)^{240}\text{Pu}$ and examining spectra for resonances for which the radiation width Γ_γ is comparable to, or larger than, the fission width Γ_F . It is relatively easy to distinguish γ rays resulting from capture from fission γ rays in resonances by applying certain criteria:

(a) Capture γ rays fluctuate widely from resonance to resonance; fission γ rays do not.

(b) Capture γ rays do not exhibit the Doppler smearing expected for γ rays emitted from moving fission fragments.

(c) Capture γ rays have energies related to the energies of known low-lying states of the residual nucleus.

Portions of the spectra from capture in the 7.8 and 11.9-eV resonances are shown in Figure 35. The distinct peaks correspond to states in ^{240}Pu , and the large peak in the 7.8-eV resonance populates the 1^- level at 597 keV in ^{240}Pu . From this experiment the neutron separation energy of ^{240}Pu has been determined to be 6533.7 ± 1.5 keV.

As part of the above study, delayed γ rays resulting from fission were observed as background between resonances in the time-of-flight spectrum. This background spectrum was measured for both ^{239}Pu and ^{235}U . Portions of the spectra, in the region of 4.0 to 4.5 MeV, are shown in Figure 36. The spectra of delayed γ rays from uranium and plutonium show similarities but also display characteristic differences. The presence of these differences suggests that these γ -ray spectra might be useful in nondestructive assaying of nuclear fuels.

The development of a self-pumped oil-flow bearing system allowed the fast-neutron chopper used in these studies to run regularly at its design speed of 15,000 rpm for the first time early in 1970. Operation at this speed results in improved neutron energy resolution and lower background at high neutron energies and permits data of higher quality to be recorded.

The H-1 beam port of the HFBR has a uniquely rich spectrum of epithermal neutrons. Four crystal spectrometers operate simultaneously on neutron beams from this port and support a variety of programs involving scientific personnel from Harvard University, the University of Rhode Island, and Queens College of the City University of New York, as well as regular BNL staff members. Experiments include high-precision

measurements of selected cross sections of special interest, γ -ray spectroscopy, improvement of techniques for obtaining monoenergetic neutron beams, and the interaction of polarized neutrons with oriented nuclei. In the latter studies, the spins associated with many resonances in ^{161}Dy , ^{163}Dy , ^{167}Er , ^{175}Lu , and ^{176}Lu were determined, and magnetic hyperfine interactions were measured. In one novel experiment the nuclear magnetic dipole moment was measured for two highly excited states in ^{168}Er .

Problems involved in more precise measurements of low energy radiative capture cross sections were investigated, and values were obtained at selected energies for nine elements. The results, obtained in collaboration with the University of Rhode Island and Queens College, were sufficiently encouraging to justify an expansion of this effort in the future, to meet the requirements for data of better precision for engineering applications.

A target for a measurement of the parahydrogen total cross section has been installed and tested in collaboration with Harvard University. This gaseous target cooled by a bath of liquid hydrogen required extensive safety approval before it could be operated in the HFBR containment shell, which delayed the start of the experiment. The final data are expected to improve the precision with which the basic neutron-proton interaction is known.

THEORETICAL PHYSICS

The interests of the Theoretical Group are in nuclear physics, many-body theory, and atomic physics. Close ties are maintained with the experimental programs in nuclear physics and with theoretical activities in solid state and particle physics. Work typical of that carried on during this last year is reported below.

The Coulomb energy separation between analogue states has been used to determine radii for the outer orbits. What information does this separation actually provide on the single-particle orbit occupied by the nucleon that changes from neutron into analogue proton? Besides the orbit-defining central potential of the shell model, there are residual interactions between the nucleons. These can be divided into two classes: those between outside nucleons, and those between outside nucleons and core excitations. The residual interactions between outside nucleons are responsible for the energy splitting between shell-model configurations.

They also affect the wave functions and therefore the Coulomb energies. A method was devised for calculating this effect in the same spirit as the more usual shell-model calculations. The result depends on the form of the residual interactions and not just the net separation energy alone. One cannot just vary the central parameter potential to fit the separation energy.

The residual interactions between outside nucleons and core excitations are also familiar in nuclear structure theory. They are important, for example, in calculating the effective charges in electromagnetic matrix elements. Their importance for Coulomb energies arose because of great difficulty in interpreting experimental results for the simple case of the pair of mirror nuclei ^{41}Ca - ^{41}Sc , whose ground states are analogues. The simplest shell-model configuration for these nuclei consists of an $f_{7/2}$ valence nucleon, either neutron or proton, together with a doubly magic ^{40}Ca core. The measured energy separation between the ground states of ^{41}Ca and ^{41}Sc can be converted into a radius only after making some obvious corrections of single-particle nature. The final result for the energy of interaction between the valence and core charges implies a radius for the $f_{7/2}$ orbit of $\approx 3.50 \cdot 10^{-13}$ cm. Since the charge distribution radius of ^{40}Ca is also $\approx 3.50 \cdot 10^{-13}$ cm, it might be concluded that the $f_{7/2}$ valence orbit lies spatially on top of the core $2d$, $1d$ orbits. This result is so difficult to fit into even a shell model with correlations that an examination of the basis of its derivation seemed in order.

The underlying assumption in the above analysis is the strict use of an independent particle model: that is, in transforming from ^{41}Ca to ^{41}Sc the valence neutron merely becomes a valence proton. The natural question concerns how small excursions beyond the single-particle model modify conclusions on orbit radii. For the case of ^{41}Ca - ^{41}Sc , the most important effect seems to be due to the admixture of a small component of the wave function in which the core is excited into an isotopic spin unity ($I=1$) state. The dominant component of the wave function involves a $I=0$, ^{40}Ca core. In both components the core is coupled with a valence particle to give an overall isotopic spin $I=\frac{1}{2}$. This admixture can be characterized as equivalent to that produced by a small isovector effective for the valence particles in an individual particle shell model. The calculation of this effective-charge correction can be related very gen-

erally to a difference of proton and neutron densities in the ^{40}Ca core, this difference being generated by the core Coulomb interactions.

Since any nuclear model is probably inadequate for calculation of this important but small density difference, it was thought preferable to resort to a phenomenological parameterization to estimate a correction to the valence-core Coulomb energy. A richening of some 2% for protons near the peak in the valence particle distribution, with a corresponding depletion of neutrons in the same region, was sufficient to reduce the Coulomb energy and remove the radius anomaly. This amounts to an isovector effective charge of about $\frac{1}{2}e$. Assuming the parameterized density difference used for the $f_{7/2}$ level, one could also remove a similar radius anomaly for the $d_{3/2}$ valence-hole level in the nuclei ^{39}Ca - ^{39}K . Although general arguments can be used to justify the assumed form for the proton-neutron density difference, only specific model calculations or direct experimental measurements can definitely settle the point. For the present, the calculation seems to provide the best avenue for removing a serious difficulty.

The three-body problem in nuclear physics has been one of considerable interest. Starting from what is known about the strong internucleon forces, can one predict the sizes and binding energies of tritium and ^3He , the cross sections for scattering and capture of neutrons by deuterons, and various electromagnetic and weak interaction properties such as photodisintegration cross sections, form factors for elastic electron scattering, magnetic moments, β decay? Can one, using these data, learn more about the basic nucleon-nucleon interactions?

By choosing a simple form for the two-body interaction, but one that fits experimental data on nucleon-nucleon scattering, a solution was achieved for the three-body equations, resulting in theoretical values for the triton bound state and scattering properties that agree remarkably well with experiment. The internucleon potentials used are highly simplified representations of the true interactions, but chosen to reproduce very closely the general behavior of the much more complicated forms currently employed to analyze nucleon-nucleon data. The three-body calculations show how to discriminate between proposed forces that give identical results for nucleon scattering. The present approach appears to be the first to yield simultaneous agreement for the triton binding

energy and the doublet n - d scattering phase shifts. This was achieved because the interaction has certain features not shared by simple forces proposed in the past. The vital features have to do with the amplitude for scattering of a nucleon by another nucleon when the initial and final relative momenta do not correspond to the relative two-body energy. Such processes cannot be observed in two-nucleon scattering experiments but do occur in three-particle systems. Since the amplitudes for such processes were used in an essential way, new information on the properties of nucleon-nucleon interactions was obtained.

Liquid mixtures of ^3He and ^4He show two kinds of phase transition. One is to a superfluid state, similar to that in pure ^4He , for which the transition temperature decreases as more ^3He is added. The other occurs at low temperatures when the mixture becomes unstable and breaks into two phases, one rich in ^3He , the other rich in ^4He . The two transitions do not seem to be necessarily related at first sight, since mixtures not showing superfluidity may separate into two phases if energetically favorable to do so. However, it has been shown experimentally that the top of the phase separation curve in the concentration-temperature plane lies on the λ line, which is a plot of the superfluid transition temperature as a function of concentration. This suggests a definite connection between the two transitions. Accordingly, an investigation of the phase diagram of helium mixtures was undertaken. The mixture was represented by a simple lattice gas model, which was shown to be mathematically equivalent to a spin-1 Ising model of a magnetic system. There are just enough degrees of freedom to display the two transitions, superfluidity being produced by the analogue of magnetic dipolar coupling, and phase separation by the analogue of quadrupolar coupling, which are included in the Hamiltonian.

The phase diagram was obtained in the molecular field approximation for various values of the ratio of the strengths of the two kinds of coupling. It was found that small quadrupolar coupling, which is to be expected for helium mixtures, gives the closest agreement with experimental data. The two transitions are closely related in this limit. Phase separation takes place because the mixture is unable to undergo a superfluid transition at high ^3He concentration, and so it breaks into two phases, with the ^3He -rich phase normal and the ^4He -rich phase superfluid. Experimentally, the

λ line has a discontinuity in slope when it meets the phase separation curve. Even with the inclusion of quadrupolar coupling, this feature could not be reproduced in the molecular field approximation, and it seems that it has been attributed to the effects of critical fluctuations.

The electronic quadrupole polarizabilities α_q of the alkali atoms were calculated, with use of valence (ns) wave functions that are consistent with the observed energy eigenvalues (ionization potentials). α_q measures the induced quadrupole moment Q_{ind} caused by a uniform external field gradient. The calculated values of α_q are very large, ranging from $60.0 \text{ \AA}^5$ for lithium to $441 \text{ \AA}^5$ for cesium. α_q was also calculated for the Rb^+ and Cs^+ ions, with use of the Hartree-Fock wave functions for these ions.

The quadrupole antishielding factors R for the three lowest np excited states of the potassium and rubidium atoms have been calculated with use of the method of direct solution of the inhomogeneous equation for the perturbation of the core wave functions. The present calculations constitute a substantial improvement over those carried out in 1956. Thus the exchange terms with the valence electron are included in the present calculations; moreover, np valence wave functions $v(np)$, which reproduce the observed atomic eigenvalues for these states, were determined and employed. The results are as follows: for potassium, $R(4p) = -0.213$, $R(5p) = -0.173$, and $R(6p) = -0.159$; and for rubidium, $R(5p) = -0.258$, $R(6p) = -0.208$, and $R(7p) = -0.191$, all values with an estimated uncertainty of $< \pm 0.05$.

SOLID STATE PHYSICS

Research in solid state physics is concerned with the understanding of the physical nature of condensed systems, with emphasis on crystal imperfections and on the structure and dynamics of solids. The experimental programs emphasize research at the large facilities at Brookhaven such as the HFBR and the machines available at the Low Energy Accelerator Facility. Theoretical work is closely related to and interacts strongly with the experimental programs. Some representative accomplishments are described briefly below.

Structure of Solids

A major experimental activity is centered around the use of neutrons in studies of the dynamical and

Figure 37. Spin-wave dispersion relation in the two-dimensional antiferromagnet K_2NiF_4 . The solid line is for $[\xi, 0, 0]$ and is a measure of the intraplane magnetic interaction. The dashed lines are for $[0, 0, \xi]$ at 2.4 meV and $[0.45, 0, \xi]$ at 38.1 meV. These give the energy variation in the c -direction and are dispersionless, which indicates the lack of measurable interplane interaction.

structural properties of solids. X-ray diffraction, Mössbauer spectroscopy, and low-temperature techniques also contribute significantly to the overall effort. Critical scattering has emerged as an essentially new research topic, with advantage taken of the unique role of neutron scattering in the study of second-order phase transition dynamics.

In the theory of cooperative phenomena, the only system exhibiting a phase transition for which exact solutions are available is the two-dimensional Ising model. It would therefore be highly desirable to find in nature a true two-dimensional second-order phase transition. Recent neutron scattering experiments have yielded the first concrete evidence of two-dimensional antiferromagnetic correlation in crystals of K_2NiF_4 and $Mn(HCOO)_2 \cdot 2H_2O$. The magnet scattering cross section in reciprocal space has the form of a *ridge*

rather than a *peak*, with the direction of the ridge perpendicular to the planes. Critical scattering and spin waves were investigated in detail through the Néel temperature ($97.1^\circ K$) of K_2NiF_4 , which exhibited almost ideal two-dimensional characteristics. The most striking result is the extreme anisotropy in spin-wave energy dependence upon propagation direction. Within the plane a normal dispersion relation is observed perpendicular to the plane along the c -direction, and the spin-wave energies are independent of wave vector, which indicates the lack of measurable interplane interaction, as illustrated in Figure 37.

The investigation of two-dimensional magnetic transitions has been extended to a series of related compounds. In K_2NiF_4 there is strong antiferromagnetic coupling of nickel moments within basal planes, but the net interaction between planes is extremely weak. The isomorphous compound Ca_2MnO_4 also contains antiferromagnetic layers, but these are stacked in a different sequence along the tetragonal axis. Rb_2FeF_4 has the K_2NiF_4 type of magnetic structure, but Rb_2MnF_4 is highly unusual in that magnetic phases of both the K_2NiF_4 and Ca_2MnO_4 types coexist and have identical ordering temperatures. This is thought to arise from the fact that the energy difference between the two phases is so small that the relative proportions are determined by microscopic factors such as impurities and imperfections. $BaNiF_4$ is another compound with two-dimensional properties and is also piezoelectric and ferroelectric; it is structurally more complicated than K_2NiF_4 but has essentially similar antiferromagnetic planes, between which the interactions are very weak.

The concept of waves has proved to be very important and useful in the modern understanding of magnetism. A spin wave represents a disturbance of an ordered magnetic structure, propagating from atom to atom in the material. The energy dispersion relation of spin waves connects their energy and wave number (wavelength and direction of propagation) and contains in principle all the information on the strength and range of the coupling forces between the atomic moments. By using inelastic neutron scattering techniques, the entire spin-wave dispersion has been measured in typical insulating antiferromagnets: Cr_2O_3 , α - Fe_2O_3 , and NiO . Many important properties, such as the exchange interaction, were deduced from the data and compared with theoretical predictions, with generally good agreement. Results in

the case of $\alpha\text{-Fe}_2\text{O}_3$ were particularly significant, with the observation of optical spin waves showing little dispersion throughout the Brillouin zone. All spin waves of energy $>80^\circ\text{K}$ were essentially unaffected by the Morin transition at 260°K .

It is now well established that certain ferroelectric phase transformations result from an instability in a long-wavelength optical vibrational mode. These transformations are preceded by a gradual "softening" of the frequency of the unstable mode, and such behavior has been observed by optical and neutron spectroscopy. Several important details of real systems, however, have never been adequately explained within the context of this model. For example, it fails to explain why real systems often transform into many small spatial domains characterized by different orientations of polarization rather than truly single crystals of macroscopic size. A recent neutron-scattering study has shown how a dynamical theory of domain formation can be constructed in which the driving force is still an optical phonon instability. In Figure 38 an example of a typical incipient phonon instability in cubic KTaO_3 is shown. In addition to the expected softening of the optic (TO) branch at long wavelength ($\xi=0$), there is a substantial lowering of the acoustic (TA) mode frequencies. This anomalous behavior of the acoustic vibrations was somewhat unexpected and not detected by ultrasonic velocity measurements of the slope of the branch at $\xi=0$. Analysis shows, however, that this behavior is the natural result of a coupling of the optic and acoustic excitations, which in centrosymmetric crystals vanishes as $\xi \rightarrow 0$ and leaves the limiting acoustic velocity unaffected. If a critical magnitude of the coupling strength is surpassed, further lowering of the temperature results not in an instability of the long-wavelength ($\xi=0$) TO mode, but in a more pronounced kink in the lower branch, which results finally in an instability of a mode of shorter wavelength ($\xi \neq 0$) and a mixed acoustic-optic character. The resulting phase can be characterized as antiferroelectric or microtwinned ferroelectric, depending on the magnitude of the characteristic wavelengths involved.

Scattering of a beam of particles by a periodic crystalline solid is subject to interference effects which cause the intensity of the scattering to vary with scattering angle (momentum transfer). A systematic study of such intensity variations for elastic (Bragg) scattering yields information concern-

Figure 38. Comparison of the calculated and observed $q(=2\pi/\lambda)$ dependence of the optical (TO) and acoustic (TA) phonon frequencies in KTaO_3 . There is a pronounced temperature dependence of the dispersion of the TA modes. The limiting slope at $\xi=0$ is temperature independent and in agreement with ultrasonic velocity measurements.

ing atomic positions in the solid and forms the basis for neutron (or x-ray) crystallography. It is less generally appreciated that the intensity variation of *inelastic* neutron scattering from various excitations in solids provides, through similar analysis, a direct description of the *atomic motions* associated with the excitation. The advent of very high flux reactors such as the HFBR and the development of increasingly efficient techniques for their usage have recently made this new "dynamic crystallography" a reality. The atomic displacements occurring in the normal vibrational modes of several ferroelectric oxides and their fluoride counterparts have been studied by this method with overall precision to within $\pm 15\%$. Hitherto such information was obtained only by constructing a model involving empirical sets of interatomic forces which were adjusted to agree with the observed vibrational frequencies. The atomic displacements could then be determined for these model forces. In addition to involving an artificial intermediate construction, this method requires the measurement of

many vibrational frequencies, even if primary interest lies in the behavior of one or a few vibrational modes. In the direct method, the study can be limited to the modes of interest, which is a distinct advantage in complex structures with many branches in the vibrational excitation spectrum. Entirely different results, reflecting the differences in the local dipolar fields and having implications concerning the stability of perovskite ferroelectrics, were obtained for the oxides and the fluorides.

Mg_3Bi_2 is typical of a number of alkaline-earth semimetal alloys that form the 3 to 2 stoichiometric unit in the solid. The melting point of the compound is typically several times the melting point of either of the pure components. The resistivity of the melt near the stoichiometric composition falls by several orders of magnitude with the addition of an excess of either component. Neutron diffraction patterns were observed on liquid Mg_3Bi_2 at two temperatures above the melting point of 823°C . The pattern is insensitive to temperature and quite different from the usual pattern. The usual first liquid peak is absent and the scattering is almost isotropic. Analysis is proceeding on the basis of two liquid models. The first model is that of a liquid of Mg_3Bi_2 molecules, while the second is that of a random homogeneous liquid-binary alloy whose components have vastly different atomic sizes.

Recent experiments in the slow-neutron chopper program included investigation of crystal-field levels in paramagnetic, rare-earth metallic and semimetallic compounds, particularly compounds of Pr^{3+} . The magnetic properties of ions such as Pr^{3+} are known to be significantly modified by the electrostatic-crystal fields produced by neighboring ions. In insulators such modifications are commonly investigated by optical spectroscopy. Almost nothing was known of crystal fields in metals, however, because photons do not penetrate sufficiently to produce observable effects. Neutron spectroscopy has also been applied successfully to the investigation of nonmetallic rare-earth compounds, and it has now been shown that this technique can be equally successful in metals; this opens up a new area of exploration. Pr^{3+} is expected to have a low-lying group of four energy levels which result from the splitting of the $^3\text{H}_4$ manifold of the ion by the crystalline electric field. Transitions induced between these levels by the incident neutrons are readily observable in the spectrum of the scattered neutrons, and the order of spacing of the levels can be determined with reasonable accuracy. From

such data considerable information concerning the environment of the magnetic ion can be derived. Thus far work has been done on the Pr^{3+} compounds PrBi , PrTe , PrSb , PrSe , and PrS , which all crystallize with the rock-salt structure. The data for each case show evidence of the expected crystal-field levels with spacings that depend sensitively on the distance of nearest-neighbor ions. In some spectra there is also evidence for relaxation effects in the form of line-widths that vary with temperature.

Crystal Imperfections

The experimental study of defects in crystals is another major research activity in solid state physics. Particular emphasis is placed on investigations of charged-particle interactions with crystals and of the formation and subsequent behavior of lattice defects. The program concerned with electron transport properties of organic crystals has become an important part of the overall research effort.

A study has been made of the trapping of triplet excitons by dislocations in high-purity anthracene. The dislocations were generated by plastic bending, and the trapping properties of these defects were obtained from measurements of the delayed fluorescence intensity and triplet lifetime as a function of temperature from 4° to 400°K . Plastic deformation introduced only one kind of trap effective over this temperature range, with a trap depth of 0.3 eV. The trapping cross section is about three orders of magnitude smaller than the geometrical cross section, which implies that a large fraction of the excitons arriving at a trapping site are not trapped. The trapping effects are eliminated by a 1-hr anneal at 340°K . The interpretation is that at this temperature the dislocations migrate to small-angle grain boundaries at least one triplet diffusion length ($\approx 10\ \mu$) apart, so that most of the triplet lifetime is spent in dislocation-free material.

The first measurements made in the new high-intensity ^{60}Co γ -ray irradiation facility for studying radiation effects directly during irradiation produced several new results. Previously, studies on the coloring of nonmetals by radiation, which is one of the most useful techniques for determining how radiation affects transparent solids, were made by irradiating samples in a reactor or an x-ray or γ -ray source and then transferring them to a spectrometer for optical absorption measurements. Thus, the absorption measurement was made some time after the sample was irradiated. In the new facility the absorption is measured during irradiation. In

Figure 39. A simulation, using the apparatus for making optical absorption measurements during irradiation, showing the type of growth curve obtained by irradiating a KCl crystal in an x-ray or γ -ray source and then transferring the sample to a spectrophotometer. The sample was alternately irradiated at 10^5 rads/hr for 30 min and then allowed to decay for 30 min. Thus, if the growth is not measured during irradiation, a reproducible growth curve would be obtained only if the irradiation and measurement times were precisely controlled. The dashed line has not been extended to the origin, to emphasize that its position is a sensitive function of irradiation and measurement history.

addition, the source can be turned off (by inserting it into a lead shield) in ≈ 2 sec while measurements continue. In the initial experiment, the growth and decay of F-centers in Harshaw KCl single crystals were studied. The samples were irradiated at dose rates of 10^5 rads/hr at room temperature. The F-center vs dose curves obtained during irradiation differ considerably from the published curves, which were obtained by irradiating the samples and then transferring them to spectrophotometers for measurement, as illustrated in Figure 39. The initial coloring rate is at least ten times higher, the transition from the initial rapid rise to the plateau occurs in a much shorter time, and the plateau is about twice as high. Furthermore, when the irradiation is terminated the coloring drops abruptly during the first 30 min and more slowly thereafter. About half of this decay occurs in the first 2 to 3 min. The growth and decay curves can be very accurately described by simple mathematical expressions, growth by a sum of one linear term and three saturating exponential terms, and the decay by the sum of four decay-exponentials.

A major improvement in the experimental method for making thermoluminescence measure-

ments was put into routine use. It is now possible to analyze complex systems which heretofore had not been resolved by conventional techniques. The improved method employs a computer for both data acquisition and limited on-line control of the experiment. This has made it possible to record the emission spectrum at 5-Å intervals between 2000 and 7000 Å once during each second while the sample temperature is increasing $\approx 10^\circ\text{C}/\text{min}$. The data are processed on the CDC 6600 computer by a procedure that includes all the necessary corrections, such as wavelength calibration and system response. One of the outputs obtainable is a "three-dimensional" ("3-D") graph showing luminescence intensity vs both the wavelength of the emitted light and sample temperature (see Figure 40). These plots have been particularly useful as starting points for determining the kinetics of thermoluminescence. The techniques described above were used to obtain a complete characterization of the thermoluminescence exhibited by KCl crystals doped with thallium. Spectra were determined from samples that had been subjected to γ -ray doses ranging from 10^5 to 10^8 rads. The "3-D" plots indicated that curves of intensity vs temperature through the emission band maximum at 4.0 eV would be free of interference from the longer-wavelength peaks and would be the ones most susceptible to analysis. Analysis of the curves obtained in this way showed the following. First, they all could be analyzed by using simple first-order kinetics without invoking any complicating factors, such as retrapping. Second, all the 4.0-eV glow curves were found to consist of varying contributions from seven distinct traps which could be clearly characterized. Third, as the γ -ray dose is increased, the maximum-intensity glow peak shifts from low to high temperature and then decreases in intensity. Fourth, some of the glow peaks were identified with other processes, e.g., F-band bleaching and the restoration of the TI^+ absorption bands. It should be emphasized that previous attempts to analyze KCl:TI glow curves made by conventional methods were subject to invalidating interference and that reliable results were obtained only after the "3-D" technique had been successfully developed.

The angular correlation of positron-annihilation radiation originating in electron-damaged or plastically deformed samples of Fe, Ni, and Pt was measured. The samples were irradiated with 2.5-MeV electrons at 95°K or were plastically de-

Figure 40. A "three-dimensional plot" of the thermoluminescence from a KCl:Tl crystal containing ≈ 100 ppm Tl⁺, after it had been exposed to a dose of 3×10^7 rads of ^{60}Co γ rays. The sample was heated linearly at $\approx 10^\circ/\text{min}$. Each line parallel to the wavelength axis represents 32 scans, at a rate of 1 scan/sec, of a grating spectrometer. The intensity vs wavelength information for each scan is stored in a small computer programmed to accumulate data with use of well-established "signal-averaging" techniques. The 32 scans, representing a temperature interval of $\approx 5^\circ\text{C}$, are then stored on magnetic tape. Each "glow spectrum," consisting of $>66,000$ individual points, is processed on a large computer. This procedure includes the normalization and calibration corrections and preparation of the three-dimensional plots. The perspective may be altered readily to obtain views that emphasize the dependence on either temperature or wavelength.

formed by cold-rolling at room temperature. Both treatments induce similar changes in the angular correlation distribution. These are interpreted as being due to an increase in the probability of positron annihilation with conduction electrons in the vicinity of lattice vacancies. Stepwise annealing studies of the specimens after irradiation or deformation indicate that the major part of the effect on the angular correlation can be attributed to a nonequilibrium concentration of vacancies, although dislocations also appear to play some part in plastically deformed specimens. Whereas the radiation-induced effect vanishes after heat treatment at 400°C , some of the deformation effect persists above this temperature.

Logarithmic decrement and dynamic modulus measurements were made on pure single-crystal

and polycrystalline platinum following 2.5-MeV electron irradiation near helium temperature. No interstitial reorientation peaks were found in the stage I region at the frequencies used (≈ 200 Hz). Evidence for the beginning of a peak was found just above room temperature. An enhancement of a background dislocation peak at 75°K after a low-dose irradiation can be interpreted tentatively as depinning due to interstitial diffusion along the dislocations. Following a heavy dose at $\approx 100^\circ\text{K}$, several new peaks were seen between 200° and 300°K . These are thought to be orientation peaks of interstitials trapped at impurities.

Some experiments were carried out, in collaboration with the Lawrence Radiation Laboratory at Livermore, to compare electron-radiation damage in ^{232}Th with self-damage produced by doping the sample with ^{228}Th . Only stage I has been investigated by means of electrical resistivity recovery experiments. Isochronal recovery data were obtained following a low-dose irradiation at $\approx 12^\circ\text{K}$ and following a similar irradiation which was preceded by a heavy-dose irradiation at $\approx 170^\circ\text{K}$ to introduce vacancies. This vacancy-doping experiment did not affect the proposed stage I(e) recovery peak, which suggests that this peak must be interpreted in some other way, since long-range migration should be altered by doping. In general, recovery following electron irradiation is somewhat different from that following α -particle damage arising from doping with ^{228}Th .

During the past year considerable interest has developed in the United States and throughout the world in the nature of switching phenomena in materials undergoing metal-insulator transition. This switching is observed by biasing a suitable sample with an electric field. The current through the device is found to increase smoothly with applied voltage up to some critical value, at which point a rapid transition occurs and the impedance throughout the device decreases substantially, often by more than an order of magnitude. In studies carried out at Brookhaven in cooperation with Fordham and Yeshiva Universities, a simple thermal mechanism was found to explain quantitatively the switching process in magnetite. Magnetite undergoes a phase transition at 121°K . Below this temperature the material behaves as a semiconductor, whereas above 121°K it behaves as a poor metal. The increase in the sample's resistivity at the transition is responsible for the sharp switching characteristics. The occurrence of a threshold volt-

age and negative resistance, and other observations on switching in magnetite, can be semi-quantitatively understood in terms of a self-heating model in which Joule heating provides local self-heating. From the model the variation of the switching voltage with the sample temperature and the temperature distribution within the sample can also be derived. Mössbauer measurements on magnetic samples verified qualitatively the calculated temperature distribution. These experiments, together with the calculations, demonstrate that, at least in the case of magnetite, Joule heating is sufficient to explain the observed switching phenomena, and no exotic or complex theories are required. In any experiments designed to demonstrate complex effects, it is now clear that it will first be necessary to show that Joule heating alone is incapable of describing the observation.

Low-Temperature Studies

The magnetism of solid ^3He is of considerable interest because this solid may be the experimental system that most nearly behaves like a Heisenberg magnet, for which the theory is very highly developed. At present it is not possible to cool solid ^3He to the ordering temperature of about 10^{-3}°K . However, much can be learned at higher temperatures. The strength of the exchange interaction that leads to magnetic ordering is known from nuclear magnetic resonance relaxation data and from precise pressure measurements. These data, however, do not give the sign of the interaction, which determines whether the ordering will be ferromagnetic or antiferromagnetic. The sign of this interaction can be obtained from susceptibility measurements. Previous attempts by other workers to determine the sign of the exchange interaction in this way have been inconclusive because of the presence of ^4He impurities and because the measurements were not carried to low enough temperatures with sufficient precision. An apparatus using dilution refrigeration and adiabatic demagnetization was developed which can attain a temperature of 0.005°K and maintain the temperature below 0.010°K for more than a week. Measurements of the nuclear susceptibility of solid ^3He have been carried out successfully. The sign of the exchange interaction was found to be such as to lead to antiferromagnetic ordering. This is in agreement with most recent theories of solid ^3He . The strength of the interaction and its variation with pressure were

found to be in agreement with the precision pressure results.

Recent work in superconductivity has been concerned with the properties of very thin films of superconducting materials. Ultrathin films are of particular interest, since Ginsburg has suggested that by making alternating layers, only a few monolayers thick, of metals and dielectrics it might be possible to attain high-temperature superconductivity by an electron-electron attraction mediated by excitons in the dielectric. To learn how to make ordered films only monolayers thick, a program of low energy electron diffraction and Auger spectroscopy was started. Equipment was constructed to permit these measurements to be made on films being held at cryogenic temperatures. This apparatus has been used to prepare and study 100-Å layers of Nb_3Sn on bulk niobium, with the result that very thin Nb_3Sn coatings can be easily made on the walls of superconducting niobium accelerator cavities, with possible improvement of the cavity performance because of the high Nb_3Sn transition temperature. Other work on cryogenic films has involved studies of the transition temperature (T_c) of transition metal films deposited on cold substrates and of very clean cryogenic films, and the effects of dielectric overlays on the T_c of the metal underneath.

Initial work by Glover at the University of Maryland and here at Brookhaven has shown that the nature of fluctuations within superconductors can be quantitatively studied by carefully monitoring the resistive transition. Recent work at Brookhaven on the resistive transitions of thin films of lead and aluminum revealed fluctuation contributions that are logarithmically divergent, with a cutoff proportional to the strength of the depairing interaction, i.e., an interaction that limits the lifetime of electrons condensed in the ground state. This, the first experimental evidence for divergent fluctuations in two-dimensional systems, confirms theoretical conjectures that fluctuations within many two-dimensional systems (thickness $\ll$ coherence length) would diverge, which would preclude the existence of long-range order in such systems.

The Solid State Physics Group takes an active part in a joint program on superconductivity involving members of the Metallurgy and Materials Science Division of the Department of Applied Science. Further research in this area is reviewed in the section on Applied Science.

Theory

The calculation of spin correlation functions in magnetic systems at high temperatures is of importance in the understanding of slow-neutron scattering by magnetic materials and is of interest from the point of view of statistical mechanics. A method developed for the self-consistent calculation of these functions is based on the idea that at high temperatures a spin in a ferromagnet moves in an effective fluctuating field due to its neighbors. The approximation used allows expression of the correlation function for spins in terms of the correlation function for the field. Since the field is produced by spins equivalent to those under consideration, a self-consistent relation is obtained. Solution of the equations for the correlation function was carried out numerically. The results are in excellent agreement with computer simulation studies and indicate that the method may be useful in similar many-body problems.

In an isotropic ferromagnet the magnetization is fully saturated at zero temperature. In a uniaxial (easy axis) ferromagnet, magnetized *perpendicular* to its easy direction by the application of a large external magnetic field, zero point deviation is present. The longitudinal susceptibility, which gives the linear response to an oscillating magnetic field parallel to the magnetization direction, is a direct measure of the zero point fluctuations. Resonant structure was found in both the long wavelength susceptibility (the microwave response) and the large wave vector susceptibility (the neutron scattering amplitude) due to excitation of pairs of spin waves with equal and opposite momentum at zero temperature. In addition, there is a small but finite amplitude for direct coupling via neutron scattering to the two spin wavebound states, even at zero temperature.

The study of two-dimensional classical Heisenberg ferromagnets was completed. The work involved inspection of square planar arrays of up to (45 by 45) 2025 spins. Monte Carlo studies of the magnetization of the system were made on the CDC 6600 computer. The Monte Carlo results were poorly convergent because of the low connectivity of the lattice, and difficulty was encountered because the "short-range" magnetic order in the lattice was as large, or larger, than sample dimensions. A ferromagnetic state does not exist for such a two-dimensional system, but there have been conjectures that some new state of magnetic

order arises. These difficulties make rigorous conclusions impossible; nevertheless it is thought that some new state of magnetic order, with its attendant phase transition, does exist in such a system.

The magnetomechanical ratio g' of an ion is the ratio of its magnetic moment to its angular momentum, while the g -factor measures the energy splitting of an ionic state in a magnetic field. In free ions these quantities are identical, but in a solid the surroundings exert forces on the ions and the two quantities are different. An approximate relation between them was derived some years ago by Kittel and Van Vleck. This has been generalized and an exact relation found. Examples illustrating the validity of the relation are now numerous.

Tritiated lithium hydride presents an interesting radiation damage problem, since the damage arises from self-irradiation. Tritium decays into a neutral helium atom and an energetic electron (β decay). Changes in properties occur because of the replacement of the normal negative constituent of the ionic crystal by He^0 , and further damage is to be expected from the energetic electrons (average energy, 5.6 keV) and recoil helium atom (average energy, 1 eV). At low temperature the most outstanding feature of the damage is the considerable volume expansion of the crystal. In a cooperative study with Queens College of the City University of New York the characteristics of a variety of defects were investigated theoretically on the basis of the polarizable point-ion model. From the energies of the defects and from the local atomic distortions around the defects, certain conclusions can be drawn which are highly suggestive as to the mechanism of the volume expansion. The results indicate that the helium atoms do not distort the lattice sufficiently to account for the volume expansion. One of the several species of interstitial lithium is most likely responsible for the volume expansion, since these defects cause sufficiently large distortion to explain the experimental data. The suggested sequence of events is as follows. A tritium ion undergoes β decay and the recoiling helium atom collides with one of its six nearest-neighbor lithium ions and transfers some of its energy. The lithium ion is pushed into an interstitial position, and the helium atom probably becomes trapped in the remaining divacancy.

Empirical interatomic potentials play an important role in theoretical lattice-defect calculations. The relevant factors that must be considered for

the empirical fitting of a two-body interatomic interaction to the elastic moduli and phonon dispersion relations were investigated. It was shown that for nickel and copper, no more complex interaction than a near-neighbor central force need be used. There is, however, no unique way to determine an appropriate potential from perfect-lattice data alone, since the interaction must be known at distances that do not occur in the perfect lattice for the calculation of lattice-defect properties. A set of three potentials for copper, which are all equivalent for the perfect lattice, was used to investigate the sensitivity of vacancy and interstitial formation and migration energies to the details of the potential. Vacancy calculations were not very sensitive. The relative formation energy of different defect configurations varied with the potential for interstitials. In all cases, however, the migration energy remained small. Although the detailed results are dependent on variations in the interactions, the overall picture presented by the calculations is unchanged – vacancy migration energies equal to or slightly less than formation energies, large inter-

stitial formation energies, and small interstitial migration energies.

Recent analysis showed that of the three measurements, x-ray lattice parameter changes, volume change, and length changes, only the first provides unambiguous information on the number of atoms (or vacancies) existing in the form of prismatic dislocation loops. The total strain produced by prismatic dislocation loops is essentially equal to the number of atoms or vacancies residing in the loops. In a sample containing no internal voids, this strain is cancelled by the number of new sites created or destroyed at the free surface, so that no net volume change is produced by the loops except that possibly due to the core volume of the dislocations. However, if internal voids exist, ambiguous volume and length changes can occur. On the other hand, x-ray lattice parameter changes are determined only by the total strain, which is independent of voids, etc. When this strain is corrected for the volume associated with the dislocation cores, the number of atoms or vacancies residing in loops can unambiguously be determined from lattice parameter changes.

High Energy Accelerators

The Accelerator Department is responsible for the operation, maintenance, and improvement of the 33-GeV Alternating Gradient Synchrotron (AGS). In addition, the Department takes part in the development of the experimental beams, plans the logistics, and designs and procures the sophisticated apparatus required by the program. It is continuing its efforts in the conversion of the AGS to a higher intensity machine with increased experimental capability and in the development of new ideas for accelerators and means for their exploitation.

ALTERNATING GRADIENT SYNCHROTRON

The number of experiments that can be run concurrently at the AGS increased during the year. This is mainly the result of a simultaneous mode of operation of the AGS in which an internal target intercepts the circulating proton beam while the slow external beam (SEB) system is in operation. This technique provides for significantly expanded AGS utilization, especially with the higher beam intensities now achieved on a routine basis.

Construction of the SEB switchyard has progressed satisfactorily. The 0° beam line to an additional external beam target station in the new Experimental Building Addition has been completed. Major emphasis has been placed on further development of various modes of fast beam extraction to be used in conjunction with the planned North Experimental Area bubble chamber complex and the development of operational modes allowing fast beam extraction simultaneously with beam extraction via the slow beam channel. The activities of the AGS Division in operation of the facility, accelerator studies, and further development of the accelerator are summarized below.

Operation

During the first part of fiscal 1970 the AGS was inoperative because of major construction programs associated with the AGS conversion effort. Immediately following the shutdown, operational difficulties were encountered with the new central

rf drive system. Partly as a result of this the AGS operated initially with beam intensities somewhat lower than pre-shutdown values. Most problems were eliminated relatively soon, and machine intensity increased steadily to 15% above that achieved in calendar 1969 (see Figure 1). The pronounced increase in average accelerated beam intensity in the first half of calendar 1970, as shown in Figure 2, reflects the increased demand for higher proton beam intensity rather than an increased total number of protons, since the AGS had been running at intentionally reduced intensities during periods in 1968 and 1969. Utilization of the AGS is shown in Figure 3. The general reliability of the AGS has remained approximately constant. During the first half of 1970 the amount of unscheduled shutdown time was normal (Figure 4 and Table 1), and the weekly utilization efficiency (Figure 5) showed improvement until May and June, when there were major failures in the preinjector and rf systems.

The average number of experiments involving data taking or equipment testing during any one period continued to increase (see Figure 6), primarily as the result of simultaneously operating the SEB system and associated beam spill from an external target with beam interception on the internal G-10 target. This mode of operation was achieved by installing additional high field orbit bumps, an improved G-10 spill servo system, and SEB monitoring and control instrumentation. The utilization potential of the AGS has increased significantly, since the internal targeting is limited to proton fluxes of $< 1.5 \times 10^{12}$ protons/pulse and the total AGS intensity is normally $> 2 \times 10^{12}$ protons/pulse.

After completion of the major shutdown, AGS performance and, specifically, fast external beam (FEB) extraction efficiency were adversely affected by an uncorrelated bunch-to-bunch position variation resulting from induced incoherent synchrotron oscillations related to beam-rf cavity interaction. In addition, when reconnecting the AGS magnet system in two symmetrical halves relative to the magnet power supply, beam closed-orbit

Figure 1. Weekly average beam intensity of the AGS, January - June 1970.

Figure 2. Yearly average beam intensity of the AGS, calendar years 1966-70.

Figure 5. Weekly efficiency of the AGS, January - June 1970.

Figure 3. AGS utilization during fiscal 1970. Sum of shaded areas represents scheduled operation time. Percentages refer to scheduled time, which is 45% of maximum possible running time.

Figure 4. AGS efficiency, calendar years 1966-70.

Figure 6. Average number of experiments being run on the machine at any one time, 1968-70.

Table 1
Machine Failures ≥ 5 Hours

Cause	Hr
Rf tuning and power supply failure	31
Magnet 241 ground short	9
Feeder power cable short	5
Main MG set motor overcurrents	10
Vacuum leak at rf station	14
Shorted coil, magnet B-11	16
Vacuum failure, E and G superperiods	9
Mercury contamination of preinjector high voltage column	71
Mercury contamination of preinjector	33
Rf final amplifier breakdown	16
Vacuum leak, superperiod A	6
Vacuum leak, superperiods F and G	9
High voltage breakdown at preinjector	14
Rf bypass capacitor shorts	69
Water leak, magnet F-11	12
Vacuum failure, rf station K	7

variations were encountered at injection field levels as a result of an unbalanced 360-cycle magnet-current ripple component, which also unfavorably affected the SEB spill modulation. Prior to commissioning of the new power supply, this problem was partially solved by temporarily using the magnet low-level backleg windings in a balanced hookup with a 360-cycle current drive.

During the extended shutdown, in addition to completion of major construction items, a number of AGS subsystems were modified. Two sets of magnet backleg windings were installed. The first set is used for simultaneous operation of the internal (G-10) target and the SEB target. The second set was installed for use with an ultrathin electrostatic septum unit to improve the extraction efficiency of the SEB system.

Additional components installed include a rapid beam deflector (RBD) for improved beam spill performance for the 80-in. bubble chamber and a remotely adjustable beam collimator in the SEB channel to reduce background for critical secondary-beam experiments.

During the shutdown the three AGS wells were acid-cleaned and reconditioned. The pumps in each well showed signs of excessive wear and new pumps were installed. Two 1000-gal/min pumps and a 6-MW cooling tower were installed in the West Experimental Area to provide cooling for beam transport equipment. A new cooling system,

consisting of three 1000-gal/min pumps, a 12-MW cooling tower, piping, and controls, was installed in the East Experimental Area. In addition, an air system containing two 50-SCFM compressors with their associated aftercoolers, dryers, and receivers was installed in the same area and is now in operation.

As part of the continuous radiation safety program, the AGS Health Physics Group converted a high-speed multipurpose radiation monitoring system from ring monitoring service to beam-cave monitoring service. In-cave monitors have been installed in two linear accelerator (linac) security areas and in the SEB primary cave.

The total radiation exposure of Accelerator Department personnel in fiscal 1970 was about 270 Rem, or about half that of the previous year, a reduction attributed to the extended shutdown.

Accelerator Studies

Since start-up of the accelerator in January, a significant part of the accelerator study effort has been devoted to the investigation of intensity-dependent incoherent synchrotron oscillations. This instability is characterized by the execution of position and shape oscillations by the 12 proton bunches independently of each other or in subgroups of three. The result is to increase the phase-space area needed for synchrotron oscillations and hence to increase the momentum spread and size of the beam. At high intensities ($>2 \times 10^{12}$) some beam loss at transition is almost unavoidable, while the FEB is made less reliable and somewhat inefficient even at modest intensities ($>8 \times 10^{11}$). Based on a theoretical analysis of the total beam-cavity system, a modification to the rf cavities was designed. Prior to making this modification, a set of bus bars had been removed from half of the ring cavities and the beam-cavity interaction had disappeared. Removal of the bus bars from the remaining cavities caused the phenomenon to reappear. The system was then operated with the bus bars removed from half of the cavities. A staggering of higher-mode resonance frequencies accounts for this peculiar effect. Incorporation of the completely redesigned cavity connection scheme resulted in the elimination of the interaction effect at present beam operating intensity.

The study of low magnetic field corrections in the AGS involved the continued search for correlation of the cause and effect of intensity loss due

to beam behavior near injection. Continuous updating of the low field corrections is needed to regain the full intensity performance of the AGS. This behavior is not yet clearly understood, and further study is required to reach the full AGS beam intensity potential.

Studies continued of the measurement of closed-orbit perturbations in the AGS. A computer program was developed which not only calculates the closed orbit from pickup electrode measurements but also locates the associated orbit perturbations. In addition, more precise measurements of the beam momentum spread were carried out.

Much of the accelerator study effort is concerned with the improvement of SEB and FEB ejection performance. The emittance of both the SEB and an FEB that was brought out in the slow beam channel was measured by obtaining beam profiles of the extracted beam in the F-10 T-channel. The

method involved computer readout of signals from an array of 12 insulated plates for various settings of a quadrupole lens upstream from the array. The beam widths were obtained from a computer fit to the profile data, and the resulting data for width versus quadrupole strength were fitted to an expression relating width to the phase-space ellipse parameters.

Studies of stimulated resonant extraction, which may have operational significance for the North Area beam, have been performed. In these tests, the $\frac{1}{3}$ -integral SEB resonant spill rate was enhanced by (1) energizing an RBD, which resulted in a $\frac{1}{2}$ -msec spill duration with extraction efficiency $\approx 50\%$ of the normal SEB efficiency, (2) pulsing a ring quadrupole, and (3) allowing the beam to move rapidly through the resonance radius at the end of the AGS flat-top, which resulted in a 5-msec spill with efficiency $\approx 25\%$ of

Figure 7. Installation of slow beam variable-aperture collimator.

normal SEB efficiency. These extraction mode options are in addition to the fast-kicker-induced resonant spill studied previously. Further studies to obtain quantitative data on the quadrupole-induced extraction method are in progress.

Calculations indicate that an alternate set of four "driving" sextupoles for the resonant extraction mode will yield a more favorable separatrix orientation for the present SEB components and will make possible a high-efficiency resonant extracted beam in the North Area. The calculations also show that the new sextupole configuration allows the position of the F-10 ejector magnet to be moved further outside the AGS aperture. Initial studies with the alternate sextupole set are yielding favorable results.

Accelerator Development

Synchrotron Components. A remote-controlled, variable-aperture collimator (Figure 7) has been constructed for the SEB system which will intercept the beam "halo" and allow a well-defined beam to be delivered to the target.

A new radiation-hardened target airlock capable of supporting two standard motors has been designed. The dynamic seals are of the bellows type where translation is required, and a harmonic drive where rotation and torque are to be transmitted through the vacuum chamber wall. In conjunction with the airlock development program, a new target-position readout system has been devised to allow placement of the target-position electronics package, whose components are sensitive to radiation damage, 20 ft upstream of the airlock in an area shielded from radiation rather than at the present 8-ft position.

Two vertical-bump magnets 20 in. long with a 6×6-in. aperture have been designed and are being fabricated. These magnets will produce an orbit deformation at the septum and ejector magnet locations of the SEB in the magnet ring and allow for greater extraction efficiencies even if the vertical orbit drifts.

Final design has been started on the new magnet inflector for 200-MeV injection. It is capable of a 200-mrad bend of the injected beam and is designed for beam stacking in the vertical and horizontal planes.

The prototype "elliptical" quadrupole magnet has been thoroughly tested. This unit was designed as a low field correction quadrupole for ν -value control near injection. However, since tests indi-

cate that higher peak currents are tolerated, it will also be used for fast variation of the ν value during transition.

New power supplies to energize the superperiod sextupoles at high field have been fabricated. Calculations show that the variation of machine tune with radius can be eliminated with this technique and "constant- ν " resonant extraction will be possible. The method's principal advantages are smaller horizontal SEB emittance and elimination of momentum variation with time in the SEB spill.

A remote-control system for the central rf system was constructed which eliminates the need for an operator in the new Rf Building. The main control room was reorganized to accommodate the increased quantity of hardware. Controls were divided into primary and secondary groups, depending on usage. The primary controls were consolidated in the existing control area, and the secondary controls were moved to a new area above the main control room. The electronic "peaker" system was replaced by a magnetic field discriminator, which will function with a very slow rate of magnetic field. A resistor matrix constructed for reduction of the magnet ripple voltage will make it possible to "null" individual ripple frequency components. New power equipment was designed for the quadrupole and sextupole magnets in order to reduce spill intensity modulation of the SEB. Similar components are being constructed for the improved G-10 spill control system.

Development of the newly designed fast kicker for the North Area FEB system, which will also facilitate multipulsing for bubble chambers, has progressed well. A prototype unit has successfully demonstrated adequate current rise and fall times into a dummy load. Lumped energy storage equipment has arrived on site which will permit testing with the long pulse width necessary for total fast extraction of the AGS beam.

Electronic interface equipment has been installed to connect the two PDP-8 computers in the AGS control room with the BROOKNET general laboratory computing system and thus greatly expand the AGS on-line computer capability. A prototype "single-wire" remote-control and data-acquisition system has been constructed and is being tested. This system will be incorporated in the SEB switchyard system.

Slow External Beam. Development of the SEB switchyard system is continuing. A 0° beam-line extension of the external channel to a new target

station (C) in the East Experimental Building Addition has been completed. In addition to the magnets and power supplies required for beam transport, the equipment includes vacuum beam pipe and pumps, television stations with instrument boxes and actuators, radiation plugs and shields, and a target turret for the C target station.

To facilitate SEB targeting in air, a 6-station, remote-controlled, automatic indexing turret was incorporated at target stations A and C. The turret can be indexed, clockwise or counterclockwise, to an adjacent target position in one machine cycle. The individual targets can be rapidly replaced manually, or the entire 6-station turret head can be quickly removed and replaced.

To obtain a more accurate beam profile, two emittance-measuring devices have been built and mounted on linear actuators. The first consists of 24 beryllium signal plates stacked alternately between 25 tantalum bias shield plates. Since this array occupies the same space as the original 12-plate array, the proton beam interacts over twice as many signal plates and a more accurate beam profile can be made. The second device consists of 24 fingers mounted on an insulated, rotatable plate and shielded by 0.002-in.-thick aluminum bias plates. By optimizing the angle that the 24-finger array presents to the proton beam, the beam can be made to interact over the entire array. The array can be rotated remotely from the control room and retracted from the path of the beam when not in use.

To obtain a spatial resolution of 1 mm over a large sensitive area (typically, 15 cm), a third beam profile device has been designed, with use of the crossed-field "commutator" principle as developed at CERN. Because the instantaneous current of the external beam is low, an ultrathin metal screen serves as a target and collects the γ rays. In addition, an improved, autoradiograph type of profile monitor has been built to be used with small-diameter beams. For a recent experiment, the user's requirement for a small horizontal beam size at target station A was satisfied by providing a beam measuring 0.040 in. horizontally and 0.060 in. vertically.

Extraction efficiency of the SEB system is still about 80%. Recently, performance has suffered somewhat from a low-frequency ripple (mainly 720, 360, and 180 Hz) modulation of the spill, somewhat larger than previously experienced. The increased modulation is due mainly to a resonance

in the AGS ring resulting from the additional capacitance introduced by the cabling for the Siemens motor-generator power supply added during the last shutdown. The amplitude of the resonant component of the main magnet current was decreased, and additional filters are being installed on other SEB power supplies which also contributed to the beam modulation.

An electrostatic septum consisting of a 90-in.-long array of 0.001-in.-diam tungsten wires has been designed to improve SEB extraction efficiency. Calculations indicate that a wire septum installed in straight section H-20 and operated at a field of 100 kV/cm will provide sufficient displacement of the SEB at the existing F-5 septum to eliminate the present $\approx 15\%$ loss at this location. The extraction efficiency expected with the new septum is $\approx 98\%$. Tests with a prototype electrostatic septum show that a field of at least 100 kV/cm can be maintained with $\approx 1 \times 10^{12}$ protons/sec traversing the septum. Backleg winding coils have been installed on selected AGS magnets to provide an orbit deformation for the H-20 septum.

New SEB extraction magnets to accommodate the larger beam emittance expected after the 200-MeV linac is operational have been designed. The new 50% duty cycle F-5 septum magnet with vertical aperture of $\frac{5}{8}$ in. is being assembled. The power supply for the F-10 ejector magnet has been modified by addition of transistor banks and cooling to improve reliability for the 50% duty cycle.

Studies of close-coupled shielding of external targets have been made with nearly contiguous side shielding consisting of layers of steel for attenuation of high energy secondary particles, lead to shield from any residual activity of the steel, hydrogenous material to moderate and thermalize neutrons, and boron to absorb thermal neutrons. Such a shield will reduce the radiation levels during operation and prevent activation of the tunnel walls; thus the target area will be more habitable for workers when the target and close-coupled shield are removed. Since proper design of this shielding requires detailed knowledge of the attenuation in steel of high energy secondary particles, experiments have been conducted using a large array of steel bricks interleaved with polyethylene foils in which carbon activation was assayed.

Efficient utilization of the AGS when it is operating with higher beam intensities will depend strongly on the ability to distribute protons over a

larger number of external target stations in a simultaneous fashion. To this end a beam splitter has been designed for the slow beam 0° beam line to permit simultaneous operation of target station C and future target station B. The splitter consists of a 2-channel electrostatic septum unit, septum thickness, 0.001 in.; a 2-channel magnetic septum unit, septum thickness, 0.020 in.; and a 2-channel superconducting septum unit, septum thickness, 0.350 in. A full cross-section, $\frac{1}{6}$ -length model of the superconducting splitter magnet has been built for evaluation purposes.

Fast External Beam. The beam transport optics have been developed for the North Area (H-10) complex. Provision has been made for a transmission target as a source of secondary particles for the rf separated beam facility in this area. Construction of the first part of the beam, including an aperture through the AGS tunnel wall in the H-10 area, an earth-shielded transport tunnel, and the concrete pad for the switchyard, was completed during the 1969 conversion shutdown.

Development continues on extraction components for the H-10 beam. The thin-septum ($\frac{1}{16}$ -in.) ejector magnet has been released for fabrication, and a $\frac{1}{4}$ -length prototype is being assembled for testing. A radiation-hardened vacuum box for the H-10 magnet has been designed. A prototype ultrathin (0.003-in.) magnetic septum was fabricated and tested for use at H-5 in a fast ($\frac{1}{2}$ -msec) extraction mode planned for the North Area. The $\frac{1}{4}$ -length prototype of a new fast kicker for the H-10 beam has been life-tested at full rated voltage. The four final tube assemblies are complete, and a vacuum box is under construction to allow testing of the vacuum feedthroughs.

Improved concepts of shielding long, target-free, external beam sections have been developed. These include provision of sufficient shielding for normal, low beam loss operation, and a fast redundant system of interlocks and radiation sensors that abort AGS beam extraction in case of anomalous localized beam spills in the external beam lines.

EXPERIMENTAL PLANNING AND SUPPORT

Additions to substantially increase the experimental program were initiated this year. The development of the SEB and its extension into the new Experimental Hall constituted the major construction effort. Design of a future bubble chamber complex in the North Area is in the final stage.

Experiments around the AGS are concentrated in three major areas, shown in Figure 8. The largest is the East Experimental Area, which fans out from a 60° sector covering the F and G superperiods of the accelerator. It contains four charged-particle secondary counter-spark chamber beams and two bubble chamber beams in addition to the slow extracted primary proton beam. Nine counter experiments are set up simultaneously. The 80-in. bubble chamber, located in the North Area, is serviced by two separated charged-particle beams emanating from targets close to the I-10 straight section. The third area, the Neutrino Area, is in the Southwest Experimental Area, which receives protons from the B-10 section. The 7-ft bubble chamber is located here.

Experimental Facilities and Program

During the first half of fiscal 1970 the AGS was shut down for the first phase of the conversion project. This shutdown made possible major changes in the configuration of beams for counter experiments in the East Experimental Area. At target station A in the SEB the shielding was increased and modified in anticipation of AGS operation at 10^{13} protons/sec after completion of the conversion project. Two new ports were provided in the massive beam backstop for the residual proton beam from station A to make possible a greater variety of beams from the same target. The first, at 0° to the direction of the incident proton beam direction, provides a well-collimated, intense beam of neutral particles operating simultaneously with beams of charged particles from the same target. The second, at 2.5 in. above the proton beam axis and at an angle of 5° to the incident proton beam direction, allows the extraction of a diffracted proton beam of sufficiently low intensity to be useful for counter experiments. Operation of this port is compatible with extraction of a high energy negative particle beam in the 0° secondary charged-particle beam channel, beam No. 10. The beam configuration from target station A was further modified to provide an alternate branch at the downstream end of beam No. 10. This allows one experimenter to be setting up or modifying his apparatus while the beam is being utilized by another experimenter in the alternate branch.

Two neutron experiments using the same intense neutron beam in a tandem arrangement were set up on the new neutral beam port. In the first, experiment No. 411, a group from the University of

Figure 8. Experimental areas at the Alternating Gradient Synchrotron.

Michigan and Princeton University is studying the differential scattering cross section of neutrons from protons in a hydrogen target with higher precision than has been attained previously and over a wider range of 4-momentum transfer. In experiment No. 486, a second Michigan-Princeton experiment, set up in tandem with No. 411, the total cross section for neutron scattering from various elements will be studied. The precision of such an experiment is a function of the available distance from the scattering target to the detector, in this case a total absorption calorimeter. The availability of the new East Experimental Building Addition with its long beam runs has been a factor in significantly increasing the level of precision in such studies.

On the 0° charged beam (No. 6), the development and testing of the large array of magnets and wire chambers with their associated computer software for experiment No. 370 (BNL) continued throughout the latter half of the fiscal year.

Experiment No. 463, conducted by Northeastern University and the State University of

New York at Stony Brook, was set up on the new long branch of beam No. 10 and the taking of data was begun in a search for massive bosons with use of a missing-mass spectrometer technique.

Calculations and refinements of the beam optics and layout for the diffracted proton beam to experiment No. 396 (BNL) also continued throughout this period.

From the internal target station at G-10 a full program of counter experiments continued and a mode of simultaneous beam sharing between G-10 and the SEB was successfully employed at beam No. 6 (G-10 + 4.7° on the outside of the AGS ring). A group from MIT and Brown and Padua Universities completed an experiment to measure the backward angular distributions for charge exchange and η production in π^-p collisions. In a neutral branch of this beam a Princeton group performed an experiment to measure both the magnitude and phase of η_{00} .

At beam No. 5 (G-10 + 10° , the mass-enriched counter beam) two experiments were completed.

Figure 9. East Experimental Area, summer 1970.
A, B, and C are target stations.

A Yale University group, using a polarized proton target, measured the asymmetry (left-right) in the elastic scattering of K^+ , K^- mesons and antiprotons. A BNL group used the other branch to test CP violation by comparing the decays of K^+ and K^- into the $\pi\pi\gamma$ mode.

In the neutral beam inside the AGS ring (beam No. 7 at $G-10-20^\circ$) a group from Princeton and Cornell Universities performed an experiment to measure the phase of $\eta^\pm$ by studying K^0 regeneration in liquid deuterium.

Alternate operation of the 30 and 31-in. bubble chambers, as instituted last year, was resumed after the AGS shutdown. A total of 809,000 pictures was taken in both chambers. Collaborators from the University of Michigan and BNL obtained 630,000 pictures of K^- interactions in a H_2 -Ne mixture in the 31-in. chamber. Late in the spring, for a joint experiment by the Universities of Syracuse and Maryland and Brandeis and Tufts Universities, 138,000 pictures were taken with use of a beam of K^- mesons in liquid deuterium, and a test run of 17,000 was made for Rutgers University. The 30-in. chamber program began in April with a 24,000-picture exposure for the University of Florida's investigation of K^-N reactions in D_2 .

Separated beam No. 2 also supplied charged-particle beams for two tests of experimental equipment. π^- Mesons were provided for tests of a track-sensitive target, filled with H_2 -Ne and immersed in a H_2 -Ne mixture in the 30-in. bubble chamber. This work was carried out by members of the BNL Bubble Chamber Group. The other test was performed by Vanderbilt University and BNL personnel using K^- mesons to test the counters and spark chambers to be used later in a measurement of the Σ^+ magnetic moment.

This year the 80-in. bubble chamber operated with beam No. 4, the rf separated beam. During the spring 550,000 pictures were accumulated with the chamber filled with deuterium. Groups from the University of Tennessee, Purdue University, Weizmann Institute, Oak Ridge National Laboratory, and Brookhaven National Laboratory received pictures with incident π^+ and K^+ mesons, antiprotons, and protons.

The feasibility of extending the useful momentum range for π mesons and antiprotons in the rf separated beam was successfully demonstrated. With a new mode of operation a π^+ beam of up to 24 GeV/ c can be delivered to the 80-in. bubble

chamber. Antiproton beams near 15 GeV/ c are also obtainable.

Experimental Equipment

During the year there were, on the average, 14 beams in operation or under construction in the East, West, North, and Southwest Experimental Areas. Figure 9 shows the configuration of beams in the Target and East Experimental Areas in the summer of 1970. Forty man-years of effort were expended on experimental beam construction by the Experimental Area Operations Group and the Laboratory's Plant Engineering and Planning Division. The construction of the SEB extension was culminated by the completion of the beam transport and shielding for target station C (see Figure 10).

A summary of the inventory and usage of major experimental service items is given below.

Item	Inventory	Usage, %
Magnets	239	85
Power supplies	205	93
Beam separators	12	83
Shielding	90,000 tons	92
Experimental power	54 MVA	70
Experimental cooling water	4,050 gal/min	93

The Power Supply Group purchased eight additional 450-kW dc power supplies and six rack-mounted 2.3-kW units. About 9 MVA of experimental power was made available in the East Experimental Building Addition via 36 distribution boxes. An improved version of a power monitoring panel was built and installed in the Experimental Area control room to monitor the 54 MVA of experimental power.

With basic construction completed, the East Experimental Building Addition was outfitted to accept experiments. This work included the addition of control cables, timing signal systems, and experimental information centers and the tying-in of all signals with the Experimental Area control room.

During the long shutdown that started in May 1969 the 40-ton crane in the East Experimental Building was modified; its hoist speed was about doubled. Many modifications were also made in magnet and power supplies to improve their performance and reliability, including (a) the radiation-hardening of 50 experimental magnets inside the ring enclosure, (b) replacement of the rubber

water-supply hoses with phosphor bronze hose on 53 magnets, (c) installation of remote coil voltage readout plugs on 66 magnets inside the machine, and (d) improvement in electronics controls on the power supplies. In addition, two older Mark I bending magnets were converted to Mark II to reduce spare-coil inventory and improve performance. Another important category of work was preventive maintenance. This included flushing, hose replacement, and flow-switch cleaning on 169 magnets, and general cleaning, checks, tightening, and regulation tests on 144 power supplies.

Seven 18D72 bending magnets, five N3Q36 and two N8Q12 quadrupole magnets, and two 10C20 septum magnets have been received and are being prepared for use in the experimental program.

One 48D48 Mark II spectrometer magnet and one 96D40 spectrometer magnet have been designed and ordered. The large transporting device, capable of lifting, moving, and positioning ≈ 120 tons, will be used to position the 96D40 magnet. It was successfully used to position 48D48 and 30D72 bending magnets during the year. The necessary vacuum boxes, collimators, mass slits, magnetic shielding, pole pieces and shims for 48D48, 72D18, 18D36, and 18D72 bending magnets are being designed and manufactured for use in secondary beams downstream from the SEB target.

The efforts of the Magnet Study Group have been mainly devoted to the design and construction of cryogenically cooled magnets for accelerator and beam transport applications.

Figure 10. Installation of the shielding for target station C.

A 1-in.-aperture magnet model has been pulsed to >40 kG with use of high-purity aluminum as a conductor. With a cycle typical of present accelerators, auxiliary losses are $\approx 15^\circ\text{K}$. In the presence of high magnetic fields the effective dc resistance is $1 \times 10^{-9} \Omega\text{-cm}$.

Annealing treatments are being refined. Samples can now be produced at 4.2°K which have a resistance 20,000 times lower than that at room temperature.

The great thermal conductivity of aluminum makes its use promising for thin current sheet separator magnets, as well as for general thermal stabilization. Currents $>50,000$ amp/cm² were passed through a ribbon $13\frac{1}{2}$ in. long, surrounded by vacuum and cooled at its ends only through contact with a cryogen at 4.2° and 15°K . Studies of high-purity aluminum as a stabilizer for superconductors are also being made.

A facility for large-scale cryogenic work has been assembled. A 2-in.-aperture magnet, 2 ft long, is being assembled. Techniques for anodizing long lengths of very low resistance aluminum ribbon were developed successfully. Procedures for winding and forming large coils, including compound bending of coil ends, are being developed.

An 8-ft magnet prototype and a Dewar are being constructed with the problems of continuous assembly of such structures in mind. Both mechanical and magnetic stability will be studied. The structure is designed to cope with the effect on precision alignment of the contraction stresses upon cooling. This prototype system will first be cooled by forced circulation of subcooled hydrogen; later, supercritical helium gas will be used. A circulating pump and heat-exchanger system capable of cooling the prototype, as well as ultimately adjoining sections, is under construction.

The Magnet Study Group has also routinely maintained and provided precision-calibrated Hall probes for the use of experimental groups and has provided precision calibration services for all beam transport magnets.

The Beam Separator Group continued to operate ten electrostatic separators in four beams in addition to the rf separated beam. During the long shutdown two new deflectors were installed in the rf beam. The older deflectors have accumulated $\approx 11,000$ hr of rf time and require refurbishing. Also during the shutdown the deflector vacuum systems changeover to an all-metal-sealed system was completed. This improved the vacuum by a factor of >10 .

A double-pulsing mode is being added to the rf separators in the form of two $2\frac{1}{2}\text{-}\mu\text{sec}$ pulses separated by 100 msec. The previous mode allowed one $5\text{-}\mu\text{sec}$ pulse. An automatic cycling feature has been devised to allow the rf separators to run up to the preset power level after an interlock tripout. This feature should reduce the need for constant surveillance of the separator.

A new 2-m (short) dc separator has been constructed which incorporates most of the improvements suggested by the separator testing and development program. This separator will be installed in the low energy separated beam (No. 11) from target station C.

Improved components of the same type have been designed for the 5-m (rectangular) separators and will be installed in three separators during fiscal 1971. Work has started on a similar program for the two cylindrical separators.

An improved interlocking and current regulation system has been designed for the dc high-voltage power supplies. Installation on each of the separator power supplies is expected to be completed late in the summer. The purpose of this system is to protect both the separator and the power supply from damage during all phases of separator operation. When the installation of these systems has been completed a reduction can be made in the number of shift operating personnel.

The Cryogenic Group support program has centered mainly around the design, fabrication, and operation of liquid hydrogen and liquid deuterium targets. Seven hydrogen targets have been designed, constructed, and operated. Most of them involve special design requirements tailored specifically to the intended experiment. These targets consist of a Mylar flask surrounded by superinsulation and a vacuum container. Supporting equipment includes a liquid supply reservoir, liquid-level detectors, vapor vent lines, vacuum electronics, electrical power control chassis, and cryogenic transfer lines.

During the year an automatic liquid hydrogen transfer system was successfully put into use. The system, which allows a target watch to service more than one system during a watch period, consists of a pressurizing H_2 gas supply, a 175-liter liquid H_2 supply Dewar, a vacuum-jacketed transfer line and cold valve, a liquid H_2 reservoir and target system, and a main electrical control chassis. This system also allows a reduction in the number of shift operating personnel.

Figure 11. Electronics from the High Energy Electronic Equipment Pool as used in BNL Experiment No. 414, a search for evidence of CP violation in the $\pi\pi\gamma$ decay of the K meson.

The Liquid Hydrogen Storage Facility distributed $\approx 300,000$ liters of liquid H_2 ; both 1000-liter and 175-liter liquid H_2 transport Dewars have been maintained by the Cryogenic Group.

The Beam Instrumentation Group's major efforts have been to improve the instrumentation and operation of beam Nos. 1 and 2 and to provide for double pulsing of these beams. Preliminary design and preparation is now being done, with use of a small, special-purpose digital computer, to further improve the quality of instrumentation and efficiency of operation in these beams.

The High Energy Electronic Equipment Pool has an inventory of some 3000 components, which they lend, maintain, and repair for use at the Laboratory (see Figure 11). The counter experiments at the AGS employed most of this equipment, each piece being used in 2 or 3 experiments during the year. Equipment utilization was about 95%.

AGS CONVERSION

During the year good progress continued to be made on the AGS conversion project. The building and facility construction work is essentially complete except for the new North Experimental Facility. Detailed design of the accelerator components is nearing completion, and much of the equipment is now on site. Emphasis has shifted to installation and testing of components; some systems are in operation and others are close to completion. The new ring rf amplifier system is operating the modified accelerating cavities at present, and the new magnet power supply is undergoing final tests. The first section of the 200-MeV linac is accelerating protons to 10 MeV. By the end of fiscal 1970 about 84% of the project funds had been committed. In spite of some delays, injection of 200-MeV protons into the AGS is expected to begin in the last quarter of 1971. During the year a peak force of about 200 persons was involved in the project, but

Figure 12. The 750-keV beam transport and 10-MeV linac cavity section of the 200-MeV linear accelerator.

this number is being reduced as parts of the work are completed.

The East Experimental Building Addition, completed last year, is now housing that portion of the experimental program associated with the extension of the SEB. The area used for storage for the past year has been cleared to make room for more experimental setups.

The main Power Supply Building and the Rf Building, both located inside the main magnet ring, have been completed and the accelerator equipment has been installed. The Linac Building complex is complete, including the beam transport tunnel into the AGS, and equipment is being installed. In all these buildings, the accelerator mechanical services are finally functioning, after extensive delays due to low contract-labor productivity.

From May to November 1969 the AGS was shut down to avoid intolerable radiation levels during construction work in the vicinity of the main magnet tunnel. The work accomplished included the conjunction section for the 200-MeV beam transport; mass concrete shielding over the

magnet tunnel at the south end of the Target Building, and concrete hinged arches covered with an additional 10 ft of sand extending over the E and F sectors of the machine; a new heavy-equipment access port at the E sector; mass concrete shielding and hinged arches extending from the north end of the Target Building to the I sector; the penetration of the tunnel wall for the new FEB line at H-10 and the H-10 beam tunnel extending to the open paved experimental area north of H-10; and a new shielding door at the H-10 access port. The hinged arches over the AB sector and the 21 large service-sleeve ports into the tunnel were installed last year. The only work remaining in connection with the magnet enclosure consists of placing the new steel shield over the tunnel in the Target Building.

Originally it was planned to construct a West Target Building inside the ring. However, as the experimental program evolved, it became clear that all bubble chamber activity should be concentrated in the North Experimental Area and serviced by beams from H-10. Since this will result in much less activity in the West Experimen-

tal Area, the money allocated to the West Target Building was reallocated to the North Experimental Area. It is now planned to build a neutrino beam tunnel about 600 ft long, extending north from the paved area at the mouth of the H-10 tunnel. A full-intensity beam (10^{13} protons/sec) will be transported to a heavily shielded target in this tunnel. This will be followed by a 30 to 40-ft steel neutrino filter, beyond which will be the 7-ft and 80-in. bubble chambers. In addition, pads and services will be provided for high and medium energy rf separated beams to the bubble chambers. Design for this facility is essentially completed and the contract is about to be let. The AEC Advisory Panel on Accelerator Radiation Safety met at the Laboratory to review the shielding and safety aspects of the North Experimental Area.

Theoretical studies of proton linacs and beam transport systems were continued during the year, but at a somewhat lower level. Numerical calculations on the behavior of different self-consistent charge distributions have been continued. Modes of collective motion caused by slight perturbations of these distributions have been investigated. All calculations are being done on a continuous beam in a very long drift space, assuming weak focusing and radial symmetry in the beam. The effect of the nonuniformity of the drift-tube linac structure on the field flatness has been calculated in further detail after revision of the computer program to yield greater accuracy. Results were obtained for a 10-MeV cavity. These calculations are being extended to 200 MeV. Final calculations have been performed to give an optimal match from the preinjector to the linac. The detailed design calculations of the beam transport from the linac to the AGS have been completed.

Installation of the preinjector is complete. Beams of 350 mA have been accelerated to 800 kV. The high-gradient column, the second such column designed and built at BNL, has performed remarkably well. All its interior metal parts are titanium, and it has three more insulating sections; although these make the external length in air somewhat longer than in the first column, the full accelerating gradient of about 45 kV/cm is maintained. When the column was first operated, it was completely seasoned and able to hold off full voltage in about 2 hr. External flashovers and internal microdischarges are virtually nonexistent. The low energy beam transport system, which is about 30 ft long, has demonstrated the ability to transport

beams of >200 mA with essentially no loss. However, because of space charge effects, the adjustment of the eight quadrupole triplets in the system, in order to maintain the beam properly matched to cavity 1, is extremely critical.

On March 24, 1970, the first cavity of the 200-MeV linac successfully accelerated protons to 10 MeV. In the following weeks beam currents of >120 mA with design-value emittance were routinely produced (see Figure 12). The preinjector and first cavity are now being operated on a regular basis to conduct a complete series of tests and measurements on the properties of high-current beams at 10 MeV. A temporary analysis station has been installed in the linac tunnel in the cavity 2 area for this purpose. Installation of cavity 2 will be delayed until the fall of 1970 to allow completion of these measurements.

All the accelerating cavities have been delivered, and the drift tubes for cavities 1 to 7 have been completed. Cavities 3, 4, and 5 are in place in the linac tunnel. Installation of cavity 3 is complete, including drift-tube alignment and rf field flattening. The cavity is evacuated, has been operated at full rf field level, and is ready to accept beams when cavity 2 is ready. Cavity 4 will reach the same stage shortly, and cavity 5 is undergoing final alignment. Cavity 6 will be installed during the summer of 1970, and all cavities through 9 will be installed by early 1971. The vacuum and cooling systems for the cavities are proceeding on a parallel schedule. The redesigned 1500-liter/sec sputter-ion pumps have exceeded their specifications. The vacuum in cavity 1 remains near 10^{-7} torr, even when the cavity is accelerating a beam. The cavity cooling system maintains the cavity temperature to better than 0.1°F under operating conditions, which minimizes the requirements for the mechanical frequency tuners.

All major components for the 200-MHz rf system have been delivered, and complete rf stations are operating on cavities 1 and 3. System tests have shown that up to 8 MW of peak power can be produced by each station, although the design requirement is only about 5.5 MW. Complete rf stations controlled from their local control stations are being installed on a schedule to match the cavity installation. A similar schedule is being followed for the focusing quadrupole magnet power and pulsing systems.

Detailed design of the digital data-acquisition and control system for the whole linac is com-

pleted. Most of the prototype units for the system have been tested and production is being initiated. The beam transport system from the linac to the AGS and the 200-MeV beam analysis system are scheduled for installation early in 1971. Detailed design of these systems is essentially complete and procurement has started.

Significant progress has been made on the modifications to the AGS during the year. The new rf power amplifier system was installed and connected during the shutdown, and the old amplifiers were removed from service. The complete system, including the ferrite biasing system for tuning, is now operating routinely on the AGS. The new system is connected to the old accelerating cavities in the ring by an arrangement of 1 5/8-in. semirigid coaxial lines with impedance matching installed at each cavity. Design of the new accelerating cavities is almost finished, parts are being procured, and installation is scheduled for the 1971 shutdown. It is hoped that difficulties being encountered in the delivery of the ferrite rings for the cavities will not delay the installation.

The new Siemens main magnet power supply is completely installed and operational checks are under way. It had been hoped to activate the power supply at the same time that the rf system became operational, but manpower shortages and low contract-labor productivity have seriously delayed the power supply work. In addition, serious technical difficulties encountered at CERN with the Siemens high-power rectifier tanks (excitrons) made it necessary to rebuild all our tanks. However, since it will take only a few hours to change connections from the old power supply to the new one, the new set can be used operationally as soon as it is ready.

The new magnet-ring vacuum chambers were installed in three superperiods of the AGS. A pressure of 5×10^{-7} torr is achieved in these chambers with the old pumps, since the new high-speed, high-vacuum pumping system has not yet been activated. The rest of the vacuum chamber sections are on site, and procurement of the special sections and straight sections is in process.

A new radiation monitoring system was installed in the ring and placed in operation. Some of the modifications to the main magnets were installed in three superperiods, and the rest are being prepared for installation during the 1971 shutdown. With the expanded plans for the North Experimental Area, the first target location has been

moved some distance north from the mouth of the H-10 tunnel, and additional beam transport equipment is being designed.

ADVANCED ACCELERATOR DEVELOPMENT

Superconducting Synchrotron Magnets

During calendar 1969 the basic problems of instability and losses in pulsed superconducting magnets were solved and Brookhaven's magnet studies entered the engineering-design phase. The predictions made during the 1968 summer study at Brookhaven, namely, that losses in pulsed superconducting magnets could be reduced to any desired level by using a cable of very fine superconducting strands transposed in much the same fashion as is found in Litzendraht (Litz wire), have been verified. Three industrial firms have been involved in developing such cable to meet BNL specifications. The final wire is 0.008 in. in diameter; it includes a copper matrix in which are imbedded about 300 fine strands of niobium-titanium superconductor. The procedure involved in fabricating this wire are standard in the wire-drawing industry, and the wire can be produced at a price of $< 1¢/\text{A-m}$, similar to the price of pure copper for use at room temperature.

The superconducting wires are braided into a flat ribbon capable of carrying about 2000 A. The braided ribbons are then wound into suitable coils for bending or focusing magnets. The coil system, usually with a circular aperture, is finally enclosed in a laminated iron shield.

It appears that superconducting magnets of this type can give fields of 60 to 80 kG, about four times as strong as the field attained in conventional room-temperature magnets. At such high fields the forces on the coils due to the magnetic field become very high, and the goal of studies now in progress is the fabrication of rigid superconducting structures that will not become distorted as the field is raised. Other studies are concerned with improvement of the uniformity and reproducibility of the field patterns.

The superconducting magnets, which must be operated at very low temperatures, will be cooled by liquid helium to temperatures of about 4°K . Engineering-design studies are in progress for the necessary enclosures surrounding the magnets and for the associated refrigeration systems.

Cryogenic Magnets With Coils of Pure Aluminum

Fields of about 40 kG can be reached at temperatures of 10° to 20° K in magnets using very pure aluminum. If the impurity level is held below ≈ 1 ppm, the resistivity of aluminum at low temperatures can be several thousand times lower than it is at room temperature. The losses in such magnets will be several times higher than those in a superconducting magnet, but the higher operating temperatures for aluminum make the problems of refrigeration more tractable.

Several model magnets with pure aluminum coils have been built at Brookhaven. Measurements indicate performance in agreement with predictions. Design studies similar to those in progress on the superconducting magnets are intended to solve the problems of field shaping, coil insulation and support, and refrigeration.

Theoretical Studies

A continuing investigation of the coil and iron configurations required to produce a variety of desired magnetic field patterns is proceeding in two directions. First is the development of analytic methods using complex variables, which has resulted in the discovery of several elegant techniques for calculating and understanding the interplay of electric currents and magnetic fields. The second approach involves the preparation of computer techniques for prediction of the performance of specific magnet configurations. These programs have been extended to include the very nonlinear behavior of saturation in iron and its effect on field patterns.

Superconducting Cavities

Losses in rf systems of the type used in linear accelerators or in particle separators are very high at room temperature but can be reduced, by the use of superconducting cavities at low temperatures, to a level that makes continuous operation possible.

Niobium has been shown to be the best material for use in superconducting cavities, and a number of test cavities have been assembled and tested at Brookhaven. The surface phenomena involved are still incompletely understood and somewhat unpredictable. However, performance of the cavities is markedly improved by heat treatment.

Particle Detectors Using Transition Radiation

When nuclear particles enter or leave a solid material they emit a spectrum of electromagnetic radiation known as transition radiation which may cover a range from optical wavelengths to x rays. It has been predicted that the energy in this spectrum should be roughly proportional to the ratio of the particle's total energy to its rest mass. Accordingly, it should be possible to use this radiation to identify particles of very high energy. A Brookhaven group has carried out a series of observations of the transition radiation from particles in AGS beams and, more recently, in the electron and positron beams at the Cambridge Electron Accelerator. The predictions have been verified, and it appears that transition radiation will be a powerful tool in particle physics. Since the necessary equipment is relatively light in weight, there is considerable interest in the possible use of transition radiation detectors in satellite-borne observations of cosmic radiation.

Study of a Proton Energy Booster Ring for the AGS

During the year supporting studies were carried out for a cold magnet synchrotron (CMS) of ≈ 100 -GeV proton terminal energy, which would make use of cryogenically cooled magnets with either superconducting coils or pure aluminum coils for magnet excitation. This proton energy booster ring would make use of the AGS as an injector and either would be located in the existing AGS tunnel or (for a somewhat larger ring) would be nearly concentric with it.

Design studies were done of the synchrotron lattice, beam orbits, aperture requirements, and beam transfer parameters. In addition, the orbit dynamics of a separated function machine with "point" compensation for the sextupole component of the dipole fields was studied, with specific reference to the capability of slow beam extraction. Design details of a low-loss slow extraction system were developed for a small-aperture CMS accelerator.

RESEARCH

Analysis of a search for the vector boson (W particle), postulated as the mediator of the weak interaction, has determined the intensity and polarization of μ mesons (muons) originating very

near the point of interaction of 28-GeV protons with nucleons. Bosons were not observed, and the upper limit on the production cross section for W particles with masses between 2.0 and 4.5 GeV/ c^2 is $B\sigma \lesssim 6 \times 10^{-36}$ cm², where B is the branching ratio for the W decay to a muon and a neutrino.

An experiment to measure the energy spectrum and the muon polarization in the decay $K^+ \rightarrow \mu^+ + \nu + \pi^0$ was carried out at Argonne National Laboratory. The experiment utilized counters and digitized spark planes on-line to a small computer. Assuming that the conventional vector-axial vector description of the weak interactions adequately describes the decay of the K meson into a charged lepton, a neutrino, and a π meson (pion), the decay Hamiltonian can be written in terms of two form factors f_+ and f_- . The term in the Hamiltonian multiplying f_- transforms like a scalar rather than a vector interaction. This scalar interaction, which depends on the difference in the form factors of the K meson and pion, is called an induced scalar interaction, induced by the strong interactions.

The energy correlations in the decay spectrum will be different for scalar and vector interactions. It is known that the interaction must contain both terms in general and that the amplitudes resulting from these two terms are coherent. If time reversal holds, the relative phases of the two amplitudes will be real. It is then convenient to consider the character of the spectra in terms of the ratio of the two form factors: $\xi = f_-/f_+$. A measure of the energy correlation spectrum will determine the value of ξ .

Further, if muon-electron universality is accepted, the value of ξ can be determined by measuring the ratio of the K -meson decay transition probabilities to electrons and to muons: only the vector amplitude and f_+ are important for the electron transitions, whereas both the vector and scalar amplitudes and both form factors (f_+ and f_-) are important for the muon transitions.

The results from previous measurements of branching ratios and energy spectra from the decays of both K^+ mesons and K^0 mesons are consistent with a value of ξ of about +0.5.

Information on the form factor ratio can also be obtained by investigating the polarization of the muons. For the scalar part of the interaction the

muon will not carry off any angular momentum. Since the K meson has spin zero, the total spin of the neutrino-muon system in the direction of its motion in its center-of-mass system must be zero. Since the neutrino (a lepton) must have negative helicity, the muon (an antilepton) will also have negative helicity. On the other hand, the vector interaction allows the muon to carry off angular momentum, and the neutrino-muon system need not have zero spin along its direction of motion. Indeed, the decay will be such that the muon helicity is positive, the natural or allowed decay for an antilepton. Clearly, then, for pure scalar and pure vector interactions the polarizations of the emitted muons will be quite different – essentially reversed. For an admixture the polarizations will depend upon the degree and phase of the mixture, i.e., on the value of ξ .

The polarizations of muons emitted in the decays of K^+ and K^0 mesons have previously been measured in different ways. The results are generally consistent with each other and with a value of ξ of -1.0 , quite different from the value derived from the branching ratio and spectrum measurements. It appears that this difference cannot be understood within the conventional framework of the weak interactions. The most probable solution to the problem is that one or the other set of experiments is wrong, even though different techniques are used for the measurements making up each set of experiments. The alternative possibilities of a breakdown in muon-electron universality, or some other radical result concerning the leptons and the weak interactions, are interesting and cannot be discounted. However, it is hoped that when the data from the present experiment, a simultaneous measurement of the energy correlation spectrum and the muon polarization, are fully analyzed, the disagreement will be resolved.

The spectrometer to measure the zenith angle distribution of muons with energy >1 TeV was erected, after a delay due to a shortage of rigging effort. The most recent results of the University of Utah group confirm with higher statistics their earlier measurement of an anomalous muon zenith angle distribution and their postulated “ x -process.” Thus it is even more important to measure this distribution with an entirely different kind of experimental technique.

Instrumentation

The Instrumentation Division suffered a substantial reduction in numbers toward the end of the fiscal year, from 84 members, including 22 scientific and professional personnel, to 65 (19 scientific and professional). Except for the administrative transfer of the glassblowing shop to the Chemistry Department, no major changes were made in the Division's responsibilities, which include the design and construction of test instruments and data-gathering devices, development of hardware interfaces and software for computer-oriented systems, and provision of repair and calibration services. The Division operates a vacuum technology shop and an electron microscopy facility (which now includes a scanning electron microscope) and does a modest amount of research, directed mostly toward improving radiation detection and measurement techniques.

The following paragraphs briefly summarize the research effort and describe some of the devices and systems built during the past year.

COMPUTER SYSTEMS

The Computer Group participated in long-range planning for future computer applications, de-

signed and built some computer interface hardware, programmed a PDP-9 computer to function as four more-or-less independent pulse-height analyzers, and assembled and programmed an elaborate satellite computer system for a high energy spark-chamber experiment.

A set of proposals was generated for the orderly growth of the computer system at the High Flux Beam Research Reactor. The objective is to provide, in several stages, megachannel storage capacity for multiparameter neutron capture γ -ray experiments, increased on-line computational power for the neutron diffraction spectrometer systems, including access to the CDC 6600 central facility for crystallographic calculations, and computer control for an additional diffraction spectrometer that cannot now be accommodated in the crowded multiple spectrometer control system.

A system using a PDP-11 computer was proposed for the collection and reduction of data from six amino acid analyzers, and a computer program was written to test models of nervous system electrical communications.

The largest project of the Computer Group has been the hardware and software implementation of the connection of a large spark-chamber exper-

Figure 1. The scoss system.

iment to a PDP-9 and then, via the BROOKNET system, to the central computer facility. The system, scoss, is shown in Figure 1. Its purpose is to permit experiment monitoring by a small satellite computer, working with a selected sample of the experimental data, and to permit extensive floating-point calculations to be done on the CDC 6600 at the central facility. Scoss provides for computer-controlled data sampling, compiling of data files, transmission of data and job files to the CDC 6600, display and manipulation of histograms, line printer output, and modest computing on data files.

The PDP-9 operating system includes the following subsystems:

1. Foreground programs driven by interrupts from external devices such as a teletypewriter, data box, or the BROOKNET terminal.
2. A monitor that schedules all housekeeping tasks.
3. File management programs.
4. Management of background programs consisting primarily of scientific calculations.

Scoss is the Division's first attempt at the on-line application of a satellite computer system to a high energy experiment. Experience gained from its operation will substantially influence the design of future systems.

SPARK AND PROPORTIONAL CHAMBERS

In collaboration with a group from Vanderbilt University, members of the Division developed a compact assembly of digital spark chambers with an internal target that has a three-dimensional spatial resolution approaching that of bubble chambers. More than 40 wire gauze electrodes, 12 cm in diameter and with 130 wires/in., have been stacked with 3-mm spacing. The planes are arranged in two-gap modules separated by thin plastic films to prevent transfer of discharges between gaps. By using high specific-ionization gas mixtures and very fast high-voltage pulsing, a single sparking efficiency of close to 99% has been achieved. Spatial resolution of about 0.5 mm has been obtained.

Several proportional-spark hybrid chambers, of the type described last year, have been built and tested. An efficiency of 97% with spatial resolution of about $\frac{1}{3}$ the wire spacing at 40 wires/in. has been obtained. The resolving time is about 75 nsec

and the recovery time is $< 100 \mu\text{sec}$. This represents an improvement of an order of magnitude over conventional spark chambers. The hybrid system has better spatial resolution than proportional chambers and makes use of the much simpler conventional spark-chamber readout systems.

A technique was developed for using pulsed spark-chamber efficiency measurements to indicate the presence of free electrons in gases. The technique was applied to the measurement of the electron-attachment coefficient of CCl_4 in helium as a function of electron energy. The coefficient at low energies was found to increase by 4 orders of magnitude. A fine structure near 0.05 eV was also observed.

Prototypes of cylindrical spark chambers for multiparticle experiments were developed, constructed, and tested in collaboration with members of the Physics Department. A low-impedance transmission-line type of electrode configuration is used to achieve high multiparticle efficiency. The electrodes are supported on a low-mass, but rigid, plastic honeycomb so that uniform gap size can be maintained in a curved chamber. The chambers will be mounted in a large magnet with the magnetostrictive readout wires shielded from the field and therefore inaccessible to manual repolarization. A pulsed system for remotely repolarizing the readout wires has therefore been developed.

SEMICONDUCTOR DETECTORS AND ASSOCIATED CIRCUITS

In addition to continued improvement of techniques for producing large, high-resolution Ge(Li) coaxial detectors, several Si(Li) coaxial detectors were made, and some promising new applications were investigated. Large-volume silicon detectors were found to have some advantages over germanium detectors for the measurement of high energy γ rays. At energies well above the pair production threshold, large silicon detectors produce a single prominent line (the double escape peak) for monoenergetic γ rays, the single escape peak and the full energy peak being almost totally absent. The resulting spectral simplicity can more than offset the lower efficiency of silicon (about $\frac{1}{4}$ the pair production cross section of germanium).

Thin slices of almost fully depleted silicon coaxial detectors were found to be very useful x-ray

detectors, with much larger sensitive area than planar detectors of comparable capacitance. The dead layer problem experienced with axially irradiated germanium coaxial detectors appears to be unimportant with silicon for x-ray energies >10 keV.

Work has continued toward better defining the problems involved in producing γ -ray-compensated germanium detectors. Hall-effect measurements are being made as a function of temperature on a number of germanium samples in an effort to correlate the effects of γ -ray compensation with the energy levels of the acceptor impurities.

In a well-designed silicon-detector x-ray spectrometer the preamplifier feedback resistor, which leaks off the detector charge, can be the major resolution-limiting element. Optoelectronic techniques have been used at other laboratories to eliminate the feedback resistor. At BNL successful tests have been made on a somewhat simpler alternative technique for removing the detector charge, in which it is not necessary to use light-emitting diodes (which must be optically shielded from the detector), or to connect any components except the detector to the field-effect transistor gate. The charge is removed by periodically pulsing the gate into forward conduction through the detector capacitance. Very short bipolar pulses are used to minimize the duration of the subsequent system paralysis. The pulse amplitudes are servo-controlled to keep the preamplifier well inside its dynamic operating range.

OTHER INSTRUMENTS

An automatic programmer for the motors and valves of an amino acid analyzer has been built, in which the punched-tape reader of a standard teletypewriter is used. The teletypewriter is also used for program preparation and provides a hard-copy record of the operations completed. After each operation is completed, the time at which the next operation is to take place is read from the tape. At that time the list of required operations is read from the tape and executed, after which the time for the next operation is read. The process continues until an END character is read or until a preset number of complete cycles has been executed.

Last year an incremental punched-tape recording pulse-height analyzer was built for use in a solar

neutrino capture experiment done at an extremely low counting rate. The system counts x rays from ^{37}Ar produced by neutrino capture and inverse β decay in ^{37}Cl , employing very small proportional counters for low background. Virtually all the cosmic-ray background is eliminated by doing the counting in a deep mine and by using anti-coincidence cancellation. Most of the small residual background is due to γ rays from radioactive nuclides in the counter wall and surrounding shielding. Even with these very small counters, it has been found that most γ -ray pulses have a significantly longer rise-time than x-ray pulses. The analyzer has accordingly been modified to record the amplitude of each pulse differentiated with a 5-nsec time constant, in addition to the amplitude obtained with a much longer time constant. The background is expected to be reduced substantially by comparing the two recorded amplitudes for each signal and rejecting those with excessively long rise-time.

A mechanism for improving the accuracy with which atomic beam resonances can be measured was built. Detector instabilities make it difficult to plot a precisely reproducible resonance curve. However, by switching the radio frequency rapidly from one side of the resonance curve to the other, most of the errors due to detector drift can be eliminated. When the resonance peak is accurately bracketed, the detector output at the switching frequency, as measured with a synchronous detector, goes through zero, independent of variations in detector sensitivity.

A number of scattering chambers at the Tandem Van de Graaff Facility are equipped with shaft angle encoders to provide a digital indication of the orientation of targets and detectors. The encoders supplied by the manufacturer were of the simple revolution-counting type, intended for visual indication, and had no mechanisms for resolving carry-borrow ambiguities that could confuse the associated computer system. Since mechanical considerations made it awkward to change the encoders, an electronic system for resolving the encoder ambiguities was designed and built. The system presents unambiguous digitized angular information to the computer despite encoder contact bounce or bridging and independent of the order in which contacts change at a multiple-contact transition. The encoder reading is periodically sampled and compared with the last valid reading. An encoder reading that differs

from the previously stored value is tested for ambiguity. If the new number is satisfactory, the stored value is updated.

A circuit that yields a digital indication of the ratio of two mass peaks was added to a conventional mass spectrometer. A voltage-to-frequency converter is used to convert the electrometer output to a pulse train. The spectrometer is tuned to the reference peak, and the time required for a predetermined number of pulses from the voltage-to-frequency converter is recorded. The spectrometer is then tuned to the unknown peak and the pulse train is counted for an equal time interval. The recorded count then represents the peak ratio. Provision is made for automatically switching between peaks and waiting for the electrometer to come to equilibrium. Zero drifts are eliminated by automatically tuning to an absent mass before each measurement and reducing the output of the voltage-to-frequency converter to zero by feedback control.

Occasionally the interval between periodic pulses must be divided into a number of precisely equal subintervals. Resonant frequency multipliers can be used, but they must be carefully tuned to eliminate phase modulation from the multiplied signal, and this makes it difficult to work over a wide input frequency range. A frequency multiplier has been made that is capable of working over a frequency range $>1000:1$, with a phase jitter of the order of 0.1%. It uses a current-to-frequency converter as an oscillator which is servo-tuned so that a digital submultiple of its frequency is equal to the input reference frequency. Servo stability over a wide frequency range is accomplished by making the control current in the current-to-frequency converter exponentially proportional to a control voltage, which is increased or decreased, depending on whether the frequency is too low or too high. Excessive searching is avoided by making the control increments small and by synchronizing the reset of the current-to-frequency converter with the reference signal whenever the output frequency is low.

In cooperation with the Tandem Van de Graaff Group, a circuit has been built which facilitates beam focusing and optimization over a wide range of beam currents. The circuit works with a moving wire beam scanner and the wire current is displayed on an oscilloscope as a function of position. Automatic gain control, using light-controlled photoconductors, over a range of 10^7 to 1 permits

display of the beam shape, independent of beam current, from <1 nA to 10 mA.

Other Instrumentation Division projects include a digital controller for a dual-detector goniometer at the Tandem Van de Graaff Facility, a controller for a 4-axis x-ray spectrometer, and the modification of a spectrophotometer for operation as a sensitive circular dichrometer.

METEOROLOGY

Program Developments

Interest in environmental research has grown rapidly at Brookhaven during the past two years, with an inevitable increase in the Meteorology Group's efforts devoted to planning, evaluation, and implementation of broad Laboratory programs, since almost all involve meteorology to an important degree.

The meteorological research program has also been reviewed in detail, with a resultant shift in emphasis toward dispersion studies on a broader scale than was typical of earlier work at Brookhaven. Surprisingly little is known of atmospheric processes on a scale of 10 to 100 km, even though they are extremely important in the understanding and control of various atmospheric pollution problems. A major proposal for study of the New York City-Long Island area has been prepared, and certain phases of the work, chiefly in the assembly of existing data and the preparation of instrumentation, have already been initiated.

An understanding of the atmospheric processes on this broader scale can be developed both by studying the atmospheric motions directly and by inferring them from the behavior of tracer materials. In the latter approach SO_2 measurements can be very helpful, and arrangements have been made to obtain recorded information from ≈ 25 stations operated by other organizations within the area. Appropriate meteorological data are more difficult to obtain, but the observations recorded at the major stations of the Environmental Sciences Services Administration are also being assembled for the study.

Even at the beginning of the program, ground-level SO_2 and meteorological data will be supplemented by aircraft measurements, and the instrument package already developed for the Atmospheric Diagnostics Program is being duplicated and expanded to give a more complete picture of

atmospheric structure and contaminants. A unique airborne isokinetic sampler has been completed and is being flight tested. The sampler is designed to collect particulate matter on a filter at the normal flight speed of a Cessna 182. The sampling head is mounted outside the propeller slipstream on the outboard end of a track extending from the cabin to a point under the midsection of the wing. This unit is connected by tubing to the air-pump device in the cabin, and the sampler head is easily retracted for changing samples.

The photometric densitometer used in the early Brookhaven oil-fog studies is also being revised to serve as a real-time detector of airborne particulate concentrations. This extremely sensitive instrument has been transistorized and electronically stabilized to adapt it for its new use.

Wind and Turbulence

The studies of wind structure have also undergone reorientation, with particular attention being devoted to turbulence measurements at higher elevations within the boundary layer, over urban areas where possible. Wind velocity and turbulence measurements have been obtained from three stations in New York City, at elevations of 920, 580, and 30 ft. These records have been extensively analyzed and have been compared with data obtained from the 1000-ft tower at the AEC's Savannah River plant and the 410-ft tower at Brookhaven.

Attempts to find acceptable turbulence measurements, especially at high urban elevations, have revealed an important deficiency that must be eliminated. Bivanes of the conventional X-tail design are not suitable for continuous untended use in urban areas. They are too flimsy and easily damaged, and progressive unbalance of the tail assembly raises the question of their ability to maintain accuracy. Two new designs have been built and are being tested; one features a modification of the annular fin tail of the early Brookhaven bivane, and the other has a pair of plastic spheres as the tail. In both instruments the emphasis is on a reliable *vertical* response, since that is the difficult element to measure effectively, rather than the horizontal fluctuations.

The analysis of wind "steadiness" has been refined to relate wind persistence to stable meteorological conditions, a meteorological combination that plays a critical role in the short-term dispersion that might be associated with a reactor ac-

cident. Brookhaven's meteorological data have been completely analyzed from this standpoint, and data from three additional sites are now being processed.

Continued analysis of wind data obtained in the forest area revealed the curious fact that turbulence reaches maximum intensity in the forest crown, where the vegetation is thickest. This result, however, is in accord with tracer studies showing very rapid interchange of tracer material through the canopy.

Dispersion and Deposition

The particulate dispersion program was largely devoted to consolidation and study of the varied pollen, copper, and uranine data collected in earlier years, with only a few field experiments to fill important gaps in the available records. Most of the data on ragweed, timothy, and corn pollens have been summarized and prepared for publication.

Atmospheric Diagnostics Program

The meteorological portion of this cooperative project has become more extensive, partly because the program has required more effort and partly because the sampling equipment, techniques, and resultant airborne data are well suited to the developing urban-rural meteorological program.

The data obtained late in the spring and during the summer of 1969 are interesting in several respects. First, the stack plume measurements obtained in Pennsylvania and over Long Island have already provided SO_2 concentrations and plume geometry that will be directly applicable to the broad-scale meteorological studies. Second, the ground-level $^{32}\text{S}/^{34}\text{S}$ ratios obtained in the New Haven area indicate a fascinating diurnal pattern in which there is an apparent enrichment of ^{32}S (or depletion of ^{34}S) in SO_2 samples taken during the nocturnal hours. This change may be associated with fluctuations in relative humidity or may result from an unsuspected photochemical process, but the effect is undoubtedly real and suggests important chemical changes in the SO_2 .

Finally, the New Haven SO_2 data provide an excellent opportunity to assess the multiple-source mathematical models of dispersion that the Meteorology Group has developed. Estimates of the actual emissions from the 20 largest SO_2 sources have been introduced into the computer program,

and concentration plots have been made for a variety of meteorological conditions and eight wind directions. Figure 2 is a plot of the anticipated concentrations in New Haven during typical daytime meteorological conditions with the common southwest wind. The points marked *TE*, *CO*, *WH*,

FE, and *FA* are the positions of sampling stations used in the study, and the numbered points represent the 20 major sources. Predicted concentrations are generally low over the city, except for a few small areas immediately downwind of major emitters.

Figure 2. Complete plot of SO_2 concentrations in New Haven, Conn., showing the joint contribution of 20 significant sources of SO_2 in New Haven under typical daytime meteorological conditions with southwest winds at 12 mph. Plots such as these are used in analyzing the isotopic ratio data obtained in this city.

Chemistry

Work in the Chemistry Department encompasses experimental and theoretical researches on the properties and reactions of nuclei, atoms, and molecules.

HIGH ENERGY NUCLEAR REACTIONS

The interactions of heavy-element targets with high energy projectiles (protons, pions, and antiprotons), principally of energies above 2 GeV, are studied to obtain an understanding of the reaction mechanisms involved. In particular, in the case of heavy-element targets, specific reactions are characterized as being due to binary fission, spallation, or possibly other mechanisms, and studies are made to learn in detail how the relative cross sections for these different types of reactions depend on the bombarding energy and on the nuclear properties of the target species. Theoretical studies have resulted in improved understanding of these complex reactions in terms of interactions between elementary particles.

Studies With Particle Detectors

Analysis of the extensive scattering-chamber data on the fission of bismuth and uranium by 2.9-GeV protons is almost complete. Energies and masses of specific fission fragments were determined, as well as total kinetic energies, excitation energies, and angular correlations between the fragments. For uranium fission an asymmetric mass distribution was found for the very lowest excitation energies of the target nuclei, while a symmetric distribution was observed for the higher excitations. For bismuth fission only a symmetric mass distribution was seen. The analysis shows that the mean fragment velocities are nearly the same as those in fission induced by projectiles of much lower energy. Thus the mechanism of fission at GeV energies appears to be essentially the same as that at low energies.

A new series of scattering-chamber experiments has begun at the Alternating Gradient Synchrotron in a 28-GeV beam. The relatively light fragments emitted by the target are being studied with thin

dE/dX solid-state detectors and time-of-flight equipment. The aim is to elucidate the mechanism (or mechanisms) by which the various species of fragments are produced.

The use of mica track detectors to measure fission cross sections is being extended to include projectiles of pions and antiprotons. Target stacks of U, Bi, and Au have been irradiated and part of the scanning has been completed. Further progress was made in the technique for particle identification by differential etching of the damage tracks left in Lexan plastic foils. Ions of S, Ne, F, and O at energies of 0.4 to 3.0 MeV per nucleon were produced at the Yale Heavy Ion Accelerator and the Rochester Tandem Van de Graaff.

Studies by Radioactivity Measurements

Radiochemical cross-section and recoil studies of U, Th, and Ta showed that the neutron-excess products of intermediate mass result from a normal low energy fission process. Neutron-deficient products may arise in part from fission and in part from a very energetic spallation process. Numerous rare-earth nuclides were separated from thorium and tantalum targets irradiated with 28-GeV protons and from uranium irradiated with 3-GeV protons. Although extensive use was made of ion exchange columns and an isotope separator, there were complications due to short-lived α -emitting species and to poorly characterized nuclides. These difficulties are being gradually overcome (see section on Nuclear Spectroscopy). Recoil range distributions are being measured for a variety of products (sodium to barium) from interaction of 28-GeV protons with thin uranium and tantalum targets (see Figure 1). The data are being processed to obtain energy spectra of the various nuclides that may represent the different types of processes occurring in high energy reactions.

An empirical correlation has been developed for "deep" spallation reactions which relates mean recoil kinetic energy (T_{obs}), recoil mass M_{obs} , and target mass M_t . Figure 2 shows the relation between mean squared momentum per emitted par-

ticle ($m_i^2 v_i^2$) and the difference in mass between target nucleus and observed product ($M_t - M_{\text{obs}}$). It is seen that for a variety of complex spallation reactions the values of ($m_i^2 v_i^2$) depend only on ($M_t - M_{\text{obs}}$) and not on the individual values of M_t or M_{obs} . This correlation, combined with a theoretical treatment of fission based on the liquid drop model, should form a very useful framework for discussion of a wide variety of recoil phenomena observed in high energy reactions.

Work has continued on a technique to determine formation cross sections by direct measure-

ment of γ spectra with Ge(Li) detectors of various targets irradiated with high energy particles. It was shown that for copper targets the mass-yield distribution can be established by counting the target foil only 6 to 8 times over a period of 6 months. Preliminary analyses of γ - and x-ray spectra from Ag, Au, and U targets indicate that large numbers of reaction-product yields can be easily and precisely measured.

Plastic scintillators were irradiated with beams of antiprotons and negative pions of momentum 2.5 GeV/c. Preliminary results gave cross sections

Figure 1. A Brookhaven chemist preparing to insert a recoil catcher into the Alternating Gradient Synchrotron's vacuum system. A stack of thin plastic foils on this apparatus will collect recoiling atomic nuclei ejected from a thin uranium target by 28-GeV protons. Subsequent analysis of the individual foils will determine the kinetic energy spectrum of various nuclear species. The insert shows the distribution of ^{28}Mg nuclei obtained in a typical experiment. Such data serve to establish the reaction mechanism responsible for forming the product.

Figure 2. Empirical correlation between mean squared momentum per emitted particle $\langle m_i^2 v_i^2 \rangle$ and the difference in mass, $M_t - M_{obs}$, between target nucleus and observed product. $\circ, \bullet$, ^{149}Tb from Au; $\blacksquare$, ^{149}Tb from Bi; $\square$, ^{149}Tb from Ta; $\triangle$, ^{24}Na from Cu; $\blacktriangle$, ^{24}Na from V; $\diamond$, $^{43,44}\text{Sc}$ from Ag; $\blacklozenge$, $^{61,64}\text{Cu}$ from Ag; $+$, ^{83}Sr from Ag.

of 31 millibarns for the $^{12}\text{C}(\bar{p}, \bar{p}n)^{11}\text{C}$ reaction and 20 mb for $^{12}\text{C}(\pi^-, \pi^- n)^{11}\text{C}$. These values are to be compared with 27.5 mb for the analogous proton-induced reaction.

Theoretical Studies

Additional refinements were made in the Monte Carlo calculations of intranuclear cascades initiated by projectiles below 400 MeV. The introduction of a minimum distance between collisions, plausible on the grounds of nucleon correlations, led to improved agreement with experimental data, particularly when coupled with the use of a velocity-dependent potential. The inclusion of pion production processes in the calculation was initiated.

A theoretical study was made of the approach to statistical equilibrium of two-component Fermi gas systems which have the gross features of excited nuclei produced in medium and high energy nuclear reactions. The object was to characterize nucleon emission from these systems before internal statistical equilibrium is reached.

Two series of calculations have been carried out in collaboration with members of the Department of Applied Science. The computer program GRØGI was improved and expanded to allow de-excitation of the products by emission of charged particles. It was then applied to recent data on the ^{75}Br compound nucleus to determine how much nu-

Figure 3. Partial decay scheme of ^{169}Hf .

clear information can be extracted and to find what further data would be most helpful. The combinatorial calculation of nuclear level densities was generalized from spherical to spheroidal potential wells. At the present early stage it has proved practical to calculate level densities and corresponding distributions of equilibrium deformations up to about 18 MeV for ^{26}Al , but only to 2 MeV for ^{166}Ho .

NUCLEAR SPECTROSCOPY

In connection with the continuing study of cross sections for the production, in high energy proton interactions, of nuclides in the rare-earth region, new data on the half-lives of ^{145}Eu , ^{146}Eu , ^{151}Tb , ^{153}Sm , ^{153}Tb , ^{155}Tb , ^{155}Dy , and ^{160}Er were obtained. Absolute abundances of γ rays emitted in the decay of ^{143}Pm and ^{149}Pm were also determined.

The half-lives and γ -ray energies of ^{168}Hf , ^{169}Hf , ^{170}Hf , and ^{171}Hf were redetermined, and in the case of ^{168}Hf several previously unobserved γ rays were found. The half-life of ^{169}Hf was found to be 3.26 min, not 1.5 hr as reported in the literature. A partial decay scheme of ^{169}Hf was worked out and is shown in Figure 3.

The analysis of data obtained on the decay properties of two newly found isotopes of argon, ^{43}Ar and ^{44}Ar , was completed. ^{43}Ar has a half-life of 5.4 min and a complex γ -ray spectrum. Eighteen γ rays accompanying the decay of ^{43}Ar were measured, and a partial decay scheme was pro-

posed. The ^{44}Ar half-life is 11.9 min, and only five γ rays were observed.

The transition energy of electron-capture decay, ΔE , is generally taken to be the end-point energy of the internal bremsstrahlung spectrum plus the binding energy in the product atom of the electron captured. It was shown at BNL by calculation from theory that an additional term, corresponding to electronic excitation other than the initial level vacancy, has been overestimated by some authors. This term turns out to be $27.2 Z(1 - 0.84 Z^{-0.6})$ instead of $32.6 Z^{1.4}$. Thus for $Z=50$ the additional contribution to the decay energy, ΔE , is ≈ 1.2 keV instead of 8 keV.

$^{113\text{m}}\text{In}$ is known to decay with a 99-min half-life to the ground state of ^{113}In by an $M4$ transition of 393 keV. It was found that there is also a small fraction ($0.07 \pm 0.01\%$) of the decay that proceeds by electron capture to the ground state of ^{113}Cd . The transition energy is calculated to be 80 ± 30 keV.

The study of chemical effects on internal conversion in 58-day $^{125\text{m}}\text{Te}$ decay was essentially completed. Inner and valence electron conversion lines arising from the 109-keV $M4$ transition and from the 35-keV $M1$ transition were measured with sources of metallic tellurium and Ag_2Te . The results showed that the $5p$ electron densities of the tellurium atom are the same, within about 5%, in the two chemical forms. This is true of the $5s$ densities as well. An upper limit thus set for the possible difference in half-lives of these two forms is considerably less than the experimental half-life difference reported in the literature. A definite error, sought and discovered at BNL in the half-life experiments, may account for this discrepancy.

Some progress was made in improving understanding of chemical and physical effects on internal conversion half-lives. Essentially all the experimentally observed half-life perturbations may be accounted for on a basis that has been used to explain the Mössbauer isomer shifts in certain compounds. Given a chemical or physical change that decreases valence electron density, half-lives are increased if density decrease is associated with the subshells that are the major contributors to the internal conversion. If the density decrease is very largely in subshells not internally converted, there is a loss of screening and a resulting increase in the density of those electrons that are internally converted; this produces a decrease in half-life. The sign of the half-life effect, in other words, depends

in first approximation on whether the sublevels involved in the chemical or physical change are the same as, or are complementary to, the sublevels contributing to internal conversion.

The fractional change in nuclear charge radius, $\delta R/R$, that occurs at the 23.9-GeV transition in ^{119}Sn was determined some time ago at BNL from comparison of the Sn metal- SnO_2 Mössbauer isomer shift with valence-shell internal conversion differences measured with $^{119\text{m}}\text{Sn}$ sources in the two chemical forms. This determination has been re-evaluated in the light of new detailed information on screening effects, with the result that $\delta R/R = (1.84 \pm 0.37) \times 10^{-4}$. This value agrees very well with a recently reported value obtained independently and in an entirely different way.

Development of Chemical-Nuclear Rate Coupling Methods for the Study of Chemical Dynamics

The application of short-lived radioactive nuclides to the study of fast chemical reaction rates and related dynamical processes has been shown to be feasible and appears to be general enough to have significant impact in chemical dynamics. The rapid nuclear decay strictly limits the signal to the time scale of interest and maintains a high signal-to-noise ratio with increasing time resolution, unlike more conventional methods in which the signal-to-noise ratio decreases. The use of radioactivity also offers great ease and sensitivity of detection and, because nuclear decay rates are practically independent of chemical state, avoids interference between the investigated system and the probe. Good generality is promised because there is a large number of nuclides of known short lifetimes from which to choose, including both ground and excited states, and a concomitant great range of time scales, from picoseconds to seconds. In addition, the same advantages of labeling are available as with ordinary tracer methods.

The main idea is to arrange apparatus so that the observed signal depends on time-dependent processes associated with the reaction under study. Two dynamical processes, translation and rotation, can be exploited. The use of these two spatial properties, together with the lifetime limitation and associated favorable signal-to-noise properties of the nuclear decay, are what is meant by chemical-nuclear rate coupling.

Experiments are under way to exploit these opportunities. In one, involving translation, chemical

interactions are studied in crossed molecular beams; in the other, involving rotation, the time dependence of the perturbation of angular correlations is utilized to study fast reactions in solution.

THE SEARCH FOR NEUTRINOS FROM THE SUN

The apparatus used to detect solar neutrinos has been described in previous reports. The detector consists of 610 tons of liquid perchloroethylene, C_2Cl_4 , contained in a single tank located 4850 ft underground in the Homestake Gold Mine at Lead, South Dakota. Equipment for extracting ^{37}Ar activity and measuring its radioactive decay is located underground.

A statistical analysis made of the counting data from experiments performed at BNL up to June 1969 indicated a neutrino capture rate in ^{37}Cl of $(2.5 \pm 5) \times 10^{-36} \text{ sec}^{-1}$. In these experiments the sensitivity was limited by the background counting rate of the counter, 0.3 counts/day. The counting system was then moved underground. After solving the shielding and electrical problems associated with this new environment, a lower background was achieved. A single experiment was performed with a counter background of ≈ 0.05 counts/day. This experiment gave a capture rate in ^{37}Cl of $(2 \pm 1) \times 10^{-36} \text{ sec}^{-1}$. These new results are to be compared with the capture rate in ^{37}Cl of $7.6 \times 10^{-36} \text{ sec}^{-1}$ that is expected from solar neutrinos according to present theory.

An experimental study showed that the rise-time of the pulses from ^{37}Ar decay is much faster than that for pulses with the same energy produced by external γ radiation. High-speed amplifiers and a recording system have been added to the underground counting system so that the pulse rise-time can be measured. In future experiments it will be possible to characterize the ^{37}Ar decays by both energy and pulse rise-time and thus effectively reduce the counter background.

Studies have continued with an 11.4-ton detector that can be moved to upper levels in the mine to study the cosmic-ray background effect. A measurement performed at a depth of 300 ft gave a ^{37}Ar production of 3.7 atoms/day. Use of this rate and the decrease in cosmic-ray intensity with depth permitted a calculation of the ^{37}Ar production rate in ^{37}Cl at a depth of 4850 ft of $0.4 \times 10^{-36} \text{ sec}^{-1}$. This cosmic-ray production rate is lower by a factor of ≈ 5 than the measurements noted above.

SPACE CHEMISTRY

The gas extraction, purification, and counting system was built and installed in the Lunar Receiving Laboratory at the Manned Spacecraft Center, Houston. It was tested prior to receiving lunar samples by measuring ^{39}Ar in several meteorite samples. Two 10-g samples of lunar rock No. 10057 and a 10-g sample of the lunar fine material, obtained from the Apollo 11 mission, were studied. ^{37}Ar , ^{39}Ar , and tritium were observed in these samples at approximately the same activity level that is commonly observed in stone meteorites. These activities were measured in two rock samples from the Apollo 12 mission (Nos. 12063 and 12065). The $^{37}\text{Ar}/^{39}\text{Ar}$ ratio from the Apollo 12 samples was more than double that observed in Apollo 11 samples; this increase is attributed to a solar flare that occurred on Nov. 2, 18 days prior to the mission. Analysis of the gas in the rock sample container revealed the presence of ^{37}Ar , which indicates that ^{37}Ar is present in the lunar atmosphere. Combining the argon activity measurements and the rare-gas contents of rock No. 10057 indicates that this rock was on the lunar surface 110 million years.

The cross sections for the production of ^{37}Ar , ^{39}Ar , and tritium in Cl, K, Ca, and Ti targets were measured with 600-MeV protons and the results were used to interpret the observations on the lunar rocks. A thick target of simulated lunar material was bombarded at the Space Radiation Effects Laboratory, NASA, to measure the production of these isotopes as a function of depth.

The ^{36}Cl production cross section was measured in iron and nickel at proton energies of 0.1, 0.2, 0.3, 0.4, and 30 GeV. This cross section is required for an accurate test of the time constancy of cosmic rays from iron meteorite data.

An apparatus was built for studying the diffusion of radioactive isotopes in minerals. Samples of the minerals are activated and the diffusion of the activity is followed in the mineral by high-resolution γ spectroscopy.

The Pueblito de Allende Meteorite

Pueblito de Allende is a type-3 carbonaceous chondrite that fell in Mexico on Feb. 9, 1969. This meteorite's large size and abundant chondrules afforded an opportunity to measure directly for the first time the U- ^{4}He and K-Ar ages of chondrules. They were found to be gas tight, and the two meth-

Figure 4. Calculated and observed intensities as a function of energy transfer at T_N for different momentum transfers q . Observed data taken with incoming neutron energy of 13 meV.

ods yielded concordant ages of $(4.2 \pm 0.2) \times 10^9$ and $(4.44 \pm 0.14) \times 10^9$ years, respectively. Ages as determined by these two methods on the whole rock are not concordant, but this is thought to be due to the presence of primordial argon and helium.

NEUTRON SCATTERING

The many similarities exhibited by dissimilar physical systems undergoing second-order phase transitions have led to a search for general principles underlying all such transitions. One such idea is that of scaling, which has been generalized recently by Halperin and Hohenberg to include dynamic as well as static phenomena. The central concept here is that the behavior of the space-time

Figure 5. The two possible low-temperature spin structures of MgCr_2O_4 : (001) projections. (a) Symmetry $P_{2b}2'2'2$; (b) $P_{2b}222$. ○, Z component "up"; ●, Z component "down."

correlation function is determined essentially by the ratio of the wavelength associated with the fluctuations to a *single* range parameter characteristic of the system. Specific predictions of the theory have been tested by measurement of the energy and momentum transfers in the critical scattering of neutrons from RbMnF_3 . Quantitative agreement with the phenomenological theory of dynamic scaling was obtained over a wide range of energy and momentum. At the Néel point (T_N) the energy dependence of the scattering for various wave-vectors, q , is quite well represented, as shown in Figure 4 by a universal three-peaked function in which the component widths and separations are all proportional to $q^{1.4 \pm 0.2}$, in excellent agreement with the concept of scaling as well as with the specific prediction of an exponent of 1.5. In the hydrodynamic region above T_N (q small compared with the inverse range parameter, κ) the scattering is Lorentzian in energy. The half-width at $q=0$ is proportional to $\kappa^{1.4 \pm 0.2}$, once again in good agreement with the scaling prediction. Over a broad region of the q, κ plane ($T \gg T_N$), where resolution corrections can be omitted, the "half-area" energy widths can be represented by a simple homogeneous function of q and κ , which confirms the basic assumption of dynamic scaling.

In the field of magnetic structure, a number of problems of long-standing interest were resolved. The normal cubic spinel MgCr_2O_4 exhibits two distinct magnetic transitions at $\approx 16^\circ\text{K}$ and $\approx 13.5^\circ\text{K}$. The complex structures associated with the various stability regions were obtained by magnetic space group analysis. The data suggest a coexistence of magnetic phases below 13.5°K . Two possible low-temperature spin structures are shown in Figure 5.

Recent Mössbauer measurements on MnTe_2 by a group at the University of Illinois have shown that the collinear spin arrangement originally proposed for this compound on the basis of neutron diffraction data is inconsistent with the computed angle between the internal magnetic field and the principal axis of the electric field gradient. Reconsideration of the data at BNL has shown that the original model, ordering of the first kind, can be generalized in a way that preserves the characteristic neighbor relationships of the ordering scheme and at the same time accounts for the noncollinear spin arrangement required by the Mössbauer results. The analysis illustrates one way in which the Mössbauer effect can be used in conjunction with neutron diffraction in the study of magnetic structures.

Because the conducting properties and magnetic state of NiS_2 are of interest in connection with the Mott insulator-metal transition, the magnetic structure of NiS_2 has been re-examined. In contrast to earlier published work of others, in which no magnetic ordering was found down to 4.2°K , the present research revealed ordering transitions at 40°K and at 30°K . The average ordered moment per nickel atom is $1.17 \mu_B$, considerably less than that expected on the basis of the observed paramagnetic behavior, which indicated two unpaired electrons.

MAGNETIC PROPERTIES OF CRYSTALLINE COMPOUNDS

The investigation of $\text{NH}_4\text{Fe}[\text{Fe}(\text{CN})_6]$ was completed. A comparison of the Mössbauer spectrum of this salt with that of $\text{K}_4\text{Fe}(\text{CN})_6$ showed that the complex ion is $[\text{Fe}(\text{CN})_6]^{4-}$, no matter how it is prepared. The experiment also showed that the complex salt is stoichiometric, with an ordered crystal lattice. Its magnetic properties are entirely due to the high-spin Fe^{3+} present, the ferrous ion being diamagnetic.

The magnetic susceptibilities of

where (en) = ethylene diamine, (dien) = diethylene triamine, and (trien) = triethylene tetramine, were measured over the temperature range 75° to 373°K . The data of all the compounds could be fitted to the equation $(\chi_{\text{exp}} - \alpha) = C/(T - \theta)$, where

χ_{exp} = measured susceptibility per mole, T = absolute temperature, and C , θ , and α = constants. The antiferromagnetic exchange term was found to be negligible except in the case of $(\text{NH}_3)_6\text{NiCl}_2$, for which $\theta = -10^\circ$. From the values of α , chosen to give a linear relation between $(\chi - \alpha)^{-1}$ and T , the energy difference between the ground and first-excited state was determined with use of the theoretical formula $\alpha = 8N\beta^2/\Delta$, where N = Avogadro constant, β = Bohr magneton, and Δ = energy difference. This energy difference was approximately the same for all salts, with $\Delta \approx 10,800 \text{ cm}^{-1}$.

After correction of the susceptibility for diamagnetism and temperature-independent paramagnetism, the spin-orbit coupling constant of Ni^{++} was calculated from the magnetic moments, which all fell in the range 3.0 to 3.1 Bohr magnetons. Using the equation $\mu = 2\sqrt{s(s+1)} (1 - 4\lambda/\Delta)$ (where $\mu = 3.0 \beta$, s = spin, and λ = spin-orbit coupling constant), $\lambda = -170 \text{ cm}^{-1}$. This value is in reasonable agreement with other determinations of λ in nickel complexes and considerably below the free-ion value, -315 cm^{-1} , which demonstrates the covalency effects of complex formation.

CHEMICAL CRYSTALLOGRAPHY

Stereochemistry of Inorganic Molecules

Sulfur-Ligated Iron(III) and Iron(IV). It was reported last year that the magnetic behavior of iron in ferrihemoglobin closely reproduced that of an $\text{Fe}(\text{III})$ derivative of perfluorodithietene. The structures of perfluorodithietene and its precursor, which contains $\text{Fe}(\text{IV})$, were investigated (see Figure 6). It was verified that both compounds are monomeric and therefore that the reported magnetic behavior is not due to an antiferromagnetic interaction between iron neighbors. An interesting result obtained from this study is that the $\text{Fe}(\text{III})$ derivative (Figure 7), like ferrihemoglobin, is capable of activating molecular oxygen.

The iron atoms in the two compounds investigated were found to be located above the plane of the four sulfur ligands. The $\text{Fe}-\text{S}$ bond lengths are $2.15 \text{ \AA}$ for the $\text{Fe}(\text{IV})$ compound and $2.25 \text{ \AA}$ for the $\text{Fe}(\text{III})$ derivative. This is one of the very few instances in which detailed comparison has been possible between the bonding parameters of two substances that differ only in the formal oxidation number of the central ion.

Substitution of a trialkylphosphine for triphenylphosphine in the Fe(III) derivative yielded a compound that has a normal magnetic behavior ($S = \frac{1}{2}$) and at the same time has lost its ability to activate molecular oxygen. It was also observed that replacement of the $-\text{CF}_3$ groups in the basal plane by $-\text{CN}$ groups caused the Fe(III) compound to lose to a remarkable degree, although not totally, its ability to fix oxygen. These studies indicate the fine balance of ligand forces necessary to prepare an Fe(III) compound capable of fixing molecular oxygen.

Pentacoordination. Compounds with the general composition $\text{Co}(\text{NH}_3)_6\text{MCl}_5$, with $\text{M} = \text{Cu}$,

Figure 6. Structure of $(\text{C}_6\text{H}_5)_3\text{AsFe}[\text{S}_2\text{C}_2(\text{CF}_3)_2]_2$.

Figure 7. Structure of $(\text{C}_6\text{H}_5)_3\text{POFe}[\text{S}_2\text{C}_2(\text{CF}_3)_2]_2$.

Zn , or Cd , were prepared and the crystal structures determined. The copper and cadmium derivatives are isomorphous and contain trigonal bipyramidal MCl_5^{3-} species. The five bond lengths of the CdCl_5^{3-} ions are identical but the axial bonds of the CuCl_5^{3-} ions are axially compressed. This result shows (a) that the d -orbital of copper that contains only one electron is the d_{z^2} -orbital, as has been suspected from optical spectroscopy, and (b) that in the cadmium derivative d -electron-ligand repulsions are responsible for the elongation of the axial bonds relative to the equatorial ones.

It was also found that the zinc salt does not contain ZnCl_5^{3-} anions but rather consists of ZnCl_4^{2-} and Cl^- ions.

Heptacoordination and Octacoordination. The crystal and molecular structure of the heptacoordinated compound tris(N,N -di- n -butyldithiocarbamate) $\text{Mo}(\text{NO})$ (Figure 8) was determined and compared with the ruthenium analogue which was found by Vaciago and co-workers to be hexacoordinated. The difference between the compounds was explained by a simple ligand field argument involving the excess repulsion of the two extra electrons in the ruthenium compound.

A family of $3d$ -transition metal compounds with the general formula tetrakis(1,8-naphthyridine) $\text{M}(\text{ClO}_4)_2$ (Figure 9), where $\text{M} = \text{Mn}^{2+}$, Fe^{2+} , Co^{2+} , Ni^{2+} , Cu^{2+} , Zn^{2+} , or Cd^{2+} , was synthesized. The compounds are all isomorphous, and the crystal structure of the Fe(II) derivative has been studied

Figure 8. Structure of tris(N,N -di- n -butyldithiocarbamate) $\text{Mo}(\text{NO})$.

in detail. It contains 8-fold coordinated Fe(II) with a dodecahedral distribution of the nitrogens around the Fe(II). This is the first dodecahedral cation ever made.

The structure of tetrakis(5-bromo-8-quinolinolato)tungsten(IV)•benzene (Figure 10) has been determined by x-ray diffraction. This tetrakis complex offers the first crystallographic evidence of Orgel's suggestion regarding 8-coordinate MA_4B_4 stereochemistry. The complex contains dodecahedrally coordinated tungsten and closely approximates D_{2d} symmetry. The four quinolinol ligands span the Hoard-Silverton* designated m edges with the π -donor oxygen atoms ($W-N_{av}=2.065$ Å) occupying A positions while the π -acceptor nitrogen atoms ($W-N_{av}=2.199$ Å) are located at the B sites diagonal to the filled metal $d_{x^2-y^2}$ orbital. Other polyhedral parameters include $m=2.499$ Å, $a=2.330$ Å, $b=3.225$ Å, $\theta_a=68.69^\circ$, and $\theta_b=144.13^\circ$. A nonbonded intramolecular oxygen-oxygen contact of 2.33 Å along the dodecahedral a edges emphasizes the importance of ligand-ligand interactions in this 8-coordinate species. The structure correlates well with the observed electronic spectral and magnetic properties of a number of complexes synthesized by collaborators at the University of Massachusetts.

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Figure 9. Structure of tetrakis(1,8-naphthyridine)Fe(ClO₄)₂.

Hydrogen Bonding

Work continued on the polymorphs of ice. Neutron diffraction data were collected for ices VI and VIII to complement the previous studies of ices II, III, and V. Although ice II and ice III have ordered proton arrangements, in contrast to the disordered arrangements in the other ices studied here, there is evidence of partial order in most of the less symmetric structures. The refinement of the order parameters has thus been an important part of the investigation. In order to investigate the short-range order in ice I, the diffuse disorder scattering from a large single crystal of D₂O ice I was measured in collaboration with members of the Physics Department. Calculations show that most of the diffuse scattering can be explained on the basis of a purely random proton arrangement, but there are subtle differences in detail which should lead to better models for the short-range order.

A neutron diffraction study of the structure of lithium hydrazinium sulfate was completed. Both the NH₃ and NH₂ ends of the hydrazinium (N₂H₅)⁺ ion are extensively hydrogen bonded. The large amplitudes of thermal vibration correspond to relatively low barriers to hindered rotation of the two ends of the molecule, but these barriers are not in agreement with the activation energies obtained from deuteron resonance studies elsewhere. This indicates that the assumed simple sinusoidal barrier shape is not adequate. This seems to be generally the case for hydrogen-bonded systems.

Figure 10. Structure of tetrakis(5-bromo-8-quinolinolato)tungsten(IV)•benzene.

Figure 11. AESOP (automatic equi-inclination spectrometer operating in parallel).

Neutron diffraction data were collected on a number of other hydrogen-bonded systems, including glycine and an acetic acid-phosphoric acid complex.

Molecular Dynamics

In addition to the study of hydrogen bond potential functions described above, a refinement of the crystal structure of sodium nitroprusside was completed. The motional parameters for the iron atom were determined and were found to agree well with those obtained from Mössbauer spectroscopy.

A three-axis neutron diffractometer has been put into operation for the study of phonon dispersion curves in molecular solids. Data from hexagonal selenium were collected and the results compared with some simple force constant models. A model with more than second-nearest neighbor interactions seems to be necessary for reproduction of the details of the dispersion surfaces.

Instrumentation and Techniques

A single-crystal orientable x-ray helium cryostat has been put into operation and performs satisfactorily. It will be used for the study of low-temperature phase transitions and for analysis of thermal motion and electron density in molecular solids. The cryostat was developed jointly by Brookhaven and a commercial firm.

Initial mechanical assembly of AESOP, the 128-multidetector x-ray diffractometer (Figure 11), has been completed, and the solid-state detectors have been delivered. This diffractometer will be the first of its kind and will increase by an order of magnitude the rate of data collection from macromolecular crystal structures.

Further work has been done on an interactive display for use in the solution and display of crystal structures (Figure 12). A novel and powerful technique for use in the solution of complex crystal structures is the computer-generated display of molecular structures in three dimensions on the screen of a color television tube. A stereoscopic pair of images is produced, one green and one red. When the display is viewed through appropriate filters, each eye sees one image and a three-dimensional view results. The computer system used allows real-time interaction of the user and the display and thus makes possible, for example, rotation of the molecule and the addition or deletion of atoms. The technique was developed in collaboration with scientists at Texas A & M University.

Molecular Biology

Neutron diffraction has been demonstrated to be a valuable adjunct to x-ray diffraction for the solution of macromolecular structures. The pro-

Figure 12. Scientist working with interactive display system.

gram this year was devoted mainly to the attempt to prepare suitable crystals of biologically active materials containing the anomalously scattering isotopes of cadmium or samarium for use in the phase-determination step of the crystal structure solution.

Neutron diffraction data have been collected on glycyl-glycine hydrochloride in order to study the stereochemistry involving hydrogen atoms and to confirm the bifurcated hydrogen bond suggested by Parthasarathy on the basis of x-ray diffraction work.

INORGANIC REACTIONS IN SOLUTION

Reaction Kinetics

The accepted two-step mechanism for the oxidation of iron(II) by thallium(III) in perchlorate medium involves formation of the unstable oxidation state thallium(II) and the competitive reactions of this intermediate with iron(III) and iron(II). The same scheme has been proposed for the reaction in the presence of chloride, with which thallium(III) forms a series of complexes. A detailed study of the reaction in the $[\text{Cl}^-]$ range 0.05 to 3.0 M was undertaken to ascertain whether the kinetics give evidence for thallium(II) inter-

mediate, and, if so, to characterize its behavior. Such evidence was found; the reaction is markedly retarded by iron(III). In the competition between iron(III) and iron(II) for the intermediate the reaction with iron(III) is favored, while in perchloric acid the opposite is true. Two reaction paths for the formation of the intermediate were inferred. In one the activated complex contains four Cl^- , in the other five Cl^- . In disagreement with another investigation the formation reactions were found to be much slower than the corresponding reaction in HClO_4 . Their relative slowness is ascribed to the effect of chloride complexing on the overall standard free-energy change.

In studies elsewhere it was found that photochemically produced thallium(II) accelerates the two-electron exchange between thallium(I) and thallium(III) by virtue of rapid exchange reactions between thallium(II) and these species. It was therefore anticipated that iron(II) would also accelerate the thallos-thallic exchange through the formation of a steady-state level of thallium(II). This effect was observed and systematically studied. One aim is to estimate from kinetic data the free energy of formation of $\text{Tl}_{\text{aq}}^{2+}$. Certain features of the rate law require further elucidation and are being investigated.

Comparisons of the effect of azide and thiocyanate on the rates of electron transfer reactions involving metal ions are being used at BNL and elsewhere as a basis for determining whether a particular reaction proceeds by a bridging mechanism. If the metal centers of the oxidizing and reducing agents are hard, and if transfer of the bridging group occurs during the reaction, then an electron transfer reaction should proceed faster when the bridging group is azide than when it is thiocyanate. This is principally due to the increased stability of a metal-nitrogen over a metal-sulfur bond. To further explore these effects, the kinetics and mechanism of the reaction of $(\text{NH}_3)_5\text{CoSCN}^{2+}$ with Fe^{2+} were studied. Comparison of the rate constant for this reaction with the rate constants for the reaction of Fe^{2+} with $(\text{NH}_3)_5\text{CoNCS}^{2+}$ and $(\text{NH}_3)_5\text{CoNNN}^{2+}$ showed that the bridging order of the ligands is $\text{SCN}^- > \text{NNN}^- > \text{NCS}^-$. This is the same order as that observed in the reactions of Cr^{2+} with CrSCN^{2+} , CrNNN^{2+} , and CrNCS^{2+} . An analysis of the rate variations in these systems yielded useful information about the electron transfer mechanisms, as well as quantitative information about the

Figure 13. Aligning the neodymium laser used in the temperature-jump studies.

stability constants of MNCS^{2+} compared with MSCN^{2+} complexes.

Potentiometric and spectrophotometric measurements were made on cobalt(III) solutions, and rate laws for the reaction of cobalt(III) with a variety of reducing agents were determined. These studies establish that cobalt(III) exists predominantly as a monomer in perchloric acid solution and show that the conclusions about the nature of cobalt(III) solutions reached earlier by other workers are in error.

Construction was begun of a temperature-jump apparatus (see Figure 13) capable of following reactions with half-lives ranging from 50 msec to about 50 nsec. In this apparatus a Q-switched neodymium laser is used to irradiate an aqueous solution; the temperature rises rapidly, and the chemical equilibria obtaining in the solution are perturbed. Relaxations have been observed in the following systems:

(HAA = 2,4-pentanedione). These relaxation times are in good agreement with those obtained by more conventional methods. It was shown that the stimulated Raman effect in liquid nitrogen can be used to shift the wavelength of the radiation emitted by the neodymium laser from 1.06 to 1.4 μ , where water absorbs 1.5×10^2 times more efficiently.

Equilibrium Studies

Extensive data have been obtained on the distribution of a number of strong mineral acids (HCl , HClO_4) and complex metal acids (HFeCl_4 , HTiCl_4 , HTiBr_4) between water and organic solvents such as tributyl phosphate and methyl isobutyl ketone. The results are relevant to general questions of complex formation, ionic hydration, and ion association, i.e., the formation of ion pairs ($\text{H}^+ \cdots \text{X}^-$) and anionic triple ions ($\text{X}^- \cdots \text{H}^+ \cdots \text{X}^-$). The acids extracted into the organic phase are characterized by triple ion formation constants of the same order of magnitude, but the values of the different ion pair formation constants differ by a factor of 10^4 . The competing influence of ionic hydration and ion association is apparent from these studies. A direct connection was found between the relative instability of the anion, caused by loss of water molecules from its primary hydration shell, and the magnitude of the ion pair formation constant. The driving force for the triple ion formation arises mainly from the relative instability of the hydronium ion, which loses its hydrating water more readily from the bound state of the ion pair than from the free ion state in solution. Different models for anionic hydration have been developed. These models account for the behavior of structure-forming and structure-breaking electrolytes and explain the differences in the solvent extraction properties and ion pair formation constants of the acids studied.

REACTION MECHANISMS IN ORGANIC SYSTEMS

Hot-Atom Chemistry

Research in hot-atom chemistry was carried out with isotopes produced by the BNL 60-in. cyclotron. Mechanistic studies were continued and focused on the structure and nature of the inter-

mediates produced in carbon atom reactions. Two major approaches were used. The first involved the effect of halogen on carbon atom reactivity, and the second involved the study of intramolecular reactivity effects with use of specifically deuterated compounds. A group of 20 halogenated methanes were studied. These included all the CH_3X through CX_4 compounds, where X is F, Cl, Br, or I. In addition, mixed halogenated methanes were investigated. The results focus attention on a new aspect of these carbon atom reactions, namely, electronic effects in the primary reaction step. Correlation of yields of acetylene with the deshielding effects of halogen were obtained, which showed that the insertion step is strongly dependent on electron availability. The studies further demonstrated that the high yields of CO_2 from fluorocarbons are uniquely due to the presence of fluorine, since all other halocarbons showed CO_2 yields identical with those observed in hydrocarbon-oxygen systems. Complementing these studies, a number of experiments on the radiolytic behavior of these systems were conducted to allow the hot-atom results to be adjusted for the radiation chemical effects occurring simultaneously. A large number of specifically deuterated compounds were run, including 3-phenylpropane-1- $^2\text{H}_3$, 3-phenylpropane-2- $^2\text{H}_2$, 2-phenylpropane-3- $^2\text{H}_2$, etc.; 3-phenyl- $^2\text{H}_5$ -propane, 2-phenylethane-1- $^2\text{H}_3$, 2-phenylethane-2- $^2\text{H}_2$, etc.; *ortho*, *meta*, and *para* chlorotoluene- α - $^2\text{H}_3$, etc. Three effects were studied in detail: the pronounced deactivating effect of halogen on the acetylene yield resulting from carbon atom-aromatic ring attack, the unique reactivity of the methylene α to the aromatic ring, and the extensive hydrogen rearrangement in the energetic complex formed after carbon atom attack. The results from these experiments also complement those for the halogenated alkanes, since they focus attention on a new aspect of carbon atom reactions, sensitivity to electronic effects.

Other series of experiments using ^{11}C were concerned with moderation studies in alkane-oxygen systems, extensive dosimetry studies in fluorocarbon systems, and pressure-moderation studies in alkane-oxygen systems. In all these hot-atom studies more fundamental information is being obtained about the nature of chemical reactions of highly energetic atomic species. These results can be used to complement other studies, both theoretical and experimental, such as trajectory calculations, shock

tube and molecular beam experiments, and reactions in plasmas.

Application of Hot-Atom Reaction Studies in Medicine

^{11}C and ^{18}F , both cyclotron produced, were used to produce compounds of interest in medical research. The techniques used involve a combination of both recoil and synthetic techniques such that the compound of interest can be prepared in the shortest possible time. A systematic study of various methods of preparing cyanide- ^{11}C was carried out. Of all the methods studied, the best are direct recoil labeling by the irradiation of NaCN with 33-MeV protons, chemical conversion of recoil-produced ^{11}CO to $^{11}\text{CN}^-$, and irradiation of $\text{N}_2\text{-H}_2$ mixtures. Methods of preparing sugars and amino acids containing ^{11}C were studied. Dopamine labeled with ^{11}C was supplied to the Medical Department. ^{18}F was used to label amino acids. A particularly promising compound currently in production is *p*-fluoro- ^{18}F -phenylalanine, which was shown to have high pancreas specificity in mice and rats. Experiments in man for purposes of pancreas visualization are under consideration. Capability in this area is continuing to grow. Targets for routine production of precursors have been built and are in operation, and an increasingly broad spectrum of compounds is under investigation. The work is important not only for its obvious use in medical research and clinical application but also because it is a clear, practical application of the research in hot-atom chemistry and labeling techniques carried out in the BNL Chemistry Department in the past.

New Methods of Labeling

Research on new labeling techniques involving the use of tritium atoms generated in a microwave plasma has resulted in the labeling of adrenocorticotropin (ACTH) without loss of biological activity. Heretofore more conventional methods of labeling protein hormones with tritium have failed because the material obtained was no longer biologically active. It is hoped that this promising result will make a whole new series of tritium-labeled compounds available for medical and biological research.

Organic Reaction Mechanisms

Work on organic reaction mechanisms was continued on carbon atoms generated from carbon

suboxide in microwave plasmas. Direct observation of both $1D$ and $1S$ carbon atoms in helium carrier gas *downstream* from the microwave *discharge* was accomplished with use of spectroscopic techniques. This direct observation of atomic species supports previous work in which the presence of these atomic species was inferred and provides a new way of studying rates of reactions involving electronically excited atomic species.

Studies involving carbene analogues of species produced in hot-atom reactions were continued. Substantial evidence was obtained for the formation of tetrahydrene (a molecule of considerable theoretical interest) in the photochemical reaction between cyclopropene and carbon suboxide.

These studies provide information on the reactions of electronically excited carbon atoms and thus help in the delineation of electronic and kinetic effects in hot-atom studies.

Secondary Deuterium Isotope Effects in Radical Formation

The secondary β -deuterium isotope effect in the formation of ethyl radicals in solution has been measured. 3-Methyl-3-pentoxyl-1,1,1- d_3 radical (I), formed initially through photolysis of 3-methyl-3-pentanol-1,1,1- d_3 hypochlorite, undergoes thermal

cleavage to give methyl ethyl ketone and ethyl radical (Eq. 1). Ethyl radicals abstract chlorine from hypochlorite to regenerate (I) and thereby propagate the chain. The isotope effect was determined between 0° and 80°C in mixed solvent (acetic acid, acetonitrile, and carbon tetrachloride) and in carbon tetrachloride alone. The isotope effect, k_H/k_D ($3D$ atoms), ranges from 1.247 (80° , mixed solvent) to 1.282 (0° , CCl_4). The effect is the largest yet encountered for secondary β -deuterium effects in radical reactions and is in accord with theoretical calculations which show that the largest part of the isotope effect arises from hyperconjugative stabilization of the incipient ethyl radical. Moreover, comparison of the magnitude

of β -deuterium effects observed in the formation of carbonium ions with that of radicals further suggests that these are not steric isotope effects but arise from hyperconjugation.

Model Systems for Enzyme-Catalyzed *cis-trans* Isomerizations

Studies continue with model systems to help elucidate the role of the enzyme maleylacetoacetate isomerase and the coenzyme glutathione in their catalytic effect on the isomerization of maleylacetoacetic acid (I) to fumarylacetoacetic acid (II).

Previous studies have focused on *cis*- β -acetylacrylic acid as a model for the natural substrate (I). A new substrate, maleylacetone (III), much closer

in structure to (I), has been synthesized. It undergoes rapid catalyzed *cis-trans* isomerization and is so close in structure to (I) that it is a substrate for the enzyme.

ISOTOPE EFFECTS

In the temperature region where vibrational energy level spacings are small compared with thermal energy, the kinetic isotope effect is given by

$$\ln(k_1/k_2) = A + BT^{-2},$$

where k_1 and k_2 are rate constants for two isotopic variations of the same molecule. The coefficient B can be expressed in terms of vibrational force constants and molecular parameters of the two isotopic reactant molecules and the corresponding activated complexes. Many of the ele-

ments of this expression cancel, either because the molecular parameters are independent of isotopic substitution or because force constants do not change during the course of reaction.

This approach has been applied to the reactions

and

In these cases, the B coefficient can be expressed in terms of only a few force constants. This method provides a more obvious connection between isotope effects and force constant changes than does the more conventional approach, which requires explicit evaluation of all the molecular vibrational frequencies.

RADIATION CHEMISTRY

Radiation Chemistry of Cyanide Solutions

Aqueous solutions of cyanide ion have not been much studied by radiation chemists, although extensive work has been done on similar compounds such as bromide, iodide, and thiocyanate ions. However, the reactions of free radicals on cyanide are particularly interesting, since they are believed to have played a role in the origin of life. The problem is approached in two ways: (1) by pulse radiolysis, to determine the immediate transient species formed by action of OH radicals on cyanide ion; and (2) by determination of the final products produced by prolonged irradiation. In (1), transients have been seen and characterized by absorption spectra and decay kinetics; to assign them chemical formulas, further pulse radiolyses of solutions of related compounds (cyanogen, cyanate ion) are being carried out. In (2), minute quantities of five different organic products have been separated from irradiated cyanide solutions by paper chromatography and column chromatography, and identification of these compounds is under way.

Properties of HO_2

Various authors agreed that the pK of HO_2 was 4.5 ± 0.15 and that two of the three possible recombination reactions of the species, $\text{HO}_2 + \text{O}_2^-$ and $\text{O}_2^- + \text{O}_2^-$, were faster than the third reaction, $\text{HO}_2 + \text{HO}_2$. Further work indicated that the observed recombination rate decreased drastically as the pH of the solution increased above

7. A reinvestigation of HO_2 in oxygen-saturated water and in oxygen-saturated sodium formate solutions demonstrated that (1) the pK of HO_2 is actually 4.9 ± 0.1 ; (2) the reaction $\text{O}_2^- + \text{O}_2^-$ is at least 4 orders of magnitude slower than $\text{HO}_2 + \text{HO}_2$; (3) the recombination kinetics between pH 0 and pH 14 are consistent with a single pK for HO_2 ; and (4) the error in earlier work was due to poorly defined pH values for the solutions used.

The Spur Model of Water Radiolysis

The spur model of water radiolysis holds that many observed effects, including the formation of the molecular products hydrogen and hydrogen peroxide, are due to the inhomogeneous distribution of the radiation-produced free radicals, which are formed in groups called spurs. Subsequent reactions of these radicals while diffusing in the bulk of the solution produce the observed effects. Earlier tests of the model at Brookhaven demonstrated that it was consistent with almost all known facts of water radiolysis but that about $\frac{1}{3}$ of the molecular hydrogen was formed in some other process. Others pointed out that, in all such calculations, a unique radius is assumed for spurs containing any given number of radicals. It has now been shown at Brookhaven that the shape of the curve relating molecular product formation and the concentration of solutes capable of reacting with the radicals is essentially unchanged by assuming a statistical distribution of spur sizes. In further work, model predictions for the formation of $\text{H}_2^{18,18}\text{O}_2$ and $\text{H}_2^{16,18}\text{O}_2$ in solutions of $\text{H}_2^{16,16}\text{O}_2$ in H_2^{18}O have been made. There are two reports on the systems in the literature. The calculated yields are in agreement with the earlier study, but the calculated $\text{H}_2^{16,18}\text{O}_2$ yield is only half that reported in the later study.

Mobility of Electrons in Hydrocarbons

Until recently, the only charge carriers observed in irradiated hydrocarbons were ions of mobility about 0.001 in the usual units ($\text{cm}^2/\text{V}\cdot\text{sec}$). It was mentioned in last year's report that a population of high-mobility electrons had been seen here in irradiated neopentane and tetramethylsilane (TMS). These electrons are easily captured by traces of impurities, but their mobilities have been determined by a method involving measurement of the buildup of current during a very short pulse of radiation (a few microseconds) during which

the carefully purified hydrocarbon was subjected to a high voltage between parallel plates. Under these conditions the lifetime of the electrons is too short to allow capture by impurities or recombination with positive ions. Successful measurements were made in eight saturated hydrocarbons as well as TMS. The results were rather astonishing. Although in all other physical properties these liquids are very similar, they showed electron mobilities ranging from 0.09 (hexane) to 90 (TMS), a factor of 1000. The degree of branching or symmetry of the molecules seemed to be the major factor in determining the electron mobility.

No adequate theory exists as yet to explain these results. It seems likely that the electrons moving through the liquid are scattered from places where the electric potential is higher or lower than the average in the liquid because of fluctuations in the arrangements of the C—H bonds in adjacent molecules. The more symmetrical the molecules, the smaller the potential fluctuations and the less the electrons are scattered.

Total Initial Ionization Yield in Liquids

Most of the electrons formed in liquids by irradiation recombine immediately with the ions from which they came; the fraction escaping depends on their interaction with the liquid molecules. Application of a strong electric field to the irradiated liquid increases the number escaping, but in most liquids the fraction escaping remains small, even when the applied field is so large as to threaten breakdown of the liquid, and no good determination of the total yield can be made. It has now been shown that in liquid argon and in neopentane, which scatter electrons much less than most other liquids, the total number of ions can be obtained by a small extrapolation and is equal to the number formed in the same materials when in the gaseous state at low densities.

Radiolysis in Heterogeneous Systems

This work has involved substances that readily accept an electron to form a stable radical anion, like tetracyanoethylene, or that give up an electron to form a radical cation, like triphenylamine or tetra-*N*-methyl phenylenediamine. Adsorbed on a silica surface (in these experiments, porous Vycor), these molecules under γ rays gained or lost an electron with a high yield (G up to 6) which was practically independent of the amount of substance adsorbed. Remarkably high yields

of the radical ions (G up to 4) were found even when the Vycor was irradiated under vacuum and the material put on the surface later. These results are in contrast to those of previous studies, in which an ordinary organic compound such as a saturated hydrocarbon or alcohol was irradiated while adsorbed; there, the reaction was one of decomposition, the yield gradually increased with increasing concentration of adsorbed material, and very little or no reaction was seen if the substrate was irradiated alone and the adsorbate added later. The new findings cast new light on the subject of radiolysis in heterogeneous systems, especially those including metal oxides or other ionically bonded components.

It appears that radiation-generated electrons and holes (or excitons, which may be regarded as electron-hole combinations) migrate fairly long distances through the matrix and are trapped at the surface in the form of a permanent, or at least long-lasting, alteration of the bonding of the surface atoms. These centers can give up or take electrons from adsorbed molecules that have especially high affinity for electrons or holes and run into these centers in the course of their random migrations over the surface. As the irradiation proceeds, the arrival of further electrons and holes results in occasional neutralization of those already trapped, with liberation of energy, which is quickly dissipated in the immediate neighborhood of the surface trap. If an adsorbed molecule such as hydrocarbon or alcohol happens to be in this neighborhood at the time, it may become excited and decompose; hence the concentration dependence and generally lower yield of the hitherto studied decomposition reactions, as compared with the recently studied electron- and hole-trapping reactions.

Work Function Measurements in Dielectrics

Measurements are being made of the photoelectric work function of metals that are in contact with dielectric liquids. The initial measurements indicate that the work function is decreased by 0.35 and 0.7 eV in 2,2,4-trimethylpentane and tetramethylsilane, respectively. This lowering represents the electron affinity of the liquid. The results provide additional insight into the properties of electrons in these liquids.

Inorganic Hot-Atom Chemistry

Recoil reactions of four isotopes of molybdenum in crystalline molybdenum hexacarbonyl were in-

vestigated. The pattern of annealing behavior of two of these (^{99}Mo and ^{101}Mo) was found to show an "isotopic" difference which, surprisingly, appeared in the activation energy. Studies of the β -decay-induced recoil reactions of technetium in ^{99}Mo -labeled hexacarbonyl revealed the presence of a volatile compound labeled with ^{99}Tc , which decomposed rapidly in the presence of water.

Work was begun on fast-neutron-induced recoil reactions of ^{51}Cr in potassium chromate crystals, and of ^{202}Tl in thallous salts.

GASEOUS ION CHEMISTRY

Considerable work has been done in developing the high-pressure ion source-tandem mass spectrometer system. The system was used to generate a variety of solvated protons and hydroxyl ions, i.e., H_3O^+ , H_5O_2^+ , H_7O_3^+ , H_9O_4^+ , $\text{H}_{11}\text{O}_5^+$, etc., and OH^- , H_3O_2^- , H_5O_3^- , H_7O_4^- , etc. These ions were shown to have been prepared in excited states resulting, in part from the distribution of heats of reaction in their synthesis among internal degrees of freedom and in part from reaction of excited molecule ions. Extensive studies have been made of the thermochemistry of these solvated ions. Data gathered from measurement of thresholds of collision-induced dissociation reactions provide a measure of the proton affinity of water and show clearly that the heats of solvation of H_3O^+ and OH^- are indeed very similar. The magnitudes of hydrogen bonding energy of these charged species were determined quantitatively and found to be identical, within limits of experimental error, in spite of the asymmetric structure of the water molecule and differences in the orientation of

water dipoles on approach to H_3O^+ and OH^- respectively.

Sizes of solvated protons and hydroxyl ions were determined by measurement of ion attenuation cross sections when energetic ion beams were passed through a collision chamber filled with helium gas at low pressure. Similarities in size of H_3O^+ and OH^- , of H_5O_2^+ and H_3O_2^- , of H_7O_3^+ and H_5O_3^- , etc., were observed which were well correlated with hydrogen bonding energies in these systems. The experimental data on solvated ion size and heats of solvation have been used with additional thermodynamic data to deduce a value of 12.0 ± 0.3 eV for the total heat of hydration of the proton in aqueous solution.

THEORETICAL CHEMISTRY

Reactivity Studies in the Molecular Orbital and Linear Free-Energy Frameworks

The problem of definition of areas of trustworthiness of approximate quantum chemical methods discussed in the previous annual report continued to be investigated, with emphasis on the structures and energetics of reactive complexes as they influence the rates and alternate pathways for reactions. The specific case of proton exchange in methane was examined in detail. Among the significant results obtained was the fact that the semiempirical CNDO (complete neglect of differential overlap) method correctly predicted the stability order of the CH_5^+ complexes expected as intermediates in the reaction, in agreement with the more exact *ab initio* Gaussian orbital calculation results, and that pathways for reaction by isomerism of initially formed complexes should allow production of stereoisomers not expected from the classical picture for the exchange (see Figure 14). Work was done on means of experimental verification by employing optical activity studies on somewhat more complicated substrates undergoing proton exchange, and on theoretical examination of the similar reaction, exchange of neutral hydrogen on methane.

Refinement of the substituent constants, σ 's, in the dual substituent linear free energy equation, $\log k/k_0 = \rho_I \sigma_I + \rho_R \sigma_R$, has progressed to the point where the differences and similarities of effects of the various substituents in aromatic reactions of the benzoic acid, conjugatively insulated, electrophilic, and nucleophilic types are well understood. These σ scales now allow classification as to mech-

Figure 14. An energetically favorable pathway for stereochemical racemization accompanying hydrogen exchange in hypothetically labeled methanes.

anism and solvation effects of reactions for which a representative body of data exists. These constants, beyond their obvious use in correlation of reactivities, present the means for quantitative testing of new models for specific site solvation, particularly hydration, in molecules undergoing reaction. Related work on the theoretical aspects of hydration of the simple ions H^+ and OH^- , studied mass spectrometrically within the last year, has obvious implications when extended to the question of specific site hydration in complicated organic molecules in solution.

Complementing the studies concerned with kinetic aspects of reactivity, tests were made of the trustworthiness of semiempirical quantum chemical methods on stability of hydrocarbons in the purely thermodynamic sense. Good correlation of heat of formation with bond order for a large variety of hydrocarbons was obtained by the CNDO method. Upon analysis it was shown that bonding as reflected in the heat of formation is due principally to classical exchange terms of the form $\sum P_{\mu\nu} S_{\mu\nu} \beta_{\mu\nu}$, where P , S , and β are respectively the bond order, overlap integral, and exchange integral between orbitals μ and ν on different atoms. Differential effects in one-center energies are shown to be negligible, and cancellation of P^2 -dependent exchange terms by the repulsion and nuclear-electron attraction terms was likewise demonstrated. Among the more significant implications of this study are that the molecular orbital (MO) bond order has a real and direct meaning with respect to bonding in hydrocarbons, and, because of the simplicity of the correlation equation, that correction of the parameters β for CC and CH, and presumably for heteroatom interactions as well, may be but a simple scaling problem to account for a most important molecular property, i.e., the heat of formation.

A Computer Program for Molecular Wave Functions

In the initial segment of the current research most of the effort has been directed toward adapting a large number of computer programs to the BNL CDC 6600 computer. Care has been taken to optimize the efficiency of all programs. The research involves the establishment and application of a quantum chemistry system, i.e., a fully integrated set of computer programs offering the capability of calculating molecular wave functions and a wide variety of molecular properties. A broad range of theoretical methods, from semiem-

pirical to *ab initio*, will be included, and it is anticipated that it will be feasible with current computer capability to undertake *ab initio* calculations for systems with as many as 100 electrons. The study of even larger systems will be possible with semiempirical methods. Properties of interest will include first-order effects such as ionization potentials, dipole moments, quadrupole coupling, and spin densities, and second-order effects such as polarizability, spin-spin coupling, and force constants.

Programs for generating single-configuration atomic and molecular orbital wave functions, both semiempirical and *ab initio*, are already in working order, and preliminary *ab initio* studies of potential energy surfaces for some chemical reactions have been carried out.

One project has been essentially completed: the study of the effect of conjugation on the degree of localization of bonds in the MO approximation. The *ab initio* MO's for methyl acetylene (hyperconjugation) and butadiene and benzene (conjugation) were localized by minimizing interorbital exchange energy. The curvature in the vicinity of this minimized quantity was found to provide a convenient quantitative measure of the tendency of MO's to localize. Thus the curvature associated with the double bonds in localized, or "Kekule," benzene is much smaller than the corresponding quantities for the double bonds in ethylene and butadiene. The conjugated double bonds in butadiene do not lead to any significant delocalization and are found to be virtually indistinguishable from the ethylene double bond.

Theoretical Studies of Chemical Reactions in Gases

Preliminary calculations of the rate of reaction between fluorine atoms and molecular hydrogen in the gas phase were completed. This study involved analysis of a large number of classical trajectories on a semiempirical potential energy surface. A computer program for the efficient handling of the statistical and numerical details of the calculation was developed. The preliminary results are in qualitative agreement with experimental data, which suggests that the method should accurately predict kinetic isotope effects when an optimized potential energy surface for a single isotopic system is employed. Such an optimization procedure is currently in progress.

A detailed experimental and theoretical study of the reactions of D^+ and H_2 , of H^+ and D_2 , and of D^+ and HD is nearing completion. The most

PHOTOMICROGRAPH

SCATTERED ELECTRON MICROGRAPH

SILICON X-RAY MICROGRAPH

ALUMINUM X-RAY MICROGRAPH

IRON X-RAY MICROGRAPH

CALCIUM X-RAY MICROGRAPH

Figure 15. Electron-beam microprobe study of inclusions within the ceramic core of a bronze statue.

significant aspect of this work is the discovery that none of these reactive systems can be explained in terms of a single potential energy surface at energies above the thresholds for various endothermic nonadiabatic reaction channels.

INVESTIGATIONS OF ARCHAEOLOGICAL AND HISTORICAL MATERIALS

Correlations are being established between the composition of Mayan pottery and specific clay sources from Mesoamerica. Examination by the electron-beam microprobe of cross sections of a

number of oil paintings has revealed new information about the nature and chronology of pigments used in these paintings. The electron-beam microprobe technique has also been applied to the determination of the microstructure of various works of art (see Figure 15). A neutron autoradiograph of a painting by the nineteenth-century American artist Blakelock has shown details of how he applied his pigments and which ones he employed. The number of elements determined nondestructively by the neutron activation analytical technique has been significantly increased.

Applied Science

The Department of Applied Science continued to engage in scientific and developmental activities, principally of an applied nature, that fulfill recognized objectives of a National Laboratory and are consistent with the character of Brookhaven. These activities are of a pioneering nature with a high degree of technical sophistication; they are required either to fulfill a national need for which the Laboratory has unique capabilities, or for the general research program of the Laboratory.

Within this general framework, the activities of the Department can be grouped into three categories:

1. Research and development, not necessarily of a nuclear nature, directed toward applications of atomic energy.

2. Research and development, and engineering when required, in support of other scientific programs of the Laboratory.

3. Research and development in the service of other national needs, with the agreement of the AEC, in cases in which Laboratory facilities and staff capabilities are superior to those of other agencies and in which the foregoing guidelines are clearly satisfied.

BNL personnel were involved in a study of operating and maintenance costs of the U.S. nuclear power industry for the US AEC's Division of Reactor Development and Technology. Other work for the Division concerned a pumped storage study and the development of codes and standards applicable to the reactor field.

In the Reactor Physics Division, theoretical and experimental work emphasized studies in support of the Liquid-Metal-Cooled Fast Breeder Reactor (LMFBR). These included experiments to resolve uncertainties in the breeding gain of fast breeders and in calculations of the effects of their heterogeneity. Theoretical work included reactor dynamics, transport and slowing-down of fast spectrum neutrons, and fluid dynamics, as well as the analysis of critical experiments. A compendium of fast critical experiments was initiated and cooperative work on computer code coordination was carried out for the AEC.

The Nuclear Materials Division, which provides technical advice and guidance to the US AEC's Office of Safeguards and Materials Management, conducted field tests of nondestructive assay instruments at four selected facilities. The program of analytical and system studies included the development of a computer simulation model to replicate the flow of nuclear material in the fuel cycle.

Meetings of the Cross Section Evaluation Working Group were hosted by BNL's National Neutron Cross Section Center (NNCSC) in September 1969 and March 1970. In addition, the NNCSC participated in a workshop meeting, sponsored by the International Atomic Energy Agency (IAEA), of the world's four neutron data centers in November 1969 in Moscow.

A PDP-10 computer was purchased from the Digital Equipment Company and officially installed in October 1969 at the NNCSC, for its exclusive use in meeting the growth rate and expanded use of its neutron data libraries.

Members of the Chemistry Division have undertaken a joint effort on porphyrin chemistry with scientists from the Brookhaven Medical Department and the Harvard University Chemistry Department. The results have shed light on the mechanism of such vital biochemical processes as respiration and photosynthesis.

In the same Division, the metal hydride program is bearing fruit. Hydrides were first chosen for study because of their potential as hydrogen storage media, and this application is now of interest in connection with fuel-cell systems used by the military. An unexpected dividend of the research has been the discovery of unusual isotope effects, which may prove useful in separation processes.

Dr. J.M. Hendrie was elected Chairman of the AEC's Advisory Committee on Reactor Safeguards for calendar 1970. He became a member of the committee in 1966 and served as its vice-chairman in 1968.

Dr. Hendrie was also named as a recipient of the E.O. Lawrence Memorial Award for 1970. This award is presented to persons who have made

especially meritorious contributions to the development, use, or control of atomic energy in all scientific areas related to atomic energy, including medicine and engineering.

The Radiation Division received a letter of commendation from President Nixon on the development of concrete-polymer materials. The Division was also the recipient of an "IR-100" award citing these materials as one of the most significant product developments of the year.

A study demonstrated the feasibility of building the Brookhaven Linac Isotope Producer (BLIP), a facility for producing radionuclides via spallation induced by 200-MeV protons from the linear accelerator injector to the Alternating Gradient Synchrotron. The BLIP will be vital to the Hot Laboratory Division's program of developing radionuclides for medical and other applications.

In addition to presenting several invited papers and lectures at various scientific conferences and university chemistry departments, members of the Hot Laboratory Division co-authored a chapter in an IAEA manual on radioisotope production, assisted in establishing a medical radionuclide program at the Puerto Rico Nuclear Center, and advised the AEC on cyclotron production of medical radionuclides.

In anticipation of budgetary cuts that have since materialized, many departmental programs were reduced in scope or phased out at the end of the fiscal year.

EVALUATION AND TECHNICAL ASSISTANCE

The Evaluation and Technical Assistance Group carried out two major studies for the AEC's Division of Reactor Development and Technology (RDT). In the first study the operating and maintenance costs for nuclear power plants were determined and evaluated. Cost data were reviewed and compared for the various reactor systems and for fossil-fueled plants. The unique features of each reactor system influencing operating and maintenance costs were identified.

In the second study, the market potential of hydroelectric pumped storage power used in conjunction with nuclear base-load power for the U.S. generating system was assessed. An attempt was made to determine quantitative, as well as qualitative, effects of pumped storage power on operating system characteristics.

BNL is participating in the RDT-sponsored programs at Oak Ridge National Laboratory and the Liquid Metal Engineering Center at Atomics International for the development of codes and standards applicable to the reactor field. More than 79 standards involving current power technology and engineering practices, as well as the development of new standards for AEC-owned water reactors, were reviewed in detail at BNL, and the comments were forwarded to ORNL.

REACTOR PHYSICS

Theoretical Reactor Physics

The theoretical reactor physics effort was primarily in support of fast breeder reactors. The analysis of BNL experiments included exponential experiments on Pu-Al rods in heavy water and an experiment to determine capture-to-fission ratios of ^{239}Pu and ^{235}U by foil irradiations in the High Flux Beam Research Reactor (HFBR). The analysis of non-BNL fast reactor experiments included ZPR assemblies at Argonne National Laboratory and a series of fast critical experiments carried out at the Lawrence Radiation Laboratory and Los Alamos Scientific Laboratory. An analysis of a series of light and heavy water moderated critical experiments was carried out to determine the adequacy of the standard ENDF/B cross-section library for the design of modern power reactors.

In computer code development, the NOMURK code was developed and used for reactor kinetics and safety studies. Other kinetics codes used by industry were tested and made operational on the CDC 6600 computer. The REPCDC and MOCA Monte Carlo codes for resonance energy and fast neutron transport in reactor lattices were developed for the CDC 6600 and compared with standard codes used for these purposes, such as HAMMER, ZUT-TUZ and RABBLE. These comparisons revealed serious inadequacies in the latter codes. Similarly, the AEC-sponsored code mc^2 and its auxiliaries were made operational. A number of defects in this code were corrected. Other inherent defects, particularly in the treatment of resonance capture and anisotropic scattering, were pointed out to the originating laboratory.

In the cross sections area, the analysis of integral experiments revealed inadequacies in ENDF/B data for ^{238}Pu and other fast reactor materials. The most serious unresolved problem was the un-

certainty in values of α for ^{239}Pu at intermediate energies. The BNL work aided greatly in the resolution of this problem. In addition, discrepancies were uncovered in the scattering cross sections of graphite and D_2O and in epithermal values of α for ^{235}U .

In the area of methods development, transform methods and analytical continuation were used to place the theory of pulsed fast reactors on a rigorous basis. To reduce the complexity of multiregion fast breeder calculations, space-energy flux synthesis methods were developed for treating the transport equations. Methods for treating spatial effects in fast transients were developed and applied to SPERT transients. The intermediate resonance approximation was tested against the standard narrow resonance approximation for fast reactor materials such as sodium and shown to be a considerable improvement. A method of determining stability bounds was developed and applied to important feedback problems. In fluid dynamics, equations were derived with use of non-equilibrium kinetic theory to describe heat transfer when there is net mass transfer.

Experimental Reactor Physics

The experimental reactor physics program included measurements of neutronic parameters in clean and well-defined assemblies of fissionable and moderating materials. The experiments are coordinated with parallel programs in theoretical reactor physics. An experiment was completed on delayed neutron fractions for thermal fission of ^{235}U , ^{233}U , and ^{239}Pu . In addition, the broad compilation of fast critical experiments data was continued for the AEC.

The fast critical assembly FS-1 (Figure 1) was used in a series of careful studies of heterogeneity effects in fast breeders. The results were in excellent agreement with transport theory calculations. An accurate analysis of the moisture content of graphite components was found to be necessary for reliable experimental results.

A broad series of measurements was completed in exponential assemblies of plutonium rods in heavy water in order to provide benchmarks for the evaluation of ^{239}Pu neutron cross sections in the intermediate energy range. The results were useful in improvement of the ENDF/B library. Another experiment on the epithermal capture-to-fission ratio of ^{235}U and ^{239}Pu involved irradiation

of foils in the HFBR. The best agreement with calculations based on Gwin's data was obtained by the mass spectrometric analysis of neodymium isotopes. A novel experimental method of determining delayed neutron parameters for fissionable materials was developed. This involved continuous rotation of a long belt of fissionable material through a source reactor. The belt was run at high velocity for several days without any failure or air contamination.

Three volumes in the compilation of the U.S. fast critical experiments were completed. In addition, data from the German facilities SNEAK and SOAK and the British ZEBRA were compiled.

Reactor Safety Analysis Evaluation

Technical assistance to the Regulatory Office of the AEC continued. This work, which is intended to provide assistance to AEC licensing personnel in the areas of reactor physics relating to reactor safety, covered a rather wide range of topics. Studies included the evaluation of requirements for in-core neutron detectors, evaluation of reactivity coefficients, calculation of control rod worths, and investigation of reactivity-induced reactor transients. The close contact maintained with AEC personnel has resulted in the work's having an impact upon the setting of technical specifications for power reactors currently being licensed, has helped to insure the safety of power reactors, and has in many cases speeded the licensing process.

Figure 1. A fast critical assembly used to study the effects of heterogeneity and fuel-plate orientation in fast reactors.

NUCLEAR MATERIALS

The Nuclear Materials Division acts as a technical support organization (TSO) for the US AEC's Office of Safeguards and Materials Management (OSMM). The function of the group is to provide technical advice and guidance in a number of areas related to research and development in safeguards.

At the request of OSMM, instrumentation for making passive γ and neutron measurements was assembled and used in field tests at four selected plants. Measurements applicable to safeguards were made of $\text{PuO}_2\text{-UO}_2$ fuel rods, unirradiated PuO_2 scrap in 55-gal drums, concentrated PuO_2 scrap in 2-liter bottles, and small Pu-Al alloy platelets intended for use in a critical assembly. TSO also organized and participated in visits to fuel fabricators and reprocessors to familiarize contractors, now developing measuring techniques for safeguards, with the operation of these plants.

TSO provided an observer at the Nuclear Fuel Services plant in Erwin, Tenn., during an IAEA safeguards inspection involving chemical processing of Yankee Reactor fuel. The objective was to develop a written record of observation and a partial evaluation of the IAEA inspection.

To evaluate their suitability for safeguards application, a study was made of available accelerator sources. The study considered linacs and microtrons as electron sources for producing bremsstrahlung, and accelerator sources of positive ions for producing high energy neutron beams. In addition, the use of methods depending on slower neutrons (slowing-down spectrometer and reactivity methods) was investigated.

The responsibility for conducting the OSMM program of analytical and system studies is divided between Pacific Northwest Laboratory, the National Bureau of Standards, and TSO. Part of the BNL effort has been spent in reviewing the models developed by Pacific Northwest Laboratory and the National Bureau of Standards. The control elements of a safeguards system have been identified, and consideration is being given to a logical definition of the responsibility and role of each of the participants (industry, national government, and international agencies) in relation to these elements. A paper describing the system of safeguards in existence in the U.S. and summarizing safeguards systems studies was prepared in cooperation with OSMM for pre-

sentation to an IAEA panel. A computer simulation has been initiated to replicate the flow of nuclear material in the fuel cycle. This simulation is intended for both analysis and design of safeguards alternatives.

Plans for two field experiments, the Plant Instrumentation Program and the Plant Integrated Experiment, have been prepared by TSO. These OSMM programs, expected to start this year, will be administered through the Brookhaven Office of the AEC, with TSO acting as technical advisor.

The New Brunswick Laboratory, OSMM, and TSO are cooperating in a safeguards analytical laboratory evaluation program. The New Brunswick Laboratory will be the control laboratory, and most of the analytical laboratories in the U.S. that are used in nuclear materials safeguards will participate.

An evaluation of the role of seals in nuclear materials safeguards has been completed and has resulted in identification of problem areas and possible solutions in some cases.

Work has started on the development of criteria for identification of light-water power reactor fuel assemblies. The object is to assign letters and numbers to fuel assemblies that will be readable under the usual depth of water encountered in spent-fuel storage ponds.

A glossary of special terms in the field of nuclear safeguards was prepared by TSO and circulated in the U.S. and abroad for comments.

NATIONAL NEUTRON CROSS SECTION CENTER

The National Neutron Cross Section Center (NNCSC) maintains and develops a computerized system for the storage and retrieval of neutron cross-section information. The information is divided into two classifications, experimental and evaluated. The evaluated data files consist of data choices from among the experimental data files and nuclear model calculations. The NNCSC also advances new methods of cross-section analysis.

The program is divided into three major areas: (1) support of the experimental data file CSIRS, (2) support of the evaluated nuclear data file ENDF, and (3) generalized computer development to achieve improved data-handling procedures and automated publication of data and bibliographies.

In order to keep users regularly apprised of its store of data, the NNCSC inaugurated a new

publication, the *NNCSC Newsletter*, which updates entries in both the experimental and evaluated data libraries and contains announcements of documentation available from the NNCSC. Other topics of interest will be included from time to time. The first issue was circulated in March 1970 to about 600 users here and abroad who specifically requested copies. At present, the plan is to issue future newsletters on a bimonthly basis.

Cross-Section Compilation Activities

Specifications have been completed for a format to allow transmission of nuclear cross-section information among the four neutron cross-section data centers [NNCSC (US AEC), Saclay (European Nuclear Energy Agency), Vienna (IAEA), and Obninsk (USSR)]. This format is designed to allow a large variety of bibliographic and data information to be transmitted in an easily machine-readable format common to the four centers (for checking and indicating possible errors) and as such has not been optimized for subsequent processing and retrieval. All new data received at the NNCSC are now being entered concurrently in the transmission format and in the NNCSC's existing system for experimental neutron data (CSISRS). A procedures manual for entering data in the transmission format is being evolved.

A three-dimensional CALCOMP plotting program has been written for use in displaying differential cross section vs angle vs energy in a new, computer-produced edition of BNL 400, *Angular Distributions in Neutron-Induced Reactions*. Volume I, Third Edition, is now available.

Cross-Section Evaluation Activities

The contents of the Evaluated Nuclear Data File (ENDF/B) are being revised, and tapes containing this information will be available for distribution. Data revisions have been recommended for nonfissile materials, including deuterium, carbon, sodium, boron-10, iron, nickel, chromium, tungsten, and tantalum. In addition, revised data sets were recommended for the major fissile and fertile nuclides (i.e., ^{235}U , ^{238}U , ^{239}Pu , ^{240}Pu , and ^{241}Pu) by the Data Testing Subcommittee during the September 1968 meeting of the Cross Section Evaluation Working Group. This recommendation was based on results from the integral data-testing program, knowledge of the availability of new and significant experimental data, and the realization that a data set produced by one labora-

tory was sometimes inconsistent with known ratios for a data set produced by another laboratory. Although this situation could have been corrected by a simultaneous evaluation of fissile and fertile materials by a single group of evaluators, this work was accomplished by a group composed of both evaluators and experimentalists, who pooled their knowledge and experience in order to ensure that the revised data sets were both internally and externally consistent (i.e., that partial cross sections for any one material were consistent with the total cross section, and also that ratios between cross sections of different materials were consistent with what was experimentally known about the ratios).

Computer Applications

A PDP-10 computer system manufactured by the Digital Equipment Corporation was installed to assist in the maintenance and development of the NNCSC data libraries. This time-sharing system will eventually maintain the data libraries on disks (as yet undelivered) for rapid retrieval. An interactive graphics terminal to assist in data analysis has been ordered for delivery late in calendar 1970.

Extensive graphics tools have been developed to facilitate cross-section compilation and evaluation activities at the NNCSC. The BNL CALCOMP-835 cathode-ray-tube device is used to produce 35-mm film records of data. This method makes possible rapid perusal of large volumes of data (see Figure 2) and is used to produce direct copy for publication as well. The simultaneous display of

Figure 2. Computer-produced film display. Such displays facilitate perusal of large volumes of data.

ENDF/B evaluated data and CSISRS experimental data is used in the re-evaluation of the ENDF/B library. Plotting techniques to expand complex portions of data displays – similar to the action of a zoom lens in photography – have been developed.

METALLURGY AND MATERIALS SCIENCE

Sodium Technology

The corrosion behavior of fuel-cladding materials in sodium and the chemistry of dissolved impurities in liquid sodium have been studied in support of the LMFBR program.

Corrosion Testing. Corrosion tests are conducted in natural- and forced-circulation loops. To determine whether particulates carried by the flowing sodium had any effect on the corrosion rate of stainless steels, the cold leg of one forced-circulation loop was modified by adding a particulate trap consisting of a filter frit, a 7-kG magnet, and an impingement-baffle section. The presence of this trap in the circuit had no effect on the corrosion rate of stainless steel.

Chemical analysis of several vanadium alloys exposed to sodium purified by hot-trapping with zirconium to <1 ppm oxygen showed that carbon was the major element picked up. However, when these same alloys were exposed to sodium containing 3 ppm oxygen, oxygen was the major element picked up. The uptake of oxygen and carbon by these alloys severely affected their mechanical properties.

Type 316 stainless steel was exposed to sodium containing about 25 ppm oxygen at 650°C under a nominal heat flux of 1×10^6 Btu/hr-ft². Weight change measurements on the specimens after a 1000-hr exposure showed that the presence of the high heat flux had little effect on the corrosion rate.

Mechanism of Corrosion of Steels in Sodium. Development of a model for the corrosion behavior of steels in high-velocity sodium has traditionally been impeded by inability to explain the low corrosion rates, given the magnitude of the available solubility data and circuit sodium analyses. A model developed at BNL predicts that this corrosion is related primarily to the kinetics of dissolution of surface iron atoms, and that the downstream effect results from saturation of the chromium and nickel in sodium, which in turn results in increased concentrations of chromium and nickel on the surface in the downstream region, where they

migrate to the active sites for corrosion and adsorb on them to reduce the corrosion rate. The oxygen effect is considered to be an activation of the surface reaction process. This model predicts that the high-velocity corrosion rates of steels as measured in small loop experiments can be used to estimate corrosion allowances for LMFBR fuel claddings, without scale-up factors.

High-Cycle Fatigue of Materials in Liquid Sodium.

The fatigue resistance of materials in liquid sodium is being studied to develop data useful in the design of LMFBR heat exchangers, piping, and structural components and in estimating the reliability of these components in an LMFBR environment. The testing parameters being studied are a cycle range of 10^4 to 10^{10} cycles at temperatures of 427° to 565°C in environments of air, sodium, and steam. MTS push-pull fatigue machines operating at 40 cps and ultrasonic machines operating at 20,000 cps have been set up and calibrated. The liquid sodium systems under construction consist of a thermal convection loop which will circulate sodium from a holdup tank over the fatigue specimens.

Figure 3. Calibration curve at 650°C and at low oxygen (<1 ppm) for a carbonate ($\text{Na}_2\text{CO}_3\text{-Li}_2\text{CO}_3$) electrochemical meter which can be used to determine carburizing or decarburizing conditions, the concentration of carbon, and the chemical activity of carbon in sodium. $C_0 = 20$ ppm, measured in a nickel vessel with a carbon meter having a 0.005-in. iron membrane, assuming ideal solution. $E \text{ (mV)} = 46.5 \log (20/C)$.

Electrochemical Carbon Meter for Use in Liquid Sodium Systems. Current designs for fast breeder reactors call for the use of sodium as a coolant in contact with both austenitic and ferritic steels. A device for measuring carbon activity is required for on-line monitoring of the extent of carbon transfer through the sodium from one steel to another, since this transfer may cause serious deterioration of the mechanical properties of the steels.

Studies at BNL have shown that a Na_2CO_3 - Li_2CO_3 electrolyte can be used in an electrochemical meter that continuously monitors the chemical activity of carbon in liquid sodium. This meter is based on the cell

in which Na(C) represents the chemical activity of dissolved carbon in the sodium stream.

Figure 4. Schematic representation of the completely ionic range of ThO_2 -15 wt % Y_2O_3 oxygen electrolyte.

Practical utilization of the meter is indicated in Figure 3, which shows the relation between the meter potential at 650°C and the ability of the sodium to carburize or decarburize stainless steel at that temperature.

Electrochemical Oxygen Meter for Use in Liquid Sodium Systems. Research is being done on the development of improved electrochemical oxygen meters for use in liquid sodium systems. The primary element in these meters is a ThO_2 -15 wt % Y_2O_3 solid electrolyte tube. Significant improvement in their performance was achieved by development of Na - Na_2O and oxygen gas reference electrodes; these have extended the temperature range over which the meters can be used and improved their reproducibility. The meters have been used to study the chemistry of oxygen in sodium coolants. The solubility and free energy of formation of oxygen in sodium were determined, and studies of the reactions between oxygen and materials such as Fe, Cr, Si, H, and C in Na are in progress. The results indicate that each of these materials is capable of reacting with oxygen in sodium under appropriate conditions. Figure 4 shows the free energy relationships, as determined by the meter, that define these conditions. These reactions may be involved in the enhancement of corrosion of most materials in sodium due to the presence of oxygen.

A Rapid Method for Measuring Oxygen Concentrations in Sodium. A rapid and accurate method for measuring oxygen concentrations in sodium has been developed at BNL. It has been found that uranium metal gains weight in sodium at a rate that depends on the oxygen concentration in the sodium. Thus the concentration can be measured by weighing a piece of uranium, immersing it in sodium, and reweighing it after it has been removed and cleaned. The oxygen concentration is obtained from a calibration curve, and the analysis can be accomplished in $\frac{1}{2}$ hr. This reaction can also be used to measure mass transfer coefficients in sodium.

Alloy Theory and Nature of Solids

Under this general heading, work is performed on effects of irradiation on body-centered cubic metals and on the superconducting properties of materials.

Temperature Dependence of Plastic Deformation in Irradiated Body-Centered Cubic Metals. The influence of impurities on the temperature depen-

Figure 5. Comparison of temperature dependence of yield stress in zone-refined tungsten crystal as a function of purification.

Figure 6. Comparison of temperature dependence of the yield stress with measured values of the obstacles per unit area of slip plane, showing that a single activation energy is controlling deformation in neutron-irradiated platinum.

dence of the plastic properties of single crystals of tungsten has been studied and it has been unambiguously shown that a major portion of the effect is impurity dependent, as shown in Figure 5. This experiment shows clearly that impurities influence the motion of defects, even at low impurity levels. Furthermore, the observation that the temperature dependence of the defect motion is dependent on purity in the limiting case of 0°K has not been made before.

A direct proof and measurement of the hardening mechanism in irradiated metals was obtained during the year. This consists of correlating macroscopic measurements of the plastic properties of

irradiated specimens with direct counting of the defects introduced by irradiation. The single straight line in Figure 6 shows the 1:1 correspondence between the macroscopic measurements (yield stress) and the microscopic measurements (defect densities). A further consequence of this direct 1:1 correspondence is that the influence of radiation damage on a material can be predicted over a wide range of irradiation exposures and test temperatures.

Superconductivity

Properties of Hollow Tubes of Type I Superconductors. The behavior of hollow tubes of type I superconductors in magnetic fields generated in the voids can be explained quantitatively by assuming flux conservation within the total system rather than in the void alone. In these configurations the transition from the pure superconducting state to the normal state occurs through a single sharp S-N boundary which begins at the inside wall and moves to the outside wall with increasing solenoid current (or internal field). This interface moves reversibly, both with increasing and decreasing field and with increasing and decreasing temperature. The effects also occur in hollow cylinders of unfavorable geometries (short cylinders with thick walls) and provide a means of making unambiguous measurements of the velocity of the transition from the superconducting state to the normal state, since in this case it occurs without the formation of a laminar intermediate state.

Superconductivity in Thin Films. The transition temperature of ultrathin films is being investigated. The possibility of high transition temperatures in ultrathin layers of metal and alternating layers of metal and dielectrics or semiconductors has been suggested by theory. To study this effect, low energy electron diffraction work is being performed with the intention of extending previous measurements by studying the structure and excitation spectrum of ordered layers only a few atoms thick. A unique cryostat has been designed and constructed for use in electron diffraction and scattering experiments on samples held at low temperatures. In this apparatus, samples can be heated to about 1400°K and then cooled to liquid-helium temperatures at ambient pressures in the 10⁻⁸ torr range. The apparatus has been used to make and measure 100-Å layers of Nb₃Sn on bulk

Figure 7. Dissociation pressures of VH_2 and VD_2 .

niobium. It has been shown that very thin Nb_3Sn coatings can be made on the walls of superconducting niobium accelerator cavities, with possible improvement of the cavity performance because of the high Nb_3Sn transition temperature.

Divergent Fluctuations in Superconducting Films.

It has been theoretically demonstrated that fluctuations within many two-dimensional systems (thickness $\ll$ coherence length) diverge, which would preclude the existence of long-range order in such systems. Superconducting systems, because of their large coherence length, permit the necessary condition for two-dimensionality to be fulfilled. It was recently shown that the nature of fluctuations within superconductors could be quantitatively studied by carefully monitoring the resistive transition. At BNL, fluctuation contributions that are logarithmically divergent, with a cutoff proportional to the strength of a de-pairing interaction (i.e., one limiting the lifetime of electrons condensed in the ground state), have been predicted and observed in the resistive transitions of thin films of lead and aluminum. This provides the first experimental evidence for divergent fluctuations in two-dimensional systems.

Nuclear Magnetic Ordering and Very Low Temperatures. Studies of the nuclear magnetic susceptibility of solid ^3He down to 6 mdeg K were completed. These show an ordering interaction corresponding to a predicted antiferromagnetic transition at 2 mdeg K for the lowest density sample (24 cc/mole). This result represents the first

determination of the sign of the interaction. The strength of the interaction was found to fall off strongly as the density increased: at 21 cc/mole the corresponding predicted transition temperature is 0.21 mdeg K. Thermal equilibrium times proved to be a few minutes, the shortest time that could be determined by the method used. The effects of ^4He impurity were studied up to 2000 ppm. There was no effect for the 24-cc/mole sample; at 21 cc/mole the principal effect was to lengthen the equilibrium time to about one day.

Further cooling was attempted by nuclear demagnetization. Temperatures of the order of 1.4 mdeg K have been obtained; however, warm-up to 5 mdeg K occurs in about 15 min, a time too short for an experiment. Work is continuing to lengthen the time at the lower temperatures.

CHEMISTRY

Metal Hydrides

The vanadium-hydrogen system was found to have several unusual and possibly useful properties. They first became apparent when the dissociation pressure of the higher hydride, VH_2 , was studied as a function of temperature and found to be higher than that of any previously known reversible hydride, amounting to 5.0 atm at 25°C. This work was done with commercial lump vanadium, 99.5% pure. When the experiments were repeated with zone-refined vanadium, which contains only a few ppm of metallic impurities, a further surprising feature was observed: the pressures were about 42% of those observed with commercial vanadium. Finally, and perhaps most important, when deuterium was substituted for hydrogen, a large isotope effect was found which was in the opposite direction from that obtaining in almost every other metal-hydrogen system. In other words, in the case of the $\text{VH-VH}_2\text{-H}_2$ equilibrium, the deuterium system has a dissociation pressure of $< \frac{1}{2}$ that of the hydrogen system. This was found to hold with both commercial and refined vanadium. In actual separation experiments using isotopic mixtures, separation factors of 1.6 to 1.8 were observed.

Some of the pressure-temperature relationships are shown graphically in Figure 7.

Thermodynamics of Alloys

A new method has been developed for studying the thermodynamic properties of alloys having an

Figure 8. Potassium activity in a series of K-Pb alloys. The points for $x_K > 0.60$ were obtained at 450°C, the rest at 600°.

alkali or alkaline earth metal as one component. The first experiments have been done on K-Pb alloys. A single crystal of KCl is equilibrated with the vapor above the alloy, which produces color centers in the KCl crystal. The color centers have a characteristic absorption spectrum, and the absorption constant at the maximum of the characteristic band is directly proportional to the fugacity of potassium in the vapor.

It can be shown that the activity of potassium in the alloy is given by the expression

$$a_K = A/A^0,$$

where A is the absorption constant of the color center equilibrated with the alloy and A^0 is the absorption constant of the color center equilibrated with pure potassium.

This method does not depend upon the composition of the vapor above the alloy and thus has inherent advantages over standard vapor pressure techniques. Results for the K-Pb system are shown in Figure 8.

Porphyrin Chemistry

The oxidation-reduction properties of porphyrins and related compounds govern their function in biological systems.

Oxidation by electrolysis or chemical electron transfer of chlorophyll a or ethyl chlorophyllide a converts these molecules into bleached species whose optical, electrophoretic, and paramagnetic

properties are consistent with their identification as π -cation radicals. Comparison of their spectra with the reported spectra of chloroplasts taking part in the natural photosynthetic process (Figure 9) suggests that oxidized P700, the first photochemical product of photosystem I in green plants, probably contains a π -cation radical of the chlorin component of chlorophyll a . This radical is the likely source of the rapidly decaying, narrow electron spin resonance (ESR) signal of photosynthesis.

Cation radicals and dications of a series of tetraphenylporphyrins (TPP) and octaethylporphyrins (OEP) were prepared by electrolytic and chemical means. Correlation of experimental ESR and optical data with theoretical calculations leads to the conclusion that these radicals may occupy either of two close-lying ground states. One has high electron spin density on the nitrogens, the other on the *meso* hydrogens; a marked difference in reactivity results. The radical ion $MgTPP^+$ is found, in practice, in the first state, while $MgOEP^+$ favors the second.

This work was performed in collaboration with D.C. Borg (BNL Medical Department), R.H. Felton (Georgia Institute of Technology), and D. Dolphin (Harvard University).

ENGINEERING

The Engineering Assistance Group contributed more than 32,000 man-hours to the support of departmental and Laboratory programs during the year. New areas of support included applications of concrete-polymer materials to mechanical structures and the Brookhaven Linac Isotope Producer. Highlights of these activities may be found in the section on Technical Operations and Services under the heading "Mechanical Engineering."

Both the Pulsed Research Reactor Project and the experiment on continuous production of delayed neutrons were terminated.

Fission-Product Release (Nuclear Safety) Studies

The purpose of this research is to develop a fundamental understanding of the chemical reactions, mechanisms of release, and transport behavior of the fission products and radioactive aerosols emanating from nuclear materials under conditions likely to be encountered in the event of an LMFBF accident.

Figure 9. Comparison of the optical difference spectrum of chlorophyll and the chlorophyll cation radical with that reported from chloroplasts. Spectra have been normalized so that the bands at ≈ 700 nm are equal. —, Oxidized minus reduced (chlorophyll *a*); ---, light minus dark (P700).

The primary area of research was a study of the behavior of PuO_2 aerosols. This work is particularly pertinent to the LMFBF program because of the health hazard associated with plutonium and the concern regarding its potential release from reactor containment vessels into the atmosphere. One of the major experimental objectives during the year was to develop methods for generating high mass concentrations of PuO_2 and UO_2 aerosols and studying their properties. To accomplish this, a 20-kW, 530-kC induction furnace was installed in the alpha facility and used to generate the fuel aerosols in a 1- m^3 chamber at temperatures $>3000^\circ\text{C}$. Experiments were done using PuO_2 and UO_2 with nominal mass concentrations of 9.0 and 9.1 g/m^3 . The observed transient behavior of the aerosol mass concentration was found to be in excellent agreement with that calculated by using a digital computer program to solve the general equation expressing the rate of settling and agglomeration of an aerosol.

Application of existing computer programs to calculation of the time dependence of aerosol concentration and size distribution has been severely limited by lack of a valid initial particle size distribution for use in analyzing practical problems. A method was recently developed for calculating the instantaneous-source size spectrum of an aerosol

Figure 10. Variation of airborne aerosol concentration with time, assuming an instantaneous aerosol source and based on a settling chamber height of 100 cm.

in terms of the initial mass concentration. On the basis of theoretical studies, it was possible to approximate the initial size distribution of high mass concentration aerosols by a log-normal distribution with a geometric standard deviation of 1.37.

This relationship was used to determine the initial particle size distribution for a series of parametric studies. The effect of initial concentration on the time dependence of the fractional mass concentration remaining airborne is shown in Figure 10 for initial concentrations ranging from 0.01 to 100 g/m^3 , a settling chamber height of 100 cm, and a particle density of 6.0 g/cc . As expected, the higher the initial mass concentration (C_0) and corresponding initial geometric mean radius (r_g), the more rapid the decrease in the fraction of the mass remaining airborne.

Additional studies were made to determine the chemical states of fission products released from reactor fuels at high temperatures and to measure their thermodynamic properties. The construction of a thermochromatograph and the installation of associated instrumentation in the alpha facility were completed. Test runs with irradiated uranium and UO_2 were conducted prior to studies with plutonium-bearing fuels. Results were in good agreement with the previously reported work on uranium.

Figure 11. Data showing the effect of flow rate on incipient boiling superheat. Tests were carried out in a forced-circulation loop, with potassium as the test fluid, at a pressure of ≈ 15.3 psia and a heat flux of ≈ 6.6 W/cm². At zero flow, the superheat corresponds approximately to the value predicted by cavity deactivation theory. Increasing flow caused significant reductions in the incipient boiling superheats.

A pulsed vaporization apparatus for measuring the thermodynamic properties of fission product-sodium systems at high temperatures was completed. Its operating principle is similar to that of the Rayleigh cell employed in making NaI-Na measurements, except for periodic evacuation and pressurization of the system to ensure that thermodynamic equilibrium is attained between cycles. Preliminary experiments were made with the cesium-sodium system over the temperature range 538° to 660°C. Work was initiated to measure the free energies of mixing for the strontium-sodium system as a function of concentration and temperature. An effort is under way to develop a suitable galvanic cell to make the required emf measurements.

Heat Transfer Research

Work in this area is devoted almost exclusively to the study of convective heat transfer in liquid metals and is mainly in support of the Fast Flux Test Facility (FFTF) and LMFBR programs. Both liquid-phase and two-phase problems are investigated in analytical and experimental studies. Two of the studies are reviewed here.

In a continuing study of incipient boiling superheat, a number of experiments were performed in fiscal 1969 in a forced-convection loop to determine the effect of flow rate. During fiscal 1970 the data were analyzed to show the parametric dependence of incipient boiling superheat on flow rate for essentially constant deactivation conditions (prior to boiling), constant boiling pressure, and constant heat flux. Superheats were measured at boiling pressures of 8 to 24 psia and over a flow range of 0.2 to 3 ft/sec, with potassium used as the test fluid. Some typical results, for one set of test conditions, are shown in Figure 11. The superheat corresponding to zero flow was found to be in approximate agreement with the value predicted from simple deactivation theory. Increasing flow rates led to markedly lower superheats. The evidence indicates that some additional phenomenon, possibly associated with turbulent flow, significantly alters the apparent thermal-dynamic conditions for nucleation under flow (vs static) conditions. A theoretical explanation for this effect is being developed, based on the existence of wall pressure fluctuations in turbulent flow. This flow effect is of great practical concern in connection with the prediction of inadvertent vaporization conditions in the FFTF or LMFBR.

In a second study, the effect of rod misalignment on single-phase heat transfer to liquid metals flowing through rod bundles was investigated analytically. For the case of triangularly spaced rod bundles, two types of misalignment were considered: (a) a rod displaced from its symmetrical position toward an adjacent rod by some fraction, σ , of the maximum distance possible, and (b) a rod displaced toward the midpoint of the line connecting the centers of two neighboring rods. The governing energy equations for slug flow were solved for two kinds of thermal boundary conditions: (1) uniform wall temperature in the circumferential direction and uniform wall heat flux in the axial direction, and (2) uniform wall heat flux in all directions. From the explicit temperature solutions, the average Nusselt numbers, $\overline{Nu}_t$ [for the boundary condition (1)] and $\overline{Nu}_q$ [for (2)] of the displaced rod, were calculated for rod bundles having P/D (pitch-to-diameter) ratios in the range of 1.0 to 2.0 and σ values varying from 0.0 to 0.9.

Both types of misalignment were found to cause a large reduction in the average Nusselt numbers, especially under boundary condition

(2). Of particular interest is the dependence of the percentage reduction in the Nusselt numbers on the P/D ratio of the rod bundle. As shown in Figure 12, the ratio $\overline{Nu}_q/(\overline{Nu}_q)_0$, where the subscript zero refers to the case of $\sigma=0$, decreases as D/P is increased from 0.5 and attains a minimum at $D/P \approx 0.9$. It then increases toward the value of unity as D/P is increased further toward 1.0. A quite different trend was found for boundary condition (1), for which the ratio $\overline{Nu}_t/(\overline{Nu}_t)_0$ increases as D/P is increased and reaches the value of unity as D/P is increased to 1.0 (see Figure 13). The analysis is being extended to treat the corresponding problems in laminar and turbulent flows. In the case of liquid metals, turbulent-flow results should be quite similar to those for slug flow.

Other active projects in heat transfer research include (a) investigation of the effects of solid-

liquid interface characteristics on boiling and liquid-phase heat transfer with sodium, (b) measurement of local heat transfer coefficients for turbulent flow of liquid metals through closely packed rod bundles, and (c) study of void propagation in liquid metals flowing through rod bundles.

Ultimate Waste Disposal

Research efforts in ultimate disposal of high-level radioactive wastes at Brookhaven National Laboratory have been directed toward fixation of the fission products in stable solids for burial in stable geologic regions. The fixation process that has been under development at Brookhaven is based on the conversion of the aqueous wastes to phosphate glass with use of a continuous process involving (1) the addition of phosphoric acid to

Figure 12. Effects of variation in D/P ratio and fractional displacement distance, σ , on the average, normalized Nusselt number for longitudinal slug flow through rod bundles. The Nusselt values are for the displaced rod when it is displaced directly toward a neighboring rod and for the thermal boundary condition of uniform wall heat flux in all directions.

Figure 13. Effects of variation in D/P ratio and fractional displacement distance, σ , on the average, normalized Nusselt numbers for longitudinal slug flow through rod bundles. The Nusselt values are for the displaced rod when it is displaced directly toward a neighboring rod and for the boundary condition of uniform wall temperature in the circumferential direction and uniform wall heat flux in the axial direction.

the raw waste, (2) volatilization of water and nitric acid, and (3) conversion to phosphate glass at 1200°C in a platinum crucible. Development of the phosphate glass process has been carried through the pilot-plant stage at Brookhaven with simulated wastes and, in a cooperative program, through the prototype demonstration stage with high-level radioactive wastes at Pacific Northwest Laboratory (PNL).

This year a number of new types of simulated reactor waste were studied. Five continuous pilot-plant runs of up to 100-hr duration were made with type PW-4 Purex waste representing fuel elements with a burnup of 45,000 MWd/tonne U and LMFBR waste representing fuel from the Fast Breeder Reactor with a burnup of 100,000

MWd/tonne U and Pu. Several glass billets, 6 and 8 in. in diameter and several feet long, produced in these runs were shipped to PNL for evaluation of physical characteristics. Process component tests involved the successful development of a screw pump for feeding the melter.

RADIATION RESEARCH AND DEVELOPMENT

Radiation Chemistry

Free-radical decay rates in irradiated crystalline amides were found to depend on both crystal growth rate and total radiation dose. In pure butyramide, the temperature coefficient for radical decay (between 12 and 28 kcal/mole, depending on the fraction of radicals remaining) corresponds to published values of the coefficient for hydrogen abstraction reactions in the liquid state and is much lower than published estimates for self-diffusion coefficients in the solid state.

The rate of radiation-induced ionic polymerization of α -methylstyrene exhibits a discontinuity in the vicinity of 20° to 30°C, with an overall temperature coefficient of ≈ 9.6 kcal/mole between 80° and 30°C and -1.6 kcal/mole between 20° and 0°C.

Figure 14. Simulated ball lightning in dc fields. Ball lightning can be simulated with spherical combustion flames, as shown, and dc current from the ball measured as a function of diameter and electric field. The results confirm a theoretical model of ball lightning and satisfactorily explain this natural phenomenon, which has puzzled scientists for hundreds of years. With more electric power it should be possible to make true ball lightning (that is, the combustion energy can be replaced by electric energy) in the laboratory.

In the radiolysis of nitrous oxide absorbed on molecular sieves, sulfur hexafluoride decreases the nitrogen yield, $G(N_2)$, from 4.1 to 1.0, but does not reduce it to zero even at very high SF_6/N_2O ratios. This suggests that the electron is not the only entity involved in the transfer of energy from the solid to the absorbate.

Pulse radiolysis studies of air-free, aqueous hydrazine solutions yielded a transient species with an absorption maximum at 230 nm, disappearing by a first-order process and exhibiting two pK_a values.

A model of ball lightning in dc fields was developed and experimentally verified with use of spherical combustion flames (see Figure 14). Observations bore out predictions, i.e., a positively charged ball with downward motion, collection of electron current from an area greater than that of the cross section of the ball, and power input proportional to both the diameter of the ball and the third power of the electric field strength. It is concluded that in nature an electric field of 2000 V/cm would be sufficient to maintain ball lightning.

Radiation Processing

Concrete-Polymer Materials. A research program to develop concrete-polymer composites as improved materials of construction is being conducted in cooperation with the Bureau of Reclamation of the U.S. Department of the Interior. The program is supported in part by the Department's Office of Saline Water and Bureau of Mines and by the Bureau of Public Roads (U.S. Department of Transportation). Other agencies have joined the program in a cooperative effort to evaluate specific applications. The U.S. Department of Agriculture is considering the use of light-weight and steel-fiber-reinforced concrete-polymer for tilt-up wall construction in low-cost rural housing. The Naval Civil Engineering Laboratory is conducting exploratory experiments on concrete hulls for underwater applications. The Army Corps of Engineers is interested in a variety of applications, including housing panels and soil stabilization.

The experimental program has evaluated monomers and impregnation methods and has measured the strength and durability of several series of specimens. For normal temperature applications, concrete specimens impregnated with methyl methacrylate have shown the greatest im-

provement in strength and durability properties; those impregnated with acrylonitrile, the least. Comparison of the compressive strengths obtained for radiation-initiated and chemically initiated polymerization indicates that for the five monomer systems studied, radiation initiation results in composites of higher strength. The durability properties appear to be dependent on the polymer content and independent of the mode of polymerization.

The mechanical properties of concrete-polymer materials involving four monomer systems are being investigated at elevated temperatures to provide materials of construction for flash distillation units in water desalination plants. High-strength OSW-type concrete impregnated with a mixture of 60% styrene and 40% trimethylolpropane trimethacrylate (TMPTMA) has shown the greatest strength and the smallest decrease in strength at elevated temperatures. Figure 15 shows the results of some corrosion testing.

Theoretical and experimental investigations are under way to determine the mechanism by which the presence of polymer in concrete increases its strength. Models based on the theory of particulate-filled systems have been developed which appear to correlate with the experimental data.

Ozone Synthesis. Ozone formation from O_2 and O_2-N_2 mixtures has been studied at pressures from 2 to 69 atm, temperatures from 28° to -140°C, and flow rates from 10 to 400 cc/min at doses up to 500 megarads. Although initial G -values are only slightly increased by lowering the temperature (Figure 16), there is an orders-of-magnitude effect on the equilibrium concentration. Initial rate of formation and equilibrium concentration are affected only slightly by pressure. The latter is almost directly proportional to radiation intensity.

Cryogenic Radiation Chemistry. The production of hydrazine by irradiation of H_2-N_2 mixtures at temperatures down to -160°C and pressures to 500 psig is being studied. Experiments for the formation of ozone are being carried out at very low temperatures with liquid O_2 and O_2 in contact with catalysts.

Polymer Composites. Possible applications for several polymer composites prepared by ^{60}Co γ irradiation are being explored. Soil-polymer containing as little as 2% polymerized methyl methacrylate has shown a compressive strength of 2000 psi. Refuse-containing concrete-polymer

Figure 15. Resistance of concrete-polymer to attack by 15% HCl. The control specimen (left) had a weight loss of 28.7% in 112 days. The specimen on the right, concrete impregnated with a mixture of methyl methacrylate and 10 wt % TMPTMA, lost 5.5% in weight in 363 days.

may have value in reuse of solid waste. Polymer-filled aluminum oxide is being investigated as a bone substitute. Radiation processing eliminates the need for toxic catalysts and disinfects the material for *in vivo* use.

Chemonuclear Production of Ozone. Economic and conceptual design studies are under way for the application of chemonuclear ozone to water treatment. Runs with the Brookhaven Chemonuclear In-Pile Research Loop gave *G*-values of up to 12 for ozone production from oxygen, nearly three times the yield obtainable with the electric

discharge method. Efforts are being concentrated on acid mine-drainage treatment under contract with the Federal Water Quality Administration. Operation of the loop has been discontinued, since financial support for the Chemonuclear Project has been withdrawn.

Radiation Chemical Engineering

Calculations showed that mixing effects in bleachable chain reaction mixtures are smaller than those associated with sensitized initiation. In addition, larger initial absorption coefficients are

optimal with bleachable reactant. An axial dispersion coefficient model was used to show that with respect to spatial nonuniformities photoreactors are intermediate between the homogeneous and the heterogeneous catalytic reactors.

An improved optical system has been provided for the work on mixing effects in photopolymerizations, and background experiments have been conducted on the benzoin-sensitized photopolymerization of methyl methacrylate.

Methods of flow dosimetry have been developed and applied to the measurement of the transit dose in a ^{90}Sr - ^{90}Y blood irradiator. An experimental reactor used in flow dosimetry studies is shown in Figure 17.

Radiation Engineering

Operations and Services. Typical of operations in the preparation and radiation cells at the High Intensity Radiation Development Laboratory were the processing of monomer-impregnated concrete specimens, the intense field testing of accelerator safety devices and phantoms for the

Figure 16. γ Radiation production of O_3 from O_2 , showing the effect of temperature, pressure, dose rate, and total dose on O_3 concentration.

Figure 17. Radiation chemical reactor, used in studies of chemical dosimetry in flow systems, being installed in a portable cave. The ^{137}Cs source protrudes from the central source well.

Medical Department, extensive source calorimetry, the loading and modification of food, biological, and medical irradiators, and studies of polymerization rate and enzyme sterilization.

About 45,000 sample-hours of irradiation were performed in the gamma facility, of which 20% were for radiation engineering program requirements, 45% for radiation processing work, and 35% for predominantly AEC programs.

Source Development and Testing. Sporadic cesium source swelling continued this year. More stringent cesium chloride preparation, encapsulation, and inspection procedures by Oak Ridge National Laboratory are expected to prevent a recurrence. The in-pool use of cesium sources, of concern from a hazards point of view, will be evaluated with use of the recently developed automatic cycling apparatus. Close support was given the recently initiated work at PNL on the optimum size, design features, and economics of production of proposed Hanford waste-product cesium sources.

Dose Distribution Measurement and Prediction. Two extensive sets of reference tables were published to simplify the task of the irradiator design engineer. Depth-dose rates, minimum specific dose rates, and uniformity ratios are tabulated as a function of target depth and density and plaque size.

Studies indicated that the FUDGE-4 computer code satisfactorily predicts the dose distributions in multipass irradiator systems with heterogeneous target geometries, such as stacks of food cans, provided that the target array is thick enough to allow homogenization of the target material.

Dosimetry. Tests conducted at six independent laboratories indicate that the Perspex HX dosimeter can achieve accuracy to within $\pm 10\%$ without precalibration and to $\pm 3\%$ with precalibration. The Fourth Dosimetry Workshop was conducted at the Natick Laboratories. Foreign participation was significant. Major ASTM participation was focused on approval of the ferrous-sulfate-cupric-sulfate dosimetry procedure and the introduction of ceric sulfate into round-robin testing.

An extensive dosimetry and dose-distribution section was prepared for submission to the Food and Drug Administration in connection with petitions in support of applications to perform irradiations on food for commercial use.

Irradiator Design, Fabrication, and Support. A shipboard irradiator was returned from Iceland

and reconditioned. Following interim use in Louisiana, it will be installed in Korea next year. The second Brookhaven portable cesium development irradiator unit was completed and shipped to India, and the third was installed in Chile late this year. The portable cesium irradiator unit, after a period of deactivation, was sent to California for short-term use and will go next to Louisiana.

Atmospheric Diagnostics

This program is a joint effort of the Radiation Division, the Analytical Chemistry Group, and the Engineering Division of the Department of Applied Science and the Meteorology Group of the Instrumentation and Health Physics Department. It is supported in part by the National Air Pollution Control Administration.

Emphasis has been placed on the study of atmospheric sulfur pollutants, although interest is increasing in the study and control of nitrogen oxides emitted from stationary sources. The isotope ratio tracer (IRT) method, based on variations in the ratio of ^{32}S to ^{34}S in natural sulfur, has been improved and is being used in two types of studies. One is the physical tracing of sulfur oxides through the air, where the emission from a specific stack may be identified and followed even in a complex metropolitan atmosphere. The other is the chemistry of pollutant sulfur in stack plumes: the change in the ^{32}S to ^{34}S ratio caused by isotopic exchange following chemical reaction is large enough to be measured with good precision and can be related directly to the degree of conversion. Sulfur hexafluoride, SF_6 , is being used in dual tracer studies. Since it is inert, it delineates the geometric behavior of a plume and provides a datum to which measurements of chemical changes determined by the IRT method can be normalized. Field investigations are under way in the study of combustion in large power stations, pollution patterns in the small city, plume dispersion from tall stacks, and the fate of SO_2 in the atmosphere (Figure 18).

HOT LABORATORY

Nuclear and Radiochemistry Research

Refined computer calculations, prompted by experimental observations, on the $^{48}\text{Ca}(\alpha, n)^{47}\text{Ca}$ reaction indicate that as the energy of the bombarding α particle is increased the direct-inter-

Figure 18. Data diagram from typical power plant plume dispersion run, with simultaneous use of SF₆ tracer and the IRT method. Shown are the concentrations of SO₂, sulfate, and SF₆ and the ratio ³²S/³⁴S in SO₂ collected aloft at the points indicated on the charts, together with meteorological and operational data.

action mechanism becomes increasingly important until it accounts for about 20 to 30% of the reactions at 36 MeV. Excitation functions measured for five products from the triton bombardment of magnesium indicate that below 3.5 MeV the reaction cross section is dominated by the Coulomb barrier.

The isomeric transition of tellurium isomers results in the simultaneous production of two or more hot atom species, at least one of which was shown to be produced by the complete disruption of the parent molecule, while a second was formed from a partial disruption of the parent molecule. The Szilard-Chalmers reaction in solid titanocene dichloride gave a surprisingly high retention of ⁵¹Ti in the original molecule. To test the assumption that such retentions are influenced by whether the struck molecule remains intact following momentary ejection of the metal atom, the two rings of titanocene have now been tied together by a trimethylene bridge, and the Szilard-Chalmers reaction on this new molecule will be studied. Another study, just begun, will use the angular correlation of γ rays emitted in cascade as a tool to give information about rates of chemical reactions occurring in the 10⁻⁷ to 10⁻⁹-sec time interval during the γ emissions.

When the nuclear level densities calculated by the numerical combinatorial method were compared with an analytical formula using higher powers of spin than conventional, several systematic effects of the nuclear shell structure were revealed, including a remarkably smooth dependence of the level density parameter a and the spin parameter c on the neutron number N , with pronounced minima at the closed shells $N = 28$ and $N = 50$. The numerically calculated level densities have also been used for calculating nuclear reactions. Where experimental results exist for comparison, the new calculations agree either as well as or better than did conventional calculations. Nuclear level density calculations were refined to include the effect of nuclear deformation. Typical results are shown in Figure 19. A preliminary conclusion based on all the cases studied thus far is that nuclei that are spherical in the ground state are predominantly spherical at higher excitation energies, while nuclei that are deformed in the

Figure 19. Numbers of energy states (shown on "contour lines") of the ^{166}Ho and ^{56}Fe nuclei as a function of spin (ordinate), deformation of the nucleus (abscissa), and excitation energy (different sets of contours).

Figure 20. Excitation function for the $^{52}\text{Cr}(^3\text{He}, 3n)^{52}\text{Fe}$ reaction.

ground state are highly deformed when excited, and the spin-vs-deformation contour curves of the latter exhibit many peaks and valleys.

Analytical and Physical Chemistry Research

Studies in this area included problems involving complexes containing mixed metals and others containing mixed ligands, electrochemical problems, and a parametric study related to air-sampling procedures important in pollution investigations. For example, mixed-metal complexes of the form InUO_2L_2 were found for $\text{L} = \text{citrate}$, malate, or tartrate, and the formation constants were measured. Preliminary studies to elucidate the structure of solid complexes of citrate and malate showed that in the latter only the carboxylic groups participate in the complex, whereas in the former other groups are also involved. Mixed-metal complexes were also found between In(III) and Cr(III) , Fe(III) , Al(III) , or Cu(II) , and between UV(I) and Cr(III) , but not between U(VI) and Al(III) or Cr(III) , or between Ce(III) and In(III) . Studies of mixed bromide-chloride complexes with

Figure 21. Site of the Brookhaven Linac Isotope Producer (BLIP).

acetonitrile showed that Ni(II) is a "hard acceptor" with respect to the halides as donors in acetonitrile solvent. From a kinetic study the mechanism of extraction of Fe^{3+} into benzene by thenoyl-trifluoroacetone was inferred.

Radionuclide Development

A specific activity of 1400 mCi of $^{28}\text{Mg/g}$ stable magnesium was achieved by bombarding enriched ^{26}Mg with tritons in a Van de Graaff generator. This will permit new kinds of studies with this isotope. The same beam on a water target produced >2 mCi of ^{18}F per $\mu\text{A-h}$. The procedure for labeling diethylenetriamine pentaacetic acid with Tc^{99m} was optimized, and the stability of the labeled complex was shown to be satisfactory not only in air prior to administration but also in the body following intravenous injection. This labeled complex is now being routinely supplied as a scanning agent to the staff of the BNL Medical Research Center, with whose active collaboration this entire program is carried out. The $^{52}\text{Cr}(^3\text{He}, 3n)^{52}\text{Fe}$ reaction has been used to achieve yields of $50 \mu\text{Ci}/\mu\text{A-h}$, and for the first

time the production of millicurie quantities of this medically important nuclide became possible. Moreover, the measured excitation function for the reaction (Figure 20) clearly shows the importance of high energy ^3He for this purpose and will be of help to others contemplating the use of medical cyclotrons for making ^{52}Fe .

Preparations were made to assure the design and construction in fiscal 1971 of the Brook-

haven Linac Isotope Producer (Figure 21), which will receive 9 pulses of 200-MeV protons/sec from the linear accelerator now under construction that will serve as the new injector for the Alternating Gradient Synchrotron. Targets suitably placed in this facility will undergo spallation and will yield large amounts of a host of radio-nuclides that are at present available only in quantities too small to be of any practical use.

Applied Mathematics

The Applied Mathematics Department performs service functions in support of the Laboratory's computational program and conducts research in the fields of mathematics and computer science.

The Department operates Brookhaven's large-scale Central Scientific Computing Facility (CSCF), supplies consulting services in certain areas of mathematics, provides programming services for the various research activities, maintains a library of service routines for general use, and conducts Laboratory-wide training in computer programming.

The Department performs research under the Mathematics and Computer Research program and also conducts research and development efforts in direct support of the CSCF. Both programs are related, directly and indirectly, to the implementation of plans for enabling the CSCF to meet the growing computational requirements of the Laboratory. In both cases the general objectives are broadened application of computers in research, increased effectiveness of computer utilization, enhanced efficiency of operations, and improved mathematical approaches and techniques for the solution of research problems. The portion of the Department's research effort that is more broadly based and primarily of more general interest is conducted under the Mathematics and Computer Research program. The remainder is carried out as part of the cost of the CSCF, allocated by user. The close coordination of these intimately related, but separately funded, efforts has been of substantial benefit in the past and was continued in fiscal 1970.

COMPUTER OPERATION

The CSCF supplies large-scale, general-purpose computing services to the overall research program at Brookhaven.

Central Scientific Computing Facility Equipment

The CSCF is currently equipped with four computer systems. Two large-scale CDC 6600 computers, each possessing 65,000 words of internal memory and both sharing one million

words of extended core storage, perform the general-purpose processing and serve remote users through BROOKNET, a high-speed computer-to-computer digital communications network. A small-scale CDC 3200 system is coupled directly to the 6600's for remote, on-line editing and updating of files. The fourth computer system, a small CDC 924, provides off-line support to the CDC 6600's. Because the present equipment is rapidly approaching saturation, a request has been made to the AEC for funds to acquire an additional, very large-scale computer in order to meet the Laboratory's computational needs through fiscal 1976.

BROOKNET Operation

BROOKNET, used for coupling any small and intermediate size computers at remote on-site locations to the large-scale computers of the CSCF, was in operation throughout the year.

Remote computers engaged in the control of experiments, data collection, and preprocessing of data now have direct on-line access, through BROOKNET, to the full computational capability of the central CDC 6600 computers. The network's two-way communication capability, which allows data, programs, and control information to be passed back and forth at speeds suitable for performing time-critical operations, enables the CDC 6600 computers to participate in the control of experiments. The facility for communicating at internal computer operating speeds allows processing to be divided advantageously between the remote and central computers, each handling the part for which it is better suited. In general, BROOKNET expands the computational capability of each coupled remote computer to that of a CDC 6600 computer for controlled periods of time. In addition, the remote computers have direct access to data stored in the data banks of the central facility and in peripheral devices such as magnetic tape and disk packs.

Focus

An existing software system, called FOCUS, capable of performing the desired file updating and

Engineer adjusting the central equipment of BROOKNET. The center rack contains control equipment for the BROOKNET branch to the Alternating Gradient Synchrotron. In the rack to the left is similar equipment for the branch to the Chemistry Department; in the rack to the right, for the branch to the Medical Department.

editing functions, was obtained from the European Organization for Nuclear Research (CERN) at Geneva. This system, developed at CERN over a period of several years, enables the following functions to be performed from on-line remote terminals:

1. Setting-up and submitting jobs to the 6600.
2. Debugging 6600 programs on-line.
3. Entering and permanently storing programs and data files for use in 6600 processing.
4. Editing and modifying permanent files.
5. Storing input and output files for subsequent processing.

Under the FOCUS system the 3200 computer is equivalent to an input-output station for the 6600 computer. Processing jobs for the 6600 received through FOCUS are placed in the 6600 input queue of jobs awaiting processing and are handled in the same manner as any other 6600 job. The remote terminals utilized by FOCUS are teletype units or

the equivalent. The initial number of eight remote stations is expected to be increased in the future.

Interactive Operator Extension

The operator extension (ox) system was developed to enable users to request information directly from the CSCF dual CDC 6600 computer system and perform certain functions previously available only through a 6600 computer operator. The hardware for ox consists of a PDP-8 computer equipped with a multiplexer capable of handling up to 8 teletype units, and a multiple access controller which directly couples the PDP-8 to both 6600 computers. A user can, through a teletype in the ready room, query the 6600 system on his job's progress, modify its priority, obtain the lengths of various queues, and determine whether a specific file or library program is resident in the system. Ox also supplies operational information such as an indication of the need for magnetic tapes, tape error data, and statistics on system performance. In addition, it provides printed output to supplement the CRT graphic output on the 6600 control consoles. The ox system became operational in January 1970, and the average number of inquiries per day passed the 300 mark early in the spring.

Operational Improvements

Work was done throughout the year to improve the effectiveness of overall facility operation, increase the computational capability of the present software/hardware system, and reduce operating costs where possible. Progress was made in system throughput capability, file recovery facilities, magnetic tape recovery techniques, and scheduling algorithms. A significant factor in the maintenance and improvement of the operating system was the knowledge gained by operating personnel through extensive operational experience. Hardware inspections, performance analyses, and cooperation with control data maintenance personnel brought about improvements in overall hardware operation. Staff requirements were reduced as the operating system was upgraded to perform more of the routine functions previously carried out by computer operators.

Computer Usage and Scheduling

The CSCF was operated 24 hr/day, 7 days/week, except for certain holidays, throughout the

year. The hour was replaced as a unit for reporting computer usage by a unit based on memory utilization. This was done because inaccuracies had arisen in reporting usage on a simple time scale for the multiprogrammed 6600 computer system, where several jobs are in process simultaneously. In addition, a system of financially weighted processing priorities was instituted.

COMPUTER PROGRAMMING

Programming-oriented service functions of the Department include maintaining and improving CSCF software systems, providing programming services to CSCF users, updating and expanding the library of general-purpose service routines, publishing the *Computer Newsletter*, and conducting Laboratory-wide training in computer programming.

Software System Maintenance and Improvement

Software system maintenance was conducted continuously during the year. Of the many improvements made in the 6600 operating system, a large number were the result of local development efforts. Among these was the means for allowing infrequently used compilers such as COBOL and ALGOL to reside on magnetic tape instead of requiring full-time occupation of 6600 computer system resources. Another was a complete revision of the memory dump routine to improve its information content and increase its speed. A peripheral processor simulator was written to allow debugging of peripheral processor programs during normal 6600 production processing. Numerous other locally developed improvements of varying significance were made. In addition, the operating system was upgraded throughout the year with improvements released by the computer manufacturer. In all, ten updated versions of the operating system were put into operation during the year.

Focus Software Revision

The FOCUS software system for file editing and management, obtained from CERN for use on the 3200 computer in the CSCF, was adapted to the BNL operating system on the 6600 computers. The entire 6600 side of the communications-link software was redesigned and implemented.

Programming Assistance Service

Programming assistance service was continued in the users' area of the CSCF. This service is manned on a rotating basis by members of the Department's programming staff, who answer specific questions about processing difficulties and supply information about control card use, setup of input decks, debugging, etc. The programmer on duty does not write programs for users or teach programming.

Program Preparation

Computer programs are written, on request, to meet the users' requirements, and existing programs are revised to meet revised requirements. In addition, programming consultation is provided to users who perform their own programming. Although most of the programs prepared have been for CSCF computers, programs are written for other on-site computers.

Computer Newsletter

The *Computer Newsletter* continued to be published to disseminate information to CSCF users on such matters as procedures, software systems, hardware acquisitions, and facility planning.

PROGRAMMING RESEARCH

The programming research activity is concerned with the general areas of advanced software development, new computer applications, and improved digital communications. Some of the efforts enhance the effectiveness of computer utilization in research through significant improvements in software systems currently in use and the conception, design, and development of otherwise unavailable software. Computer applications in research are expanded by efforts such as the continuing multiphase software development program for BROOKNET. Other software development work is concerned with the use of auxiliary computer memories, on-line peripheral devices, and remote stations of the input-output, interactive, and graphic types. Work is also done in the area of remote file editing and management. Studies are undertaken in such areas as the analysis of the effectiveness of combined hardware-software systems and the investigation of new commercially available peripheral hardware to determine its supportive value and the most effective manner of employment. Other studies are conducted on the

software techniques and problems of remote access to computers, including both high-speed remote communications and low-speed interactive access. Work is also done on design and development of interactive schemes for algebraic manipulation by computers. The character and computational capability of significant new large-scale computer systems are examined and analyses made of the suitability of the systems for use in a large research computational program, such as that at Brookhaven.

BROOKNET Software

Work continued on the design of phase 2 of BROOKNET software. New approaches in the implementation of some parts of the system resulted in revision of the initial design. Coding and subsequent debugging of sections took place throughout the year. The phase-2 software, as subsequently designed, incorporated all the features of the initial system and provided new features for file management, recovery of BROOKNET files, and scheduling. Debugging of the system as a whole began late in the year. Initial work began on the design of phase 3 of BROOKNET software, which will provide the remote computers with direct access to the extended core storage (ECS).

Statistical Analysis of Computer Operation

Statistical sampling and analysis of the operation of the CSCF 6600 operating system continued. This effort proved to be valuable in the planning of major improvements to existing software systems, and a source of pertinent data in the design and development of new software.

Advanced Operating System

A central monitor was designed in the further development of an advanced operating system for the dual 6600-ECS computer system. The central monitor possesses all the functions of the peripheral monitor contained in the standard software but has the flexibility and response time essential to input-output operations. ECS cannot be directly accessed by a peripheral processor. Further, because of the extreme speed of ECS, the overhead associated with communicating with a peripheral processor would be unacceptably high. Coding of the central monitor was performed and debugging begun.

A study based on statistical analyses of the current operating system and projected needs showed

that only relatively small gains in efficiency were possible by further system modification and that future needs of the Laboratory could not adequately be met by the current system because of limitations in facilities offered. Consequently, the direction of the development effort on an advanced operating system was altered. New goals were full availability of CSCF facilities to remote users, provisions for high-priority processing, support of extended user capabilities, and efficiency of operation. Preliminary design work was started.

Computer Graphics and Interactive Computing

Work on graphics and interactive computing continued at a somewhat slower pace, pending connection of the PDP-8I used in this work to the CSCF 6600, through BROOKNET. Plans were made for activities to be carried out after the connection is completed.

QUEST

Improvements were made to QUEST, the system developed at BNL to permit checkout and troubleshooting of on-line peripheral hardware during 6600 computer production operations. QUEST checkout programs can be run on the 6600 without system dedication, which was necessary before QUEST was developed. However, the first version of QUEST did require the dedication of a 6600 computer input-output channel to the peripheral unit under examination. A modification was developed and incorporated which enables QUEST to share a channel with other peripheral equipment actively engaged in 6600 processing.

COMPUTER RESEARCH AND DEVELOPMENT

Computer research and development efforts are directed toward the conception, design, and development of new or improved subsystems, hardware, configurations, or applications of digital hardware that have not been developed commercially. One of the principal objectives has been to develop commercially unavailable hardware or hardware systems, such as BROOKNET, for extending the application of the large-scale centralized computers to new areas of research at the Laboratory. Equally important is the design of hardware contributing to increased effectiveness in the overall utilization of the central computing facility. The provision of specialized computer hardware for

new computing services pertinent to research in the physical and life sciences is another important concern. Areas such as the analysis of computer system component function and interaction, the effective utilization of computers as an engineering and logic design tool, and the engineering analysis and assessment of significant new computer systems are included. Commercially available conversational, graphic, and input-output remote terminals are also studied and analyzed.

Flying Image Digitizer

Research continued on the development of a higher-speed bubble chamber film digitizer featuring greater resolution than previous devices. The principle of the FID was developed at BNL, and during fiscal 1970 development work was done on a suitable optical-electronic system. Preliminary consideration was given to the problem of detecting, discriminating, preprocessing, and reducing large amounts of data at extremely high speeds. A prototype digitizer based on the flying image principal was constructed and used to demonstrate feasibility. Considerable work was done on the development of low-noise detectors and amplifiers. Several methods of mechanical and optical control were investigated.

The FID research effort was transferred during the latter part of fiscal 1970 to the Physics Department, since further development is beyond the scope of the Mathematics and Computer Research program.

Content Addressable Memory

An unconventional computer memory was designed which allows searching and sorting operations to be performed many times faster than is possible with conventional memory. A unique array organization was developed and the most advanced semiconductor techniques were used to make the design of this memory economically feasible for a large variety of operations. The array and controller designs were completed and fabrication was begun. The device is called a content addressable memory because an item of information stored in it is located by specifying part or all of the item itself rather than its physical location (address), as is required by conventional memories. Whereas present computers must go through a sequential data scan and comparison operation that requires more time with each additional item of data, the

content addressable memory scans all memory locations at the same time, the total scan time being reduced to roughly that for a single item. In large searching operations the timesaving is great and is limited only by the maximum capacity of the memory. Timesaving can be equally large in repeated smaller searches or sorts. Because searching and sorting operations are an essential part of most data processing, the use of such a memory can result in substantial overall savings in computer time. Although the Brookhaven content addressable memory has been designed for attachment to a 6600 computer to augment its standard memory, the design can be modified for use with other existing computers.

BROOKNET

Further development of BROOKNET took place. Additional network equipment, designed and developed at BNL (not commercially available), was installed to provide higher-speed transmissions, faster response time, and improved versatility. Ad-

Engineers examining circuit boards in a piece of BROOKNET equipment. To the left is test equipment for checking individual circuit boards. In the foreground is a remote computer adapter mounted in a rack which will also hold the other units required for interconnecting a remote computer system to the BROOKNET network. The rack will be installed at the site of the remote computer.

ditional coaxial cables were installed underground to interconnect the Medical Department and the CSCF. Hardware for two new branches of BROOKNET was completed: two PDP-8's and one PDP-9 computer have been added at the Alternating Gradient Synchrotron, and a Sigma-2 computer has been installed in the Medical Department.

Hardware Monitor

A device was developed for gathering statistics on the utilization of the various component parts of a computer system. The results of this monitoring operation will be useful in improving the resource allocating algorithms of the computer operating system, identifying bottlenecks in the configuration, and indicating possible malfunctions. The prime capability of this device is to sense the occurrence of a digital signal, measure its duration, and combine it in a Boolean expression with other signals. An initial hardware monitor with 24 input probes and 8 visual readout channels was designed and constructed.

Universal Equipment Controller

Examination was begun of the feasibility of a general approach to the solution of the common problem of resolving the mismatch between the external interfaces of any two digital devices, to allow their connection and operation as a single system. An interfacing device was sought that would be versatile enough to connect most computers to most input-output devices, even though not originally designed to work together. This device was termed a universal controller. A basic approach was the use of a modifiable, read-only microprogram, stored in the universal controller, to resolve the logical mismatch between two digital devices. The problem was defined in detail and several avenues were explored. A logic block diagram was generated and a read-only instruction repertory was proposed.

Computer as a Design Tool

The use of the digital computer as an electrical engineering and logic design tool was studied. The development of computer programs for circuit design, logic design, diagnostics, documentation, and packaging was begun. ECAP and SCEPTRE, circuit design programs written for other computers, were modified to run on the CDC 6600 computers of the CSCF.

MATHEMATICS RESEARCH

The mathematics research activity is medium-to long-range in character and broad in scope, its areas of concern ranging from numerical methods to mathematical physics and including combinatorial analysis and mathematical statistics. Another area of concern is the mathematical formulation and analysis of physical problems. One particular objective is the development of new and improved approximation techniques and advanced numerical, computer-based procedures for the solution of research problems in the physical and life sciences. The provision of mathematical support in specific areas of the Laboratory's overall research program is also an important function.

Calculation of Energy of Many-Fermion Systems

New techniques were developed for calculating the energy of many-fermion systems from quantum mechanical first principles. The ultimate goal is to develop reliable means for evaluating the energy of large atomic nuclei and thereby gain a theoretical understanding of the origin of the energy released in atomic fission. Previous efforts were concentrated mainly on developing the energy of the system from the energy of nucleons interacting only two at a time (and more recently three at a time). Definite evidence was found at BNL of an important region of density and strength of interaction in which most of the nucleons suddenly change from one type of behavior to another. Techniques, involving the rearrangement, and powerful methods of summation of the perturbation series were developed for eliminating this problem. Calculations carried out by the new method gave good results for certain model systems that are simpler than the general problem. For these models the techniques employed by previous researchers do not produce accurate results. The techniques developed at BNL were applied to the more general problem.

Quantum Field Theory Accuracy

Some new results were obtained in an investigation of the fundamental mathematical question of whether quantum field theory is capable of producing answers of unlimited accuracy or whether only limited accuracy can be expected for the behavior of fundamental particles (nucleons, mesons, etc.). It is important for the understanding of par-

ticle physics to know whether this theory is a complete or incomplete theory. It has long been known that quantum field theory can predict only a series of successive approximations to the answer and that these get further from each other instead of ultimately approaching a single number. Study at BNL of the structure of these approximations made it possible to relate them to a certain class of integrals. It then became feasible to study whether the integrals tend finally to a single answer, even if the original series did not. This convergence is a generalization of the classical problem of the difference of two series of Stieltjes (a series of Stieltjes is represented by the integral of a particular kernel multiplied by a nonnegative definite weight function). Classically unique integral answers had previously been obtained only when the successive approximations converged sufficiently rapidly, and no method was known for cases in which they did not. A more powerful procedure was invented which allows the solution of the convergence problem in the more general case. The method was based on the principle of minimum-maximum generalized modulus.

Unfolding Experimental Data

A new procedure was developed for analyzing a certain class of experimental data concerned with atomic energy release. One such experiment involves irradiated material that is allowed to decay through the process of internal conversion; i.e., the energy of nuclear decay is used to eject an electron from the atom surrounding the decaying nucleus. Electrons ejected from the same atomic subshell have approximately the same energy. If perfect experimental equipment were available, a plot of the energy distribution of the electrons would show a family of very narrow, well-defined peaks. However, because of imperfections in the apparatus, the observed peaks are distorted. Their shapes are not known theoretically, since they are complicated functions of the experimental equipment used. What is known is that the functions are essentially the same for each member of the family of peaks. The distortion of the experimental data is thought of as a folding together of the error function of the experimental apparatus and the energy distribution functions being studied. The problem is to unfold the complicated experimental results and determine the actual relative strength and spacing of the peaks. A general criterion was used to select a peak shape smooth enough to

eliminate the effect of random experimental error. This criterion implies a complicated set of coupled nonlinear mathematical equations. A double iteration procedure was devised for their solution. This procedure is in some ways a generalization of implicit heat-flow and neutron-transport methods.

Properties of Magnets at Low Temperatures

A new method was developed for deducing the behavior of various models of magnetism at low temperatures. At the Curie temperature (at and above which spontaneous magnetism ceases to exist), various experimental properties become extraordinary in size and rate of variation. Many experiments using neutron diffraction scattering (and other methods) are now in progress at AEC Laboratories and elsewhere to measure accurately these properties. It is a challenging problem to predict them theoretically with comparable accuracy near the critical point. For the simpler and better-known Ising model of magnetism, the new method (which involves the production and extrapolation of exact series expansions at fixed magnetization) permitted calculation of many of the low-temperature properties in terms of what had been previously thought to be purely high-temperature results. These calculations agreed well with previous low-temperature results, and it was possible to go beyond these results in some respects. The method was then applied to the more realistic Heisenberg model. For the first time, it was possible to obtain a reliable calculation for the variation of the spontaneous magnetization with temperature near the critical point and to compute the variation of the magnetization with applied magnetic field for this model at the critical point.

Combinatorial Theory Research

In recent years much mathematical interest has developed in combinatorial theory because of its wide application in many fields of mathematical physics to operations research. Combinatorial theory is concerned with problems involving some type of counting, for instance, determining the number of elements in a collection that possess a given group of attributes. Combinatorial theory research at BNL concentrated on using the algebraic structure of the set on which the counting is done and developing analytic counting methods based on these properties. Methods have been developed for counting on sets having certain im-

portant algebraic structures. The type of application for which this approach is useful is exemplified by the question of how many different organic molecules can be formed of a type consisting of a carbon atom to each of whose 4 bonds is attached either a methyl, ethyl, hydrogen, or chlorine molecule. Since each of these organic molecules can be modeled as a regular tetrahedron with the carbon atom in the center and CH_3 , C_2H_5 , H, or Cl at each corner, the problem is to count the number of equivalence classes of organic molecules of this type. Molecules were regarded as being equivalent and of the same equivalence class if one could be transformed into the other by permutation of the groups at their corners. The methods developed were for counting on sets having algebraic structure similar in type to the above example. The mathematical structures on the set depend on the structure of the set. The higher structure is an algebra of functions whose values are numbers. These methods were developed by studying the interrelationships between these functions and expressing complicated ones in terms of simpler ones.

Perturbation Theory

Problems concerning perturbation of differential operators arise in such fields as nuclear physics, quantum physics, quantum chemistry, and electromagnetic theory. Research in this area was concerned primarily with the application of perturbation techniques to the solution of problems involving the scattering of particles and waves. Elsewhere scattering theory had been developed extensively in the case of certain symmetric differential operators. The work at BNL extended these results to nonsymmetric operators, i.e., the case in which energy is lost by the system under observation. Previously very little had been accomplished along these lines. A particularly important problem involves wave propagation in a cylindrical wave guide subject to a disturbance, which may be due to either a variation in the medium inside the wave guide or a change in the shape of the wave guide. Such problems also occur in the propagation of sound waves. Explicit formulas were obtained for the transmitted and reflected waves as well as other pertinent physical quantities. In addition, power series expansions were obtained for these quantities and the convergence of these series for small perturbations was rigorously established, which provided a means for calculating these quantities in many

cases. The methods employed include both time-dependent and stationary techniques and are similar to those used in connection with quantum mechanical scattering problems.

Neutron Scattering From Beta Brass

Another mathematical effort led to better theoretical understanding of the neutron scattering from β -brass near its order-disorder transition temperature. Previous investigations elsewhere used a rigid Ising model and were based on the assumption that the expansion of the system as it passes through its transition is unimportant. Recent experimental work done at BNL and elsewhere showed that, although theoretical predictions obtained by using the rigid Ising model agreed reasonably well with observations, a number of discrepancies still existed. At BNL a remarkable improvement over earlier results was obtained by using the compressible Ising model of Domb, which includes the expansion effects. This model has been criticized on the grounds that local density fluctuations are ignored. However, an investigation that included the exact mathematical solution of a fluctuating model indicates that in β -brass these effects are relatively unimportant.

Almost Periodic Functions

Mathematical studies of "almost periodic" phenomena were initiated by Harald Bohr in 1925. Work in almost periodic function theory has applications in the mathematics of electrical engineering and celestial, statistical, and quantum mechanics. A number of differential equations arising in the theory of optimum control of machine systems have almost periodic solutions. The largest class of almost periodic functions are the so-called Besicovitch functions. A central problem has been to obtain a simple description of these functions in terms of their quasi-periodic properties. Currently known descriptions are cumbersome and difficult to use in the applications mentioned above. In work done partly at BNL and partly at the University of New Mexico a simple description of the Besicovitch functions was obtained. The description is in terms of two conditions of a quasi-periodic nature and is far simpler and easier to work with than any other description known to date. One of the conditions is a well-known periodicity condition, and the other is that the functions must satisfy an integral equation that has not been previously applied to this area.

Lebesgue Spaces

A great deal of modern mathematical analysis makes use of geometric spaces called Lebesgue spaces (L_p -spaces), which serve as a convenient basis for modeling a number of physical phenomena, especially in probability theory. Many differential equations are best solved by viewing them as equations between entities in Lebesgue spaces. One of the main features of Lebesgue spaces is

a useful symmetry between two spaces related by a certain equation. In work done at Brookhaven and Duke University, this symmetry was shown to persist when composite spaces are formed from many different Lebesgue spaces. Other properties of the new spaces also were studied. The work considerably extends recent results published in Scandinavia and has particular application to the calculus of variations, which applies to "optimum control" theory.

LIFE
SCIENCES

Biology

Studies conducted in the Biology Department cover a broad range of interest, from ecology to the three-dimensional structure of molecules. A principal objective is the development of fundamental biological information to provide an understanding of the effects of ionizing radiations on biological systems. Such radiations are used for beneficial purposes, especially the production of mutations for crop improvement and insect sterility.

A noteworthy portion of the research studies is concerned with algae and higher plants. Extensive controlled environmental facilities are available for growing plants under closely defined conditions. The research reactors and particle accelerators of the Laboratory are used as irradiation sources in several projects.

The work of the Department is carried out by staff members, postdoctoral Research Associates from this and other countries, and visitors and colleagues from other laboratories and universities.

PLANT SCIENCES

Biological Effectiveness of Fission Neutrons vs X Rays for a Wide Range of Genotypes and Criteria of Response

A characteristic finding in plants irradiated as dry seed is the remarkably high biological effectiveness of neutrons relative to x rays. For further study of the phenomenon, seeds of six species of plants, chosen because of wide differences in radiosensitivity, were exposed to 250-kVp x rays and to fission neutrons. Five criteria of response were measured: seed set, pollen fertility, plant height, survival, and emergence above ground. Within a single species, the RBE, i.e., the ratio x-ray dose/neutron dose for equal effects, varied inversely with the dose required to produce the various criteria of response. For a single criterion and the six species, the RBE varied inversely with "radioresistance." As a consequence of the inverse relation of RBE to dose, the RBE's were relatively high (21 to 32) for sensitive species and criteria and low (7 to 12) for resistant species and criteria. A logarithmic plot (Figure 1) of neutron dose vs x-ray dose for equal effects shows a

close correlation ($r=0.95$) and an approximate linear relationship ($\log N = -1.6 + 1.3 \log X$) over four orders of magnitude of neutron dose. This simple power function is amenable to the interpretation that radiation damage (due probably to chromosome breakage and loss) increases linearly with dose for neutrons and with the square of the dose for x rays.

Photoperiodism and Photomorphogenesis

Previous work on flowering suggested that photoperiodism in the duckweed *Lemna perpusilla* strain 6746 involves endogenous circadian rhythm – the "biological clock." However, direct evidence for such involvement requires the study of an overt, continuous rhythm (as an indicator of the state of the clock) in the same plant and under essentially the same conditions as in the work on flowering. Thus, the rate of CO₂ output by axenic cultures supplied with sucrose and kept at constant temperature was followed by infrared analysis. Four sets of cultures were monitored concurrently (see Figure 2). Alternations of ¼ to 21 hr of dim red light with darkness in 24-hr cycles were found to synchronize the CO₂ output to a 24-hr periodicity. In continuous darkness following either continuous dim red light or synchronization to a schedule of 12 hr of light and 12 hr of darkness, the CO₂ output oscillates through two maxima and two minima, with a circadian (roughly 24-hr) periodicity, before damping. In continuous red light, the rate is linear.

The "skeleton" photoperiodic schedule $\frac{1}{4}(5\frac{1}{2})\frac{1}{4}(18)$, with its two alternating dark periods of highly unequal length, rapidly synchronizes the CO₂ output in a phase relationship that is the same irrespective of which dark period is given first. Flowering is also rapid in either case. However, the effect on CO₂ output of the skeleton schedule $\frac{1}{4}(10\frac{1}{2})\frac{1}{4}(13)$, with its two dark periods nearly equal in length, depends entirely on which of the two dark periods is presented first; the same is true of the effect on flowering. These and other similar results strongly support the concept that a circadian clock is involved in photoperiodic timing, and also provide a new experimental system in which to study its action.

Figure 1. Relationship between the doses of x rays and neutrons required to produce equal change in various criteria in six plant species. The data are interpreted in the text.

Plant Bile Pigments

The biliproteins found in plants are complexes of bile pigments with specific proteins that serve as light-harvesting pigments in photosynthesis and as photoregulators of growth and development. In continuing work, the algal biliproteins were found to dissociate readily into subunits on treatment with the detergent sodium dodecyl sulfate. The subunits range in molecular weight from about 14,000 to 20,000, and each bears a chromophore. The number of kinds of subunit per biliprotein varies from one to four. The relatively small size of the subunits should facilitate chemical study of the proteins.

Protochlorophyll Holochrome

Formation of chlorophyllide from protochlorophyllide in dark-grown bean leaves involves a series of intermediates, the first produced by photoreduction, the others by dark reactions. The conversion of the intermediate absorbing maximally at 678 nm to that absorbing maximally at 683 was found to be photoreversible. In the dark,

Figure 2. Circadian rhythm in *Lemna perpusilla*. The points indicate the half-hourly rates of CO₂ production of four sets of cultures. The horizontal shading indicates the end of continuous exposure to dim red light, the vertical lines a 1/4-hr exposure to the red light. During the intervals between the exposures to red light, the cultures were kept in the dark. The numbers in the day I panels indicate the length of the dark periods. Plants exposed to the top schedule flower slowly, while those exposed to the others flower rapidly. The schedules that lead to rapid flowering also resulted in synchronization of CO₂ output. The findings are analyzed in the text.

the photochemically produced 678-nm form is again converted into the 683-nm form. This is the first demonstration of a photoreversible step in the chlorophyllide interconversions.

Plant Growth Studies

The growth of many plants raised in controlled environment chambers under apparently adequate light intensities and day length is abnormal. The plants are very short and show more branching than obtains in the field or greenhouse. The abnormal appearance of the plants suggests insufficient exposure to far-red light. In growth chambers, the far-red light lacking in fluorescent lamps is supplied by tungsten lamps. To increase the ratio of incandescent to fluorescent lamp wattage in present tests, tubular tungsten-halogen lamps enclosed in large water-cooled condensers to remove unwanted ultraviolet and infrared

radiation were used. With increase in the ratio of incandescent to fluorescent wattage to 1:1, plant growth was markedly improved, as indicated by evaluations of height, weight, and habit. Improved supplementary illumination in the greenhouse was also obtained by use of the tungsten-halogen lamps.

Electron Transport and Oxygen Evolution in Chloroplasts

The effects of activation of photosystems I and II on the redox states of the chloroplast cytochromes were determined by use of the double-beam spectrophotometer. Cytochrome *f*, as expected, was oxidized by activation of system I and reduced by system II. Cytochrome 559 was oxidized by system I in the presence of an uncoupler, without the mediation of cytochrome *f*. The reduction of cytochrome *b₆* by system I was inhibited by all treatments that reduced cytochrome *f*. The findings allow the current scheme for chloroplast electron transport to be replaced by another which involves two new features, two parallel pathways between the photosystems and a role for cytochrome *f* in the overall regulation of electron flow patterns.

The ability of artificial electron donors to bypass the requirement of Cl^- for oxygen evolution was examined in detail. Hydrazine, which proved to be the best donor, apparently donates electrons at two sites, one of them sensitive to mild heat treatment. One site appears to lie between the water-splitting enzyme and the labile manganese function, and the other, between the manganese site and the photochemical reaction. Donation at the latter site is accompanied by higher rates of photosystem-II electron transfer than have hitherto been achieved.

Plasma-Rich Cells of Grass Stamen Filaments

Certain cells in filaments of grass stamens are termed plasma rich. These dense, thick-walled cells occur in the epidermis of the filament and, in some species, the outer cortex. The plasma-rich cells are responsible for the remarkably rapid growth of grass filaments at the time of flowering. They may elongate 6-fold in <1 hr, during which they respire at a high rate, absorb water, and become vacuolated and thin-walled.

Study of the plasma-rich cells from stamen filaments of wheat (*Triticum aestivum* L.) using the electron microscope revealed the following. The

Figure 3. Plasma-rich cells of grass stem filaments as seen in the electron microscope. *C* = cuticle; *W* = wall; *M* = mitochondria.

cuticle (*C*, Figure 3) is a dense sheet about 100 nm thick covering the epidermal cells. It must be quite plastic to accommodate the stretched filament. The thick walls (*W*) are made of elements unusually well-spaced from one another, an arrangement that probably allows for easy slippage of the fibers during filament elongation. The cytoplasm contains abundant ribosomes and endoplasmic reticulum, sparse plastids and dictyosomes, and dispersed small vacuoles. Particularly notable is the extraordinary concentration of mitochondria (*M*). These organelles may occupy as much as $\frac{1}{2}$ the volume of the cytoplasm. The appearance of the dense matrix and well-developed cristae of the mitochondria is more typical of animal tissues showing high metabolic rates than of most plant tissues. The high oxidative requirements of the filaments are reflected in the unusual density of the mitochondria and their internal morphology.

Chlorophyll-Protein Complexes and Photochemical Reaction Centers

The purple photosynthetic bacterium *Chromatium* carries out primary light-driven reactions in chromatophores (M.W. = 13 million) that contain

Figure 4. Absorption spectra of *Chromatium* chromatophores and of fractions A and B derived from the chromatophores by treatment with detergent. Fraction C (not shown) is similar to fraction B. The relationship between the pigments in the fractions and the light reaction centers involved in photosynthesis is discussed in the text.

all the pigments and electron transfer components necessary for energy conversion. On treatment with the detergent sodium dodecyl sulfate, chromatophores are dissolved into three bacteriochlorophyll(Bchl)-carotenoid-protein complexes (see Figure 4). The reaction center P883/P800 is part of fraction A (M.W. = 500,000), which contains 40 Bchl (B890), 19 carotenoid, and about 9 cytochrome molecules. Fraction B (M.W. = 100,000) contains Bchl (B800 + B850), carotenoid, and P836, which might function as a second reaction

center. Fraction C (M.W. = 100,000) contains Bchl (B*800 + B820) and carotenoid, but no reaction center pigments. Variations in the relative concentrations of each of these membrane components account for the differences in far-red absorption spectra when *Chromatium* is grown under varying conditions. In the presence of phenazine methosulfate, fraction A carries out a light-driven cyclic electron flow via the high potential cytochrome 556 ($E_m = +0.34$ V at pH 8) with a quantum efficiency between 0.5 and 1.0. This indicates that the reaction center with its associated cytochrome survives the detergent treatment without disruption of the essential structure required for photochemical activity.

Regulation and Synchronization of Root Meristematic Cells in the Mitotic Cycle

Culture of mammalian and lower-plant cells for use in the study of regulatory mechanisms is of long standing, but was achieved only recently for cells in a complex tissue. In cultures of isolated primary pea roots, not only was the control of DNA synthesis and mitosis demonstrated but also the synchronization of meristematic cells and the experimental regulation of their distribution at the G_1/S boundary. In the present kinetic study of the entry of suitably controlled cells into S phase after prolonged stationary periods, the distribution of cells in G_1 was found to be and to remain fixed in a rectangularly shaped pattern that in no manner resembles a normal or a skewed distribution. The rigidity of the pattern, maintained even after a 5-day stationary period, suggests the existence of a principal control point, associated with the terminal functions of G_1 , that regulates cell advancement to S. A quantitative analysis of synchronized cells at the G_1/S boundary showed that none were lost as the population traversed S, G_2 , and mitosis. This observation, along with a fixed rectangular distribution in the stationary phase, demonstrates that cells exit from the mitotic cycle immediately after mitosis if they are going to differentiate. Thus, the point of regulation for the very initial events of differentiation is postmitotic (early G_1), while that for advancement to S is in late G_1 .

Cooperative Radiation Mutation Program

Under this program irradiation services are provided to cooperative plant breeders and geneticists. Some of the projects were begun a number

of years ago and involve irradiation of materials on a continuing annual basis. In this category are efforts to develop mutant strains of American elm that are resistant to the Dutch elm disease (F.H. Holmes, University of Massachusetts, 1961) and the establishment of highly variable populations of oats (K. J. Frey, Iowa State University, 1956) and bread wheat (N.F. Jensen, Cornell University, 1967) for breeding improved varieties. Recently initiated work has as objective the control of boll weevils through radiation-induced male sterility (H. Flint and W. Klassen, Entomology Research Division, USDA, Fargo, North Dakota), induction of sugar cane mutants with high yield combined with nonflowering habit (Sugar Cane Breeding Station, Barbados; Sugar Planters Association, Guyana), and recovery of male sterile mutants in finger millet to simplify production of hybrids (Uganda).

In January 1970 Utah State University released to farmers a new variety of barley, Bonneville 70, developed from seeds irradiated under this program. The parent variety was irradiated in 1952, the year the service was made available, in the hope of inducing a mutation for brittle awns which would alleviate poor threshability. The new variety has favorable awn characteristics and also retains the desirable qualities of the original.

GENERAL PHYSIOLOGY

Diabetogenic Effect of Growth Hormone

Growth hormone injected into the dog at a level insufficient to cause temporary diabetes (1 mg/kg body weight/day) was found to alter glucose and fatty acid metabolism initially in the same way as does a larger diabetogenic dose (3 mg/kg/day). As indicated by use of glucose- ^{14}C , transfer of glucose from liver to blood and from blood to other tissues increases with only a moderate increase in blood glucose concentration. The plasma insulin concentration, as indicated by insulin- ^{131}I immunoassay, increases manyfold. The increase in uptake of blood glucose by nonhepatic tissues is small compared with the increase in plasma insulin. Thus, the tissues are resistant to insulin action. As indicated by use of palmitate- and glycerol- ^{14}C , the transfer of free fatty acids and glycerol from nonhepatic tissues to the blood and from the blood to the liver increases progressively during days 1 to 3 of the growth hormone regimen. Between days

3 to 6 the turnover of free fatty acids and the concentration in plasma return to normal, but glycerol turnover remains above normal, i.e., triglyceride hydrolysis in the tissues remains accelerated, but the liberated fatty acids are not released to the blood. Between days 5 to 9 at the higher level of hormone administration, the resistance of tissues to insulin action suddenly increases further. This occurs without change in the already elevated glucose output by the liver or in plasma insulin concentration. As a result of the increase in resistance to insulin, the blood glucose increases sharply to the level at which glucose appears in the urine. With precipitation of the diabetic state, the turnover of glycerol and free fatty acid and the concentrations in blood again increase. The changes in metabolism peculiar to the higher level of growth hormone administration are suspected to result from alterations in the rate of secretion of some other hormone.

Hemoglobin Heterogeneity in the X-Irradiated Duck

The erythrocytes of the adult Pekin duck contain two hemoglobins that differ in amino acid composition and in amount and rate of synthesis in blood. Comparable hemoglobin heterogeneity appears common to most if not all species of animal. In the present work, the relative amounts and rates of synthesis of the hemoglobins in blood were measured in the x-irradiated duck. Synthesis of both hemoglobins decreased and remained depressed during the first week or so postirradiation, increased to above the control level during the next two weeks, and then returned to about the control level. The decrease in rate was greater for the major than for the minor hemoglobin, while the increase in rate was greater for the minor hemoglobin. The relative amount of the major hemoglobin in blood decreased some weeks after the irradiation and then returned to the control level. The findings suggest that the cell system giving rise to the major hemoglobin is more affected by irradiation than that concerned with formation of the minor hemoglobin.

Radiation-Induced Aging

The late effects of irradiation in animals closely resemble those of natural aging. The close parallel between chromosome stability and both natural and radiation-induced aging points to mutations

in somatic cells as an important component of the aging process. However, other stochastic changes are relevant. Thus a composite theory was developed which proposes aging as the result of a series of cellular events. Degenerative disease, a presumptive sign of aging, generally requires five or more independent events for induction. The theory successfully explains many otherwise puzzling phenomena, in particular the late effects of irradiation. It predicts a high rate of spontaneous mutation in somatic cells. This prediction is substantiated by studies of the frequency of chromosome aberration in the cells of various organs. It is important to know why the frequency is so high and whether it can be lowered. Others have shown that calcium stabilizes the DNA of plant cells. This raises the possibility that individuals with relatively high calcium levels and thus more stable DNA live longer than others. Extensive test of this possibility produced convincing evidence that the calcium level is not a factor in mammalian aging.

The theory was based largely on work with liver cells, which seldom undergo division. Others have reported that bone marrow cells, which divide almost continually, "wear out" after about 50 divisions and then disintegrate. Although the results of preliminary tests appeared to be in agreement with this report, those of much more careful and extensive work were not. In the bone marrow cells the frequency of chromosome aberrations remains unchanged even into extreme old age. In young animals given a large dose of radiation the frequency of chromosome aberrations in bone marrow increases promptly and then decreases within hours to a level that approaches but never quite reaches the control value, even when the animals become very old. It is of interest that the approach of the frequency to the control level is closer with fast neutron irradiation than with x-irradiation. Apparently cells are more severely damaged by neutrons than by x rays. Thus, cells damaged by neutrons will die and be replaced by normal cells, while those damaged by x rays will survive a long time.

Pressure Differences Associated With Plant Cells

The steady-state mechanical and osmotic pressure differences that appear across the limiting membranes of living plant cells can be related theoretically to the rates of various intracellular chemical reactions. A two-compartment model

system was constructed to test some of the predictions given by theory. One compartment was closed and initially filled with an aqueous solution of urease; the other was open and perfused at a constant rate with an aqueous solution of urea. The system develops pressure differences across the cellophane membrane separating the compartments that are proportional to the rate of hydrolysis of the urea in the closed compartment. When the production rate of ammonia was $10 \mu\text{moles NH}_3$ per min per sq cm of membrane, the mechanical and osmotic pressure differences were 0.59 and 8.8 atmospheres, respectively. Thus, in actual plant cells the pressure differences appear to be a function of the resistance of the limiting membranes to the passage of the chemical species participating in the metabolic reactions of the cells. Further, the kind of reaction occurring must affect the pressure differences. For example, during periods of photosynthesis the production of large, relatively impermeable molecules which tend to accumulate intracellularly would be expected to lead to greater pressure differences than obtain during periods of respiration when breakdown of the large molecules occurs. The expected change in the pressure differences is observed in nature.

Radiosensitivity of Some Amphibian Species

The radiosensitivity of amphibians was investigated to determine whether the relationship between nuclear characteristics and radiosensitivity demonstrated previously in higher plants and microorganisms also obtains in vertebrates. Amphibians were studied since, as a group, they offer a wide range of chromosome and nuclear size and, correspondingly, a wide range of DNA content not generally found in other classes of vertebrate. The survival of *Desmognathus fuscus* (dusky salamander), *Taricha granulosa* (rough-skinned newt), *Amphiuma means* (three-toed congo eel), and *Necturus maculosus* (mud puppy) was determined after acute x-irradiation. The data obtained and that in the literature for *Rana* (leopard frog), *Notophthalmus* (newt), and *Ambystoma* (Mexican axolotl) were correlated with the corresponding nuclear and chromosome volumes. In the amphibians as a group, the LD_{50} (exposure required to reduce the starting population by one-half) determined at various times after irradiation (until no further radiation-induced deaths occurred) decreased with increase in nuclear and chromosome

Figure 5. DNA from cultured Chinese hamster cells. Cells containing DNA labeled with ^3H -thymidine were allowed to lyse for 60 min in an alkaline medium placed on a sucrose gradient. Upon ultracentrifugation, the DNA separated into two fractions, indicated by the peaks of radioactivity. A decrease in the peak at fraction 12 and a corresponding increase at fraction 17 occur with increase in lysis time and when the cells are irradiated before lysis (see text).

volumes, the same relationship found for plants and microorganisms. In the amphibians, the latent period before radiation-induced deaths began to occur increased with increase in nuclear or chromosome volume, perhaps as a function of the increase in mitotic cycle time.

The LD_{50} was 724 R at 50 days postirradiation for *Rana* and 530 R at 70 days for *Desmognathus*. For *Necturus*, the LD_{50} at 170 days was 112 R. Extrapolation of the *Necturus* data to 200 days suggests an even lower value, 76 R. These values for *Necturus*, which has the largest known chromosome volume of any amphibian, establish it as the most radiosensitive vertebrate yet investigated.

Radiation Damage to Mammalian-Cell DNA

A technique involving lysis of cells on top of a sucrose gradient and subsequent ultracentrifugation is being employed to study (1) the organization and composition of the chromatin of mammalian cells, (2) the effects of radiation on the chromatin, and (3) the ability of mammalian cells to repair radiation damage. Significant progress was made by use of alkaline gradients. Such gradients cause separation of the normally duplex DNA in chromatin into single strands but minimize mechanical damage. For detection, the DNA

is labeled by incubation of the cells with ^3H -thymidine. Figure 5 shows typical results for cells lysed 60 min on an alkaline sucrose gradient before sedimentation; two peaks of radioactivity are observed. With extension of the lysis the first peak (fraction 12) decreases, while the other (fraction 17) increases; i.e., the DNA of fraction 12 appears in fraction 17. Small doses of radiation (200 to 700 rads) applied to the cells speed this transition, and large doses (>1500 rads) cause the peak at fraction 17 to bulge to the left, which is indicative of breaks in single strands of DNA. Incubation of the cells after the irradiation reverses both effects. The findings indicate that, although the DNA of fraction 12 sediments more slowly, it has a larger radiation "target" and probably, therefore, a larger gross molecular weight than the DNA of fraction 17. Further, cells have a self-stimulated capacity to repair damage to this larger target as well as to the single strands of DNA resolved from it.

MOLECULAR BIOLOGY

Structure and Function of Enzymes

Enzymes have two important characteristics, specificity and the ability to promote chemical change. The structural features of the proteolytic enzyme trypsin responsible for these properties are being sought. The amino acid residues functioning in catalysis, histidine-46 and serine-183, were identified earlier. To account for the specificity of trypsin for amino acid residues with positively charged side-chains, a particular ionized carboxyl group in trypsin is presumed to function as a specificity site through electrostatic attraction. Evidence for this was provided by chemical modification studies in which carboxyl groups in trypsin were converted to a nonionizable state (substituted amide) by gentle means. With limited conversion, the specificity of trypsin was more rapidly abolished than the reactivity of the catalytic center. The findings confirm the nature of the specificity site as a carboxylic acid group and should lead to its location in the amino acid sequence when a purified product is isolated. Meanwhile, the identity of this carboxyl group was deduced from other work. When the two-chain, or α , form of trypsin is allowed to act on itself, a new form of the enzyme appears. Because the new form lacks, in large measure, the characteristic specificity of

trypsin, it is called pseudo trypsin. Examination of its structure revealed a new internal split between lysine-176 and aspartic acid-177. On the basis of the known three-dimensional structures of chymotrypsin and elastase and their sequence homology with trypsin, it is generally assumed that the three-dimensional structure of trypsin is similar. From examination of a molecular model of chymotrypsin, it was deduced that aspartic acid-177 of trypsin would be in satisfactory spatial orientation to the catalytic center to serve as the specificity site of this enzyme.

The Intracellular Development of Bacteriophage ϕ R

When ϕ R infects its host, *Escherichia coli*, the entering parental strand of DNA becomes attached to the membrane of the host, where replication of the phage DNA ensues. The membrane-bound phage DNA was separated into two infective DNA fractions differing in buoyant density. Actively replicating parental DNA was found in the dense fraction, the nonreplicating in the light fraction. Thus, the parental DNA molecules in the two fractions apparently differ in function during phage replication. Results of tests in which increasing multiplicities of phage were used and in which actively replicating bacterial DNA was fractionated support this conclusion.

Structural Studies of the Small Bacteriophages ϕ R and ϕ X174

The phages ϕ R and ϕ X174 were found to differ in several ways: ϕ R is stable under conditions that inactivate ϕ X174, the conditions for maximum adsorption of phage to host differ, and the conditions required for extraction of DNA from phage and for dissociation of the phage coat are more extreme for ϕ R than for ϕ X174. The composition and assembly of the spike components of the phages conceivably account for the differences observed. To explore this possibility, mutants of ϕ R in the cistrons that determine the function of two distinct spike components were isolated. Comparison of these with similar mutants of ϕ X174, based on electron microscopy, acrylamide gel electrophoresis, and equilibrium centrifugation, is under way.

Pneumococcal Mutants and Transformation

Testing of individual cells in a population of *Diplococcus pneumoniae* treated with the mutagenic agent 1-methyl-3-nitro-1-nitrosoguanidine led to

the isolation of three types of mutant conceivably pertinent to the mechanism of genetic transformation. When normal pneumococci are treated with a mild detergent such as sodium deoxycholate, lysis of the cell walls occurs. The enzyme responsible for the lysis may normally produce small gaps in the cell wall which allow entry of DNA in transformation. However, a mutant lacking the cell-wall lytic activity still incorporated transforming DNA. Certain genetic markers in donor DNA are integrated at a much lower frequency than others in wild-type recipient cells. Several mutants showed uniformly high efficiency of integration for all markers. Apparently, therefore, wild-type cells contain a special mechanism, perhaps an enzyme system, which strongly curtails either the integration of particular configurations of donor DNA or the viability of genetic recombinants bearing such configurations. The mechanism of repair of ultraviolet-induced damage of cellular DNA perhaps shares steps in common with the mechanism of genetic recombination. However, an ultraviolet-sensitive mutant, which was apparently deficient in the mechanism of repair, did not show any alteration in the uptake or recombination of transforming DNA.

The Genetics and Physiology of Bacteriophage T7

The bacteriophage-host system is perhaps the simplest available for study of the chemical and physical bases of genetic phenomena. An examination of bacteriophage T7 is being made in depth in order to develop and apply physical-chemical techniques for analysis of such biological processes as DNA synthesis, genetic recombination, the control of genetic expression, and viral assembly. Two main advantages of using T7 are the ease with which mutants can be obtained and the ready availability of large quantities of material. To date, 19 genes have been identified in T7 and ordered on a linear map. The first six genes at the left end of the map affect DNA synthesis; the others affect late functions such as viral assembly. By use of polyacrylamide gel electrophoresis and autoradiography the pattern of T7-directed protein synthesis was studied (in collaboration with Dr. J.V. Maizel, Jr., of the Albert Einstein College of Medicine) (see Figure 6). It appears that ≈ 20 to 30 proteins are made by T7. The proteins specified by 16 of the 19 known genes were identified, including 9 of the 11 that make up the

Figure 6. Proteins of T7 bacteriophage. Infection of the host, *E. coli*, by the phage was carried out in the presence of amino acids containing ^{14}C to label the phage proteins. The proteins were separated by electrophoresis on polyacrylamide gels and located within the gel by autoradiography. As indicated by the autoradiographs, mutants 1, 5, 9, 10, 12, 15, and 16 lack proteins present in wild-type phage.

mature phage particle. The directions of translation and transcription and the orientation of the DNA molecule relative to the genetic map were determined.

Inhibition of Proteolytic Enzymes Involved in the Metabolism of Peptide Hormones

The metabolism of the peptide hormones bradykinin and angiotensin involves proteolysis reactions that (1) release biologically active peptides from precursor proteins, (2) convert an active peptide to a smaller form of somewhat different activity, or (3) inactivate the peptides by hydrolysis. By use of specific inhibitors of the proteolytic reactions, it is possible to demonstrate participation of the hormones in various physiological processes. Perhaps such inhibitors would serve to selectively control the flux of these peptides through certain metabolic pathways. *Bothrops jararaca* venom contains material (the bradykinin potentiating factor) that inhibits some of the proteolytic enzymes involved in the metabolism of bradykinin and angiotensin. From the venom nine biologically active peptides were obtained by chromatographic procedures. Each peptide contains 5 to 12 amino acid residues per molecule, has a high proline content, and has the cyclized form of glutamic acid, pyrrolidone

carboxylic acid (PCA), at the amino-terminus. The structure of one peptide was shown to be PCA-Lys-Trp-Ala-Pro, and it was synthesized by the solid-phase method. The peptides potentiate the activity of bradykinin *in vivo* and *in vitro*, i.e., increase the effects of bradykinin on smooth muscle contraction, capillary permeability, and blood pressure. Infusion of synthetic PCA-Lys-Trp-Ala-Pro in the rat inhibits pulmonary inactivation of bradykinin as well as the pulmonary conversion of angiotensin I to angiotensin II. The findings illustrate the potential of enzyme inhibitors for control of the metabolism of the hormones.

Determination of Biological Structure by X-Ray Crystallography

A solid-state low-temperature crystal mount, based on a design by David Haas (Purdue University) was completed. It permits collection of a complete set of diffraction data for a protein isomorph from one crystal without significant radiation damage. Thus, the empirical cross-scaling of data from the half-dozen or so crystals previously required for a data set, which introduces inaccuracies of several percent, is eliminated. More important is the elimination of the need to enclose the crystal in a glass capillary, which diminishes counting rates and requires large empirical absorption corrections, a principal source of error in protein data.

Attempts continued to determine the crystal structure of 6-Se-deamino-oxytocin. Direct methods were used, including Sim-weighted heavy-atom electron-density Fourier maps, minimum-function superposition maps, and symbolic addition plus tangent refinement, for all of which computer programs were written.

Generation of Bifunctional Enzyme by Fusion of the *hisD* and *hisC* Genes in *Salmonella typhimurium*

The gene order of the *his* operon in *S. typhimurium* is *hisOGDCBHAFIE*, translation proceeding from left to right. The *D* gene encodes histidinol dehydrogenase (HDH), the *C* gene the "aminotransferase" (AT). These enzymes have no known tendency to associate. The polar prototroph TR767R81 arises through a frameshift or deletion at the COOH-terminus of the *D* gene and thus produces functional HDH lacking the normal COOH-terminal amino acid and tryptic peptide. In the present work, nonpolar revertants of the

prototroph were selected on aminotriazole by J.R. Roth (University of California at Berkeley). The HDH from one such revertant, TR1024, was purified to homogeneity and found to possess strong AT activity as well. The HDH and AT activities of this preparation are chromatographically inseparable. Tryptic peptide maps of TR1024 enzyme show spots that are the sum of those of HDH and AT. Electrophoresis in sodium dodecyl sulfate gels reveals for wild-type AT a band of $\approx 40,000$ daltons molecular weight; for wild-type HDH, a band of 45,000; and for TR1024, a band of 85,000. Native AT is thought to be a dimer of identical subunits of $\approx 35,000$ daltons, and native HDH, a dimer of identical subunits of 40,000 daltons. It appears, therefore, that in TR1024 the spacer between the *D* and *C* genes has been obliterated and that a single gene now encodes the chemical subunits of HDH and AT in a single polypeptide chain. These results suggest a mechanism by which multifunctional proteins can evolve from monofunctional proteins.

The Cell Wall in *Pneumococcus* and *Meningococcus*

A major component of the cell wall in pneumococcus, a gram-positive bacterium, is the *C*-polysaccharide. In the gram-negative meningococcus, major components are the group-specific polysaccharides. These polysaccharides are involved in the immune response to infection by the organisms. The structures of these polysaccharides are under continuing investigation. Accumulative findings show that the pneumococcal *C*-polysaccharide consists of two polymeric substances; one is a typical mucopeptide, the other, a novel polymer of *N*-acetyl-galactosamine phosphates and 2,4-diamino hexose. The polymers are cross-linked by muramic acid phosphate. The immunological properties of the polymers differ. Three group-specific meningococcal polysaccharides were obtained in pure form. One is a polymer of *N*-acetyl-mannosamine phosphate which is also *O*-acetylated. The other two are both homopolymers of sialic acids but are chemically and immunologically distinct. The three polysaccharides are all antigenic in man and have been used elsewhere as a vaccine against meningococcal infection.

Conformation of Macromolecules

The applicability of neutron diffraction to protein structure determination is under exploration.

Earlier data for myoglobin were obtained to 2.8-Å resolution; recent data to 2.0-Å resolution. Interpretation of the Fourier maps resulting from the data is not complete, but new structural detail, i.e., H atom positions, for the pigment can be postulated.

The cyanogen bromide, ethyl hydrogen peroxide, pentane, and butane derivatives of myoglobin were compared by x-ray diffraction difference analysis. In the first two derivatives, the complexing agent interacts with the heme and distal histidine. In the others, binding was not detectable.

ECOLOGY

Atmospheric CO₂ and Photosynthesis in the Brookhaven Forest

During the past 100 years the concentration of carbon dioxide in the atmosphere has increased by about 10% (30 ppm). The increase presumably reflects combustion of fossil fuels and is continuing. Because photosynthesis is usually limited by the amount of carbon dioxide available, there is reason to wonder whether the change in atmospheric carbon dioxide has increased the photosynthesis of plants in nature and, potentially, the total fixed carbon on earth. Greenhouse experiments indicate an approximately linear increase in the rate of photosynthesis with increase in CO₂. However, many factors affect the rate, and there has been no evidence that such an increase occurs in nature. By use of specialized equipment developed here during several years for the measurement of plant metabolism in the field, the question of the extent to which increased atmospheric CO₂ might affect rates of photosynthesis was examined. In an extensive series of tests made in the forest, the CO₂ exchange rates of trees receiving normal or enhanced CO₂ concentrations were monitored. For the forest as a whole, the findings indicate a linear increase in the rate of net photosynthesis with increase in CO₂ concentration through a range of more than 100 ppm. Accordingly, the increase in atmospheric CO₂ concentration noted must have increased the net rate of photosynthesis of the forest by about 8%. However, the degree of response to CO₂ was not the same for all species. The enhancement of photosynthesis was greatest for the scarlet oak. The effect of this is to increase the competitive ability of the scarlet oak relative to other species and enhance its already conspicuous ten-

dency to increase in dominance as succession progresses. Thus, there is substantial reason to believe that human activities that have changed the composition of the atmosphere have already affected natural ecosystems worldwide by not only increas-

ing the net fixed carbon but also shifting the competitive abilities of the diverse species of natural ecosystems, a change that will almost certainly affect the characteristics of climax vegetations.

Medical Research

In evolving the research program, the Medical Department is responsive to the needs of the Atomic Energy Commission. Accordingly, programs of research leading to an understanding of the short and long-term effects of radiation on man, the treatment of radiation injury, and the application of radiation in its diverse forms in diagnosis and treatment of human disease are developed. Progress in all these fields of study requires a continually expanding base of information on the molecular, subcellular, and cellular phenomena associated with living processes. The basic and applied studies complement each other and proceed from one to the other, the direction depending on the requirements for further advances. A great influence on these advances is the rapid development of new techniques for the examination of structures and mechanisms at the molecular as well as the subcellular and biochemical levels of organization. Information revealed through these techniques and with the aid of such instruments as the electron microscope dictates re-examination of such medical and biological phenomena at even finer levels of organization. Findings from such investigations present the Department with the additional responsibility of exploiting them for clinical applications. The diversified talents and extensive facilities uniquely concentrated at Brookhaven provide the Department with unusual advantages for pursuing its objectives. Its broadly based program incorporates the experience and skill not only of those devoted to research in the field of medicine but also of many from the various disciplines in other departments and from collaborating institutions. The interchange of ideas, information, facilities, and services is essential for the staff to keep abreast of the new developments that have medical implications, and within the framework of the program opportunities are limited only by the scope of the vision and interest of the individual investigator. Thus, in its role of service to Associated Universities, Inc., to the Atomic Energy Commission, and to the medical community, the Department's primary responsibility is the assemblage of talented scientists capable of elucidating biological phenomena at the finest level of organi-

zation and experienced physicians capable of relating these researches to clinical studies. Specific examples of research under way are given in the following pages. The report is not comprehensive, and the reader may obtain additional information from publications of the Department.

EFFECTS OF RADIATION

Radiological Research Accelerator Facility

The Radiological Research Accelerator Facility (RARAF) is a joint enterprise between scientists from the Medical Research Center of Brookhaven National Laboratory and members of the Radiological Research Laboratory of Columbia University. A Van de Graaff accelerator has been developed to provide reliable and stable charged-particle beams of protons and deuterons at energies up to about 4 MeV. Such beams have been used directly for physics investigations, but they are usually employed to bombard special target materials to produce beams of essentially monoenergetic neutrons for use in a variety of radiobiology irradiations. The services of RARAF have been utilized in studies of the genetic effects of monoenergetic neutrons in *Drosophila melanogaster*, in studies of the cytogenetic effects in the stamen hairs of inflorescences of *Tradescantia*, and in studies of the survival of bone-marrow stem cells in mice. The RARAF charged-particle beam has been used for microdosimetry research employing wall-less tissue-equivalent proportional counters and for radiological physics studies dealing with the accurate measurement and monitoring of neutron doses for the radiobiology experiments.

Genetic Effects of Neutrons and X Rays in *Drosophila melanogaster*

The induction of both chromosome translocations and recessive-lethal mutations by neutrons or by x rays is being investigated. A translocation is the result of breaks produced in two chromosomes, followed by a reciprocal exchange of chromosome parts. Recessive-lethal mutations can be divided into two general categories: those involving two chromosome breaks, such as inversions and dele-

tions, and those not associated with chromosome breaks, i.e., point mutations. When mature *Drosophila* sperm were exposed to several doses of x rays the number of translocations was found to increase as a power of the dose >1 but <2 . Under the simplest assumptions, if the two chromosome breaks involved in the formation of a translocation were produced by independent ionizing particles the yield of translocations would be expected to vary as the square of the dose. On the other hand, if both breaks were produced by the same ionizing particle the yield of translocations should be proportional to the first power of the dose. Since the observed dose-response curve was intermediate between linear and dose-square kinetics it is concluded that a fraction of the x-ray-induced translocations were caused by a single track and the remainder were the result of breaks produced by two independent tracks. In contrast to the results obtained with x rays, the yield of translocations was found to increase linearly with neutron dose. The failure to find a two-track component with neutrons indicates that both chromosome breaks were caused by the same ionizing particle and that the two breaks must be near each other if they are to interact. The difference observed between the shapes of the neutron and x-ray dose-response curves was attributed to the fact that neutrons are much more densely ionizing than x rays and therefore are more likely than x rays to break two adjacent chromosomes. With x rays, often only one of the adjacent chromosomes was broken by an electron track, and a second track was required to break the intact chromosome. Since the two curves varied in shape, the relative biological effectiveness (RBE) must be considered to be dose dependent, with variations from 4 at low doses to 2 at high doses. The frequency of recessive-lethal mutations was found to increase linearly with dose for both neutrons and x rays with an RBE of 1.8. It was assumed that the probability of producing a recessive-lethal mutation was a function of the amount of energy deposited within a critical target volume. Since neutrons are more densely ionizing than x rays, they deposit more energy within the target volume and therefore are more effective in producing recessive-lethal mutations.

Radiation Effects on the Central Nervous System

A series of experiments to elucidate the functional and morphological pathogenesis of radiation damage to the central nervous system involves

a multidisciplinary approach to the problem of matching functional and structural changes in the neural tissues of several species following exposure to radiation. Structural changes following irradiation are measured by standard techniques of neuropathology, while changes in functional integrity are measured in various ways, depending on the experimental subject. Exposure of the monkey visual cortex to 3500 rads has caused a reduction in the amplitude of EEG response in that area resulting from photostimulation, the photoevoked response of the retina, that becomes progressively greater with time and continues for at least three years following exposure, with no evidence of return to normal levels within that time period. About 90 weeks after irradiation of one visual cortex, a depression in evoked response is seen not only on the irradiated side but on the contralateral side as well. Examination of tissues from the unirradiated side have indicated no pathological correlation for this functional change. In a related study it has been found that when both of the monkey's visual cortices receive 3500 rads of x rays, they develop a visual decrement within ≈ 90 days, which progresses to functional blindness by 120 to 150 days. The results of the above two studies have shown that when only one side is irradiated, a large degree of function remains for a relatively long period in the other side, but in time this too is severely affected by a functional inhibition unaccompanied by structural changes. However, when both sides are irradiated, a much accelerated and more severe effect is seen. In a species comparison study it has been shown that the elasmobranch brain can tolerate an exposure greater than that tolerated by the mammalian brain by at least a factor of 10.

Lens Opacification in Man and Mouse With Aging or Irradiation

Since the epic findings in 1907 of Tribondeau and Belley, investigators have become increasingly sure that the germinal epithelium of the lens is a primary receptor site of ionizing radiation insult by low to intermediate exposures. One manifestation of radiation injury to the lens has been recognized as consisting initially of tiny opaque flecks (also called dots, vesicles, or vacuoles) which appear in the posterior lens fibers and are visible in the live animal through a slit-lamp biomicroscope with a magnification of $300\times$ or more. Only recently have attempts to count lens flecks

Figure 1. Counts of anterior and posterior lens flecks in nonirradiated Marshallese within equal sample volumes within the lens (observed via a slit-lamp microscope with a reticle) and averaged within each exposure group for persons of similar age.

been successful in both mouse and man. The incidence of lens flecks in nonirradiated mice is low until the 13th week of age, after which it increases at a constant rate. Groups of mice exposed to a low dose of radiation when 6 weeks old also revealed a low incidence of flecks until the 13th week, but then the flecks increased at a constant rate almost twice that of the controls. These data suggest that (1) the normal-lens germinal epithelium contains a small number of abnormal "stem" cells which at intervals produce defective lens fiber cells, and (2) irradiation can create additional abnormal germinal lens cells, with a resultant increase in the proportion of defective lens fiber cells. Lens fleck counts obtained in the 1969 Medical Survey of the normal Marshallese Island population are shown in Figure 1. The incidence of these defects increases steadily in the male after 13 years of age, but in the female it appears to increase rapidly during adolescence and then change to a slow phase during maturity. The findings in persons exposed to 175 rads from radioactive fallout in 1954 are shown in Figure 2. The data point

Figure 2. Lens fleck counts in Marshallese people exposed to 175 rads of fallout radiation on Rongelap Island in 1954.

for each age subgroup is connected to that point on the "nonirradiated" curve where it presumably fell at the time of exposure. The minimal evidence of a lens effect in man from 175 rads of γ rays is compatible with the finding of other workers. These studies suggest that similar development of minute lens fiber defects occurs with age in nonirradiated mouse and man and that these are derived from abnormal but viable stem cells resident in the lens epithelium. The similar nature of the lesions induced by aging or irradiation has implications for a relationship of these two factors.

Radiation Carcinogenesis in the Rat Mammary Gland

The well-studied, rapid, and large neoplastic response of rat mammary tissue to sublethal radiation exposure is being used as a model system to investigate mechanisms of radiation carcinogenesis. Data on the effect of age at time of radiation exposure have indicated that female rats exposed before the age of sexual maturity give a smaller

yield of mammary tumors than rats exposed at older ages. Thus the age at time of exposure must be controlled in each experiment, and data collected from animals of differing ages at the time of exposure cannot be compared directly. This change in radiation sensitivity with age is thought to be related to changes in ovarian radiation sensitivity. The observed change of radiation carcinogenesis with age approximates the age change of chemical carcinogenesis for the rat mammary gland. An experiment to compare the mammary neoplastic response to radiation has indicated that the Sprague-Dawley strain is much more sensitive than the Lewis strain. The reason for this strain difference is not understood, but the ovarian-pituitary axis is thought to be involved. When two fractions of 200 R were given at intervals of 2, 6, or 24 hr and the percent of rats with mammary neoplasia was compared with that obtained with a single dose of 400 R, all exposures produced approximately the same yield of breast tumors. This means that mammary-cell survival kinetics and its repair either were too small to detect or are not important in radiation carcinogenesis of rat mammary neoplasia at the dose studied.

Antibody Responses in Normal and Irradiated Mice Elicited With Antigen-Antibody Complexes

Enhanced primary antibody responses are obtained in mice immunized with a complex of fluid tetanus toxoid and mouse tetanus antitoxin formed at equivalence (EQ). In contrast, a complex of bovine serum albumin (BSA) and rabbit anti-BSA formed at EQ failed to elicit antibody formation. Primary sensitization was achieved, however, since a second injection of BSA given 3 days later elicited enhanced antibody responses. Forty-eight groups of mice were immunologically primed for BSA with a BSA-rabbit anti-BSA complex formed at EQ. A second injection of BSA was given at various times between days 2 and 30 to determine whether the degree of immunologic responsiveness changed with time in normal or irradiated mice. A γ -radiation dose of 300 rads was delivered 1 hr prior to the second injection of BSA. Serum was obtained 7 days after the second injection of antigen. The antibody responses (Figure 3) demonstrate enhanced formation of antibody to BSA by normal and irradiated mice between days 2 and 6, followed by a refractory period of low responsiveness in normal mice. The irradiated animals, however, retained the capacity

for antibody synthesis when radiation was given 1 hr before the second injection of antigen. An explanation for this observation is not evident at present. In view of the findings in the preceding experiment, in which the antibody in the complex was foreign to the mouse (rabbit anti-BSA and BSA), an experiment was carried out to determine whether enhanced antibody responses also occur when mice are primed with a complex of isologous mouse antitoxin (MTA) and fluid tetanus toxoid (FTT). Ten groups of mice were primed with a complex of MTA-FTT formed at EQ. A second injection of FTT was given on days 3, 6, 9, 12, and 15. Five groups received a γ -radiation dose of 400 rads 1 hr before the second injection of antigen. Both normal and irradiated animals gave enhanced antibody responses when FTT was given as early as 3 and up to 15 days after primary immunization with the MTA-FTT complex. Normal animals failed to produce antibody when immunized with the amount of FTT used in the complex. All irradiated mice produced more antibody than control animals (Figure 4). This is in keeping with the results obtained with irradiated mice primed with a rabbit anti-BSA complex and given a second injection of BSA. In sharp contrast, the observed refractory period of immuno-

Figure 3. Antibody responses to bovine serum albumin in mice primed for BSA with an antigen-antibody complex of rabbit anti-BSA and BSA. Serum was obtained 7 days after a second injection of BSA. The antibody titer to BSA was determined by the serum binding capacity for ^{125}I -BSA.

Figure 4. Tetanus antitoxin responses in mice primed for tetanus toxoid with a complex formed at equivalence of mouse tetanus antitoxin and fluid tetanus toxoid. Antibody titers are expressed as the number of M.L.D. of potent tetanus toxin neutralized per ml of serum.

logic responsiveness was not evident when mice were primed with the MTA-FTT complex. Radiation-induced enhancement of antibody formation was achieved throughout several weeks when animals were primed with complexed antigen formed at EQ and a second injection of antigen was given shortly after exposure to radiation.

Lymphocyte Depletion and the Immune Response

Lymphocytes of the host play an important role in the rejection of organ transplants. Lymphocytes are highly radiosensitive cells. Whole or partial-body irradiation and drugs are used to deplete the host lymphocytes in order to prolong the survival of organ transplants. To avoid the serious side effects of whole or partial-body irradiation or drugs, extracorporeal irradiation of the blood (ECIB) has been used to deplete the lymphocytes in the circulating blood and in the lymphoid organs (Figure 5). This lymphoid organ depletion is due to the fact that a fraction of the blood and tissue lymphocytes are in a state of equilibrium and are constantly recirculating from blood to lymphoid organs. The survival following bilateral nephrectomy and kidney transplantation of goats with lymphocyte depletion induced by ECIB has been studied. In 8 control goats receiving no ECIB treatment, the survival time ranged from 15 to 18 days. In the first group of 8 ECIB-treated goats, the survival time ranged from 14 to 24 days. The goats in this group received pretransplant ECIB to about 5 to 10 blood volumes per day for 10 to

14 days. The transit dose (the dose of radiation received by the blood during a single passage through the radiation coil) ranged from 250 to 700 rads. In view of the rather poor results obtained with this schedule of ECIB, it was decided to increase the number of blood volumes irradiated per day. Such a change necessitated reducing the transit dose to 40 to 50 rads in order to minimize radiation-induced damage to the goat red blood cells. In a series of studies completed this year, goat red blood cells were shown to be more radiosensitive than human or bovine red cells. Accordingly, in the second group of 5 goats, pretransplant ECIB to 20 to 80 blood volumes per day was given for 3 to 5 days. The survival time in this group has ranged from 20 to 84 days. These studies are being continued, and because of the encouraging nature of the early results with pretransplant ECIB alone, studies combining pre- and post-transplant ECIB are planned. To improve the therapeutic effectiveness of ECIB, it is desirable to induce greater than normal numbers of tissue lymphocytes to enter the blood. Pertussis vaccine produces blood lymphocytosis, but the mechanism of its action is not known. With a view to the eventual use of pertussis in conjunction with ECIB, studies were carried out in calves, goats, and sheep to elucidate the mechanism of pertussis-induced lymphocytosis. The results showed that (a) an initial increased mobilization of lymphocytes from the lymphoid tissues to the blood takes place 10 to 20 min after the pertussis injection, and (b) the normal migration of lymphocytes from the blood to the tissues is inhibited.

Medical Survey of the People of the Marshall Islands Accidentally Exposed to Fallout

The annual medical surveys of the Marshall Islanders who were accidentally exposed to radioactive fallout in 1954 are conducted by Brookhaven National Laboratory with support by the Trust Territory of the Pacific Islands. The acute effects of exposure of these people have been well documented. The most serious of the late effects has been the development of thyroid abnormalities resulting from exposure of the thyroid gland to radioactive iodines in the fallout. Of the 82 people exposed on Rongelap Island, 66 are now living, and of these 21 have developed thyroid abnormalities, 19 with nodularity and 2 with atrophy of the gland associated with hypothyroidism. Of

19 children receiving doses of 700 to 1400 rads to the thyroid at <10 years of age, 17 have developed thyroid abnormalities. Surgical exploration with thyroidectomy, partial to complete, in 18 Rongelap patients has revealed benign adenomatous nodules in 17 cases and malignant lesions in 3 cases. Cancer was noted in one girl exposed at 7 years of age and in 2 women exposed as young adults. In addition, one Utirik woman operated on during the past year had a thyroid malignancy, but the association with radiation exposure in this case seems unlikely in view of the low dose of radiation received by the population of this island. It was encouraging to note that in the most recent survey no new thyroid nodules were found in the exposed population. Growth retardation noted in some Rongelap children has been correlated with hypothyroid tendency due to thyroid lesions, and some of these children appear to be responding favorably to thyroid hormone treatment.

BIOCHEMICAL AND MOLECULAR STRUCTURE AND FUNCTION

Bioenergetic Mechanisms Involving Free Radicals

It is now beyond question that free radicals are involved in many fundamental biological reactions, especially those of oxido-reduction, and it is known that many of the effects of ionizing radiations on biological target molecules are exerted by free-radical intermediates, especially in oxygenated tissues or liquids. 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 the widespread application of electron paramagnetic resonance (EPR) spectrometry, because EPR and related magnetic resonance techniques can identify and describe free radicals with greatest sensitivity and specificity. During the year on-line, real-time operation of the EPR spectrometer with the Department's Sigma-2 computer was well established. The system employs three data buffers and a magnetic disk file and can read or write from magnetic tape. Programs are available under keyboard control for time-averaging of multiple spectral scans, for arithmetical or transfer operations on spectra, curve smoothing and filtering, integration and differentiation, curve shaping and resolution en-

Figure 5. Goat receiving ECIB prior to kidney transplantation. The arterial and venous ends of an arteriovenous shunt in the neck have been uncoupled and connected to the ends of the radiation coil, part of which is exposed to the source of radiation. The goat blood enters the radiation coil at the arterial end and returns at the venous end.

hancement by convolutional methods, and for simulation of isotropic EPR spectra. A more extensive but similar program (CONVOL) was written in FORTRAN for the CDC 6600 computer. Although these programs were developed primarily for use with EPR, they are general in format and can be applied to data arrays of many kinds, including nuclear magnetic resonance, optical, β , or γ spectra, and chromatographic data. The basic oxidative reactions of living cells, those of biological electron transport, involve many heme enzymes, which are iron-porphyrins complexed to proteins. Free radicals of the porphyrins may be vital intermediates in these processes, and a free radical of chlorophyll, the porphyrin-like photoreceptor of green plants, appears to participate in photosynthesis. In active collaboration with individuals in BNL's Department of Applied Science (J. Fajer), at Georgia Institute of Technology (R. Felton), and at Harvard (D. Dolphin), research in this area has been pursued by studying, with EPR and other methods, free radicals formed chemically or electrochemically from synthetic and natural porphyrins. Cation radicals and diamagnetic dications were produced and analyzed

from metal-free and metalloporphyrins, mostly of the tetraphenylporphyrin, octaethylporphyrin, and etioporphyrin classes. Means were found to stabilize some of the radical forms in the solid state. Formation of a new class of porphyrin derivatives, isoporphyrins, in aqueous or alcoholic solvents was demonstrated. A π -radical cation of chlorophyll *a* was identified and shown to resemble closely the first photochemical product in green-plant photosynthesis. It is believed that cellular radiosensitivity results, in large measure, from damage to DNA caused by intracellular free-radical reactions. Radiation-accelerated "aging" and some aspects of natural aging may depend upon the same mechanisms. The immediate local molecular environment of the DNA molecule (conformation, bound histones or water, etc.) is known to influence radiosensitivity and probably affects the corresponding aging processes also. Significant environmental effects of this kind on free-radical formation were found in substituted adenine-like compounds following γ -irradiation and exposure to hydrogen or deuterium atoms. Interpretation of the results required isotopic substitution techniques. The hydrogen addition radicals in adenine, adenosine, deoxyadenosine, and 9-methyladenine were then identified. Use of the computer's resolution-enhancement capabilities has provided surprisingly rich detail in an EPR spectrum of free radicals in a polycrystalline sample of γ -irradiated deoxyadenosine.

Scintillation Counting of $^{14}\text{CO}_2$

A simplified procedure has been perfected for determination of the specific ^{14}C activity of carbon. To obtain activity in terms of curies per gram it is necessary to measure both the amount of carbon and its radiations. One procedure is to turn the carbon into CO_2 gas, measure the gas by the pressure it exerts at a definite volume, and then transfer it to a counter where the β rays emitted by the disintegration are counted. Such a procedure, devised earlier in this Department, uses the manometric apparatus of Van Slyke and Neill to evolve and measure the CO_2 , which is then transferred to a gas counter devised at BNL by Bernstein and Ballantine. This procedure is still in use; however, scintillation methods for counting ^{14}C disintegration have been so improved in accuracy and convenience that it has become desirable to combine the manometric measurement of CO_2 with transfer to a scintillation fluid

as an alternative to the transfer to a gas counter. The CO_2 is evolved and measured in the manometric chamber. The plastic scintillation vial is evacuated and attached, and the CO_2 gas is transferred to it. Chamber and vial are shaken mechanically for a minute, during which the CO_2 is absorbed by the alkaline amine solution in the vial. The vial is then disconnected, 10 ml of a solution of scintillating material is added, and the scintillations are counted. An advantage over the gas-counting procedure is that the glass gas counters are expensive and require careful handling, while the plastic scintillation vials can be purchased by the hundred and are virtually indestructible. In addition, the capillary T tube that connects the chamber to the scintillation vial is simpler than the connecting piece with a glass coil for freezing water vapor that is required for transfer to a gas counter.

Structure and Function of Nucleic Acids

Research on the physical basis of genetics and the way in which a wide variety of chemicals damage molecules carrying genetic information is essential for understanding how radiation, carcinogens, and other environmental hazards cause disease. Study of the structure of a particular genetic material – 2-stranded RNA – has led to the development of x-ray methods for determining its exact purity. This has led in turn to practical tests of such material in the treatment of several virus diseases and of tumors in animals. In experiments in collaboration with Dr. Chester Southam at the Sloan-Kettering Institute for Cancer Research, New York, some highly purified, synthetic preparations of 2-stranded RNA gave protection against systemic herpes simplex infection in mice and herpes simplex-induced keratoconjunctivitis (pinkeye) in rabbits. Herpes simplex, a DNA virus, is well known as a cause of cold sores and pinkeye in man, but it also occasionally causes blindness and death and is associated with some malignant tumors in man. Protection of animals by 2-stranded RNA complexes extends to other kinds of virus. In work done in collaboration with Dr. J. Richmond at the Plum Island Animal Disease Laboratory, U.S. Department of Agriculture, Greenport, N.Y., 2-stranded RNA was found to induce host resistance to foot-and-mouth disease virus (an RNA virus) when microgram quantities were injected into mice. Protection was effective for >48 hr after a single injection.

tion of the RNA complex. The mechanism of protection is now being examined. Preliminary experiments in guinea pigs and cattle have shown similar responses to the RNA complexes. Because of their effectiveness in protecting against certain virus diseases, the 2-stranded RNA complexes were tested against experimental animal tumors in collaboration with Drs. G. Tarnowski and C.C. Stock at the Sloan-Kettering Institute. With one tumor the complexes have been consistently active. Toxicity studies in mice, rats, rabbits, and dogs are being carried out in cooperation with Dr. F. Philips and his associates at the Sloan-Kettering Institute as a prerequisite for testing the RNA complexes against human cancers and serious virus diseases in man. These unexpected therapeutic applications of synthetic RNA's arose from basic studies on the structure of the genetic molecules originally studied as *the* targets for radiation damage, e.g., in producing genetic defects and cancers. A principal means of investigation was x-ray diffraction. The potential usefulness of these RNA's that mimic certain types of infectious molecules in the treatment of some cancers and virus diseases in man directly relates to the nuclear energy program, since there is abundant evidence that radiation induces cancers and activates virus infections.

DNA consists of a large number of discrete units (genes), each controlling a single cellular process or structure. In any given cell of higher organisms only a small fraction of the genes are expressed; the rest, although present, are silent. Although each cell type has a different set of active genes, normally only genes controlling processes that interact harmoniously to form a smoothly functioning cell are expressed. The activation of genes controlling discordant processes or the inactivation of genes regulating essential processes can cause serious distortion of cell function and may be responsible for a large number of pathological states ranging from cancer to aging. This research, aimed at exploring the mechanism by which the expression of genes is permitted or suppressed, has led to the development of a reaction with DNA that (1) permits the incorporation of radioactive label (^{131}I) into DNA, to facilitate the measurement and location of very small amounts of DNA; (2) specifically modifies one of the components of DNA and thus indicates how it is involved in control; and (3) can determine whether active DNA is in the form of a single

strand or is present as two strands specifically linked together.

Knowledge of the structure of the ribosome is central to understanding the nature and regulation of protein synthesis. Bacterial ribosomes are composed of various RNA and protein molecules and consist of 2 subunits, 50S and 30S. Partial digestion of *Escherichia coli* 70S ribosomes with pancreatic ribonuclease released about 3% absorbance at 260 m μ . Little RNA could be removed from the particles with digestion at 10 mM MgCl_2 , when the particles were tightly folded. Although only a small quantity of RNA was removed from 70S ribosomes with partial nuclease digestion, the RNA from the particles was appreciably degraded. These ribosomes could sustain ribonuclease-induced breaks in the high molecular weight RNA fraction and retained activity in polyuridylic acid-directed polyphenylalanine synthesis. Thus the surface RNA, removed by limited digestion with ribonuclease, is of little importance in maintaining the ribosomes functional in *in vitro* polyphenylalanine synthesis.

Collagen, Heparin, and Mucins

The amino acids hydroxylysine and hydroxyproline occur only in collagen, an important animal structural protein. They are formed by enzymic oxidation of lysine and proline during collagen formation after the amino acids are incorporated in the polypeptide chain. In earlier work, partial purification of the enzyme responsible for hydroxylation of peptide-bound proline was achieved and some insight into its mode of action was gained. Extensive studies have been carried out on the possible efficacy of competitive inhibitors bound to insoluble supports for the isolation of collagen proline hydroxylase. For this purpose three inhibitors – gelatin, polyproline, and poly-(prolyl-glycyl-proline) – each bound to an insoluble polysaccharide matrix, have been studied. Each behaves as a typical, reversible, competitive inhibitor, even though bound to the polysaccharide. By contrast, if a solution containing hydroxylase activity is passed over the bound inhibitor, as in a chromatographic experiment, the bound inhibitors appear to remove hydroxylase activity from solution irreversibly. This observation suggests that the high molecular weight enzyme is in reality a multienzyme complex which the chromatographic procedure separates into inactive parts of the complete system. The nature

of various tritium-labeled heparin fractions has been studied after preparation by an electric discharge technique in the presence of tritium gas and followed by fractionation on Dowex 1,X-2. The molecular weight was found to increase with increasing biological activity and with decreasing radioactivity. Thus the molecules that have lost the most in biological activity during the labeling process have the highest radioactivity. This condition could lead to erroneous results if unfractionated, labeled heparin were used in tracer experiments.

An understanding of the macromolecular structure of mucins is important for an understanding of the complications of cystic fibrosis and other diseases in which mucins are involved. In collaboration with a group at Mt. Sinai School of Medicine (M. de Salegui, F.C. Knowles) the subunit structure of pig submaxillary mucin has been investigated. The nonionic detergent Triton X-100 has been found to cause a very slow disaggregation of the mucin, which has an initial average molecular weight of about 3 million, to a product with an average molecular weight of about 233,000. The product is heterogeneous, and indications are that part of the material has a molecular weight as low as 40,000. This fall in molecular weight is accompanied by a dramatic fall in viscosity. If the Triton is removed with ether there is an almost instantaneous reaggregation to a product with an average molecular weight of 893,000.

Analysis of Compensatory Growth

Previous experiments with compensatory growth in the kidney have shown that a period of cytoplasmic growth is required before DNA synthesis is initiated. After 24 hr of intense cellular hypertrophy there is a sudden burst of mitotic activity which reaches a maximum at 48 hr and declines to normal within a week. This unexplained pattern of hyperplasia, characteristic of compensatory growth in other tissues as well as kidney, can be accounted for by the "critical mass" hypothesis, which proposes that cell division is triggered when the growing cell reaches a certain critical mass. Based on this hypothesis, a theoretical relationship has been developed which allows calculation of the mitotic index at any given time after the initiation of compensatory growth. This relationship requires a knowledge of the initial size distribution of cells, the cell-growth rate constant,

the mean cell size at the time of cell division, and the tissue deficit. Data from the regenerating liver of the mouse have been used in this theoretical relationship; substitution of experimental observed values gives the absolute magnitude and the time course of the mitotic response as predicted by the critical mass hypothesis. The calculated patterns of hyperplasia have been found to be in good agreement with observed patterns. The close correspondence between theory and experiment strongly suggests that some version of the critical mass principle is operative, at least in compensatory growth of the liver.

Metabolic Interrelationships of D- and L-Tryptophan

DL-Tryptophan metabolism has been studied extensively in man and animals. Nutrition studies in the rat have shown that L- and D-tryptophan are of approximately equal value in the diet. There is a species variation in ability to handle the D isomer, which makes it important to know the extent of utilization of the enantiomers in the metabolism of tryptophan to CO₂. A meaningful interpretation of the metabolism of DL-tryptophan cannot be made without knowledge of the metabolism of the unnatural isomer and the possible effects it might have on the metabolism of the natural isomer. DL-Tryptophan-7a-¹⁴C was chromatographically resolved into the D and L isomers on powdered paper columns. Pairs of rats were intraperitoneally injected with aqueous solutions (a) of one ¹⁴C isomer only; (b) of the same ¹⁴C isomer 30 min after a loading dose of the unlabeled enantiomer; or (c) of the same ¹⁴C isomer combined with an equimolar amount of unlabeled enantiomer in a single solution. This series was carried out with each isomer. Radioactivity in exhaled CO₂ and urine was measured by gas counting. Urinary o-aminohippuric acid, kynurenine, kynurenic acid, hydroxykynurenine, xanthurenic acid, quinolinic acid, nicotinic acid, and picolinic acid were isolated by carrier methods and purified, and their radioactivity was measured with carbon dating equipment. Both isomers of tryptophan were metabolized to ¹⁴CO₂ equally well by the rat. A load of either isomer increased the ¹⁴CO₂ production by the opposite labeled isomer almost twofold, but did not affect the urinary ¹⁴C levels. The kynurenic acid levels were slightly elevated when the D isomer was given, but did not approach the 30% concentra-

tions seen when labeled D-kynurenine was given to rats in previous studies. The loads of either isomer slightly increased the urinary kynurenic acid, quinolinic acid, and picolinic acid levels, and the similarities in urinary levels of these components showed that comparable quantities of either isomer were metabolized via similar pathways. The concentration of activity from either isomer in the tissues decreased in the order liver, plasma, kidney, testes, heart, spleen, and brain. The level of ^{14}C in tissues was depressed when a load of either unlabeled isomer was given in the presence of the opposite labeled isomer. No detectable activity appeared in urinary 3-hydroxykynurenine when L-tryptophan was given. Urinary levels of 5-hydroxyindoleacetic acid indicated that this pathway was of minor importance from a quantitative aspect. The data suggested that D-tryptophan was not converted to D-kynurenine in any appreciable quantity, but more likely was deaminated by a D-amino acid oxidase to a form (such as indolepyruvic acid) that was readily metabolized to CO_2 .

CLINICAL AND METABOLIC STUDIES

In vivo Measurement of Radionuclides in Man

In the nuclear energy program, *in vivo* measurement of absolute levels of internally deposited radionuclides is needed both for diagnosis of cases of accidental intake of radionuclides and to meet the requirement for absolute measurement in clinical research studies. A 54-detector whole-body counter with an on-line computer was designed to meet these objectives. The counter has many unique properties besides its high sensitivity and resolution capacity and represents the most significant advance in whole-body counter technology in recent years. Its ability to correct for variable absorption size and weight of subjects counted makes it possible, for the first time, to measure absolute levels of radionuclides as well as rapid changes in their spatial localization in the body. It is now possible to perform clinical studies heretofore not amenable to study. Studies have been conducted to measure ^{40}K in grossly obese children in order to determine their lean body mass. The rapid kinetic changes have been measured in the spatial distribution of (1) anesthetic gas (halothane) labeled with ^{82}Br , (2) tracer ^{56}Mn in patients with Parkinson's disease treated with dopa, and (3) ^{45}Ca and ^{18}F tracers in patients with

osteoporosis. An *in vivo* neutron activation technique was developed for measuring body calcium by exposing patients to a low dose of 14-MeV neutrons. The induced ^{49}Ca is measured in the whole-body counter and the absolute weight of calcium is thus determined. This technique, the only one to date that permits the absolute measurement of whole-body calcium, has been useful in measuring the rate of loss of calcium in osteoporosis. Calcium is only one of a number of important body elements that can be measured by this technique. *In vivo* neutron activation analysis is also being used for the simultaneous analysis of whole-body sodium, chloride, phosphorus, manganese, and nitrogen.

Studies of Carbohydrate and Lipid Metabolism in Diabetes and Obesity

Over the past few years a comparison of $^{14}\text{CO}_2$ in the breath with blood glucose has been made in obese and diabetic patients after an oral glucose load in which the glucose was labeled in position 1 with ^{14}C . Results suggest that oxidation of glucose-1- ^{14}C to $^{14}\text{CO}_2$ in obese patients tends to be decreased and in positive correlation with blood glucose values. The ^{14}C test appears to have potential diagnostic applications. Studies using glucose-1- ^3H suggest that the decrease in oxidation of glucose noted above may represent a diversion to metabolic products other than CO_2 . The oxidation of glucose-1- ^{14}C has been compared with that of galactose-1- ^{14}C . Preliminary studies with both sugars given in oral loads suggest that some obese patients may show slightly lower ratios of galactose : glucose oxidation than do normal subjects. It has been observed that rats adapted to high sucrose diets incorporate more ^{14}C into liver and plasma lipids from sucrose- $\text{U-}^{14}\text{C}$ (U = uniformly labeled) than from either glucose- $\text{U-}^{14}\text{C}$, fructose- $\text{U-}^{14}\text{C}$, or a mixture of these two monosaccharides, which are the products of hydrolysis of the disaccharide sucrose by the enzyme sucrase in the intestinal mucosa. Preliminary studies with such patients suggest that they are likely to have a higher than normal ratio of sucrose : glucose oxidation to CO_2 , which could be due to higher than normal sucrase activity. In addition, some obese patients have shown earlier and higher serum insulin elevations, with generally lower blood glucose curves, after a sucrose load than after an equivalent amount of glucose. To understand better the pancreatic insulin response to glucose

and other sugars, a system has been developed for the perfusion of isolated pancreatic islets.

Studies on Hypertension

Studies continue on genetic and environmental interactions that lead to the development of hypertension. Two strains of inbred rats, developed at Brookhaven, provide a unique model for this disease which so commonly afflicts man. The two strains have opposite genetic propensities for hypertension, and members of one strain rapidly develop chronically elevated blood pressures after exposure to the same noxious insults that are usually ineffective in members of the other strain. The genetic heterogeneity of man would make populations of such extremes highly unlikely; populations and individuals with somewhat middling predispositions to hypertension would be expected to be more common. In such circumstances, nongenetic or environmental influences would determine the prevalence of hypertensive disease. Identification of such noxious environmental factors is critical for success in the efforts to decrease the incidence of hypertension and its complications. One such environmental influence is the chronic ingestion of salt (NaCl). Salt is added in excess to most processed foods. An intake greatly in excess of metabolic needs is therefore usual from infancy onward, and a general reduction of this intake is both feasible and desirable as a public health measure. Another possibility is to look for a "marker" indicating genetic predilection for hypertension in an individual that would allow hypertension-prone subjects to receive the main concentration of effort toward preventing the disease. During the past year such a marker was identified in the blood of rats from the hypertension-prone strain. Animals from this strain have the capacity to inhibit the enzyme renin, long believed to play a role in the development of hypertension. Animals from the strain resistant to hypertension lack this inhibiting capacity. Further studies of this inhibitor are in progress and attempts are being made to find it in the blood of man. The NaCl requirements of the normal infant are met by mother's milk. Commercially prepared baby food has enough added salt to promote hypertensive disease in sensitive rats. The initial effect of a chronically high salt intake begun in infancy may be no more than to induce a salt appetite. This appetite will be satisfied, or enhanced, when the child graduates to processed adult foods which,

except for fruits, also generally contain high concentrations of added NaCl. Indeed, the addition of NaCl to processed foods is now so ubiquitous that it is difficult to obtain a diet low in salt even when required by prescription. If the primary effect of a chronic high salt intake is merely the induction of a salt appetite, a secondary effect may be the induction of hypertension. The fulminating hypertension displayed by salt-fed rats is rarely found before the third or fourth decade of human life. It is suggested that, in genetically predisposed persons, a high salt intake, even if confined solely to infancy, might initiate hypertension either then or later. The possibility that evidence of injury from salt might remain covert for years is by no means unique. The appearance of thyroid cancer in adolescence from thymic radiation received in infancy, of blood dyscrasias long after exposure to benzene or radiation, of Parkinson's disease decades after encephalitis, and of cancer and emphysema after many years of cigarette smoking provides strong precedent for the possibility that manifestations of injury from salt could be similarly delayed.

Clinical Studies of Parkinsonism and Related Conditions

The amelioration of Parkinson's disease by the use of L-dopa has now been confirmed both here and abroad in several thousand cases. The drug is about to become released for general use. In cooperation with Dr. Ismael Mena of Santiago, Chile, studies were extended to chronic manganese poisoning. It is not known whether chronic manganese poisoning induces low dopamine concentrations in the brain, as is the case in Parkinsonism, because analyses of the brain at autopsy have not been completed. However, the dramatic, sustained improvement in these cases proved that L-dopa can be used to detect dopamine deficiency in the human brain without waiting for analysis at autopsy. The question of whether dopamine is indeed one of the active metabolites of L-dopa was answered when 15 patients were given apomorphine injections instead of L-dopa. Apomorphine was used because of its chemical similarity to dopamine (see Figure 6). The direction of the neurological change was the same with either drug, although the therapeutic effects of apomorphine lasted only about 2 hr. Apomorphine constitutes a prototype for the synthesis of a new generation of drugs. The diseases in which such drugs

Figure 6. Structural relationships of apomorphine and dopamine.

may be useful perhaps include various dystonias, since two of the dramatically improved victims of chronic manganese poisoning had dystonia. Various dystonias are therefore being studied. In order to potentiate the effect of L-dopa, studies are being made of a peripheral dopa decarboxylase inhibitor which blocks the catabolism of L-dopa outside the brain. Some qualitative differences encountered between the use of L-dopa alone and in combination with inhibitors suggested that L-dopa produces within peripheral tissues some metabolites that modify the effect of L-dopa on the brain. To identify such metabolites and possibly use them in therapy, a bioassay was devised which permits the quantitative estimation of L-dopa effects on the central nervous system of mice. Mice are placed on a platform, and the number of mice falling from the platform is counted. This number is proportional to the dose of L-dopa between 0.5 and 5.0 mg/gm of mouse weight. A similar linearity between dose and number of animals falling was detected with apomorphine and with some other dopaminergic agents currently under study. With this bioassay it will be possible to identify and quantitate agents that potentiate or diminish effects of dopaminergic agents on the central nervous system. Regarding the mechanism of action of L-dopa in the brain, the metal manganese has emerged as an important cofactor. As indicated earlier, the language used for the intercommunication of cells during the administration of L-dopa includes the words dopamine, cyclic AMP, and manganese. No effort is being made as yet to discover additional words in the complex language used in the intercommunication of brain cells. The above words, however, are being studied intensively in order to determine how their "loudness"

affects neuronal intercommunication in both normal animals and patients suffering from the diseases mentioned above.

Clinical Research in Leukemia With Extracorporeal Irradiation of Blood and Cell-Labeling Techniques

Treatment of adult patients with leukemia by extracorporeal irradiation of blood (ECIB) was started in November 1964, and to date 35 patients have been treated. The technique involves the diversion of blood from the radial artery past a source of radiation (^{60}Co), via a chronic arterio-venous shunt. ECIB is carried out from 2 to 4 hr each day per patient or less frequently. The median survival time in 16 patients with acute myelocytic leukemia was 8.0 months, equivalent to that obtained after intensive chemotherapy. There was an apparent positive correlation of survival time with transit doses >340 rads. Results obtained in six patients with chronic myelocytic leukemia have been too variable to allow any definitive conclusions to be drawn. Seventeen patients with chronic lymphocytic leukemia (CLL) have had a marked decrease in the concentration of lymphocytes in the peripheral blood, and many have had a decrease in splenomegaly and lymphadenopathy. Although the number of patients is small, the overall survival of patients treated with ECIB plus conventional methods is longer than that of those treated with the latter alone. Three patients in early stages of CLL have been treated with ECIB alone and will be followed for the time of onset of the usual complications, which are expected to be postponed because of the reduction in the body burden of lymphocytes. Major efforts will be continued in early treatment of CLL, since among human leukemias this appears to be the most apt to show a good response to ECIB. Studies of DNA synthesis time, with ^3H -thymidine used as a cell label in an effort to understand the basic aberrations in leukemia, showed no difference in the DNA synthesis time (14 ± 0.8 hr) of blood and bone marrow myelocytes in patients with chronic myelocytic leukemia. RNA turnover *in vivo*, as estimated by the change in the mean grain count of *in vitro* labeled (^3H -cytidine) autotransfused lymphocytes in CLL patients, was found to be inversely related to the clinical course of disease and radiosensitivity of lymphocytes as indicated by response to ECIB. These labeling studies were also utilized to measure the population of lymphocytes rapidly exchanging with the circulating

blood compartment. This pool is readily mobilizable and can be depleted quantitatively if ECIB is continued for sufficient periods.

NUCLEAR MEDICINE AND BENEFICIAL EFFECTS OF RADIATION

Californium-252 Studies

Californium-252 is a newly available nuclide which emits neutrons in a relatively high ratio of flux density to weight, as compared with other neutron sources currently available. It has been proposed that this nuclide might be especially useful in the radiotherapy of certain kinds of tumors that tend to have anoxic regions. Cells in these anoxic regions are partially protected against γ radiation, but not against neutron or other heavy particle radiation. However, before clinical studies are undertaken, experimental determinations are required of the relative biological effectiveness and the oxygen enhancement ratio (OER) for the radiations from ^{252}Cf . Also, because of differences between γ rays and neutrons in their reactions with tissues and attenuation by filters, the methods of dose calculation used for γ rays (principally from radium) require modification to be of use with neutron emitters. The studies under discussion were designed to obtain these basic data. The ^{252}Cf sources used are contained in platinum-iridium tubes about 1 mm in diameter and 1.5 to 3 cm long. The radiation doses from individual tubes and from arrays assembled for the irradiation of tissue cultures and animals are measured with silicon diode fast-neutron dosimeters, thermoluminescent rods and ribbons, and a tissue-equivalent ionization chamber. These give independent measures of the γ and neutron dose rates, the total being about 3 rads/hr for 1 μg ^{252}Cf at 1 cm, of which about 55% is from neutrons. In tissue culture studies using dose rates of 15 to 16 rads/hr, the OER's were determined by comparing effects with and without oxygenation during irradiation. The results indicate that the OER for ^{252}Cf at these dose rates is about 1.2 to 1.3, compared with 2 to 3 for 250-kVp x rays with the same material. The skin of pigs has many similarities to human skin and the radiation tolerance is not significantly different. An initial study with protracted continuous irradiation of pig skin has indicated that ^{252}Cf requires about $\frac{1}{3}$ the exposure that must be used with radium to produce the same degree of reaction. This investigation is being extended to ir-

radiations carried out at different dose rates in order to better delineate this factor as well as the limits of tissue tolerance. For computation of the radiation doses from arrays of ^{252}Cf sources for use in treatment planning and treatment evaluation, a computer code, CALDOS, has been developed. This code assumes that the coordinates of the source ends are determined in two orthographic x-ray views and uses the dose-rate constants determined experimentally to calculate the dose from these sources at points in a $21 \times 21 \times 21$ -unit grid. A current effort is directed at combining some of the features of CALDOS with a code developed at the M.D. Anderson Hospital and Tumor Institute, their RADCOMP-II, which is designed for computing and plotting isodose curves for arrays of radium needles and other γ -ray sources comparable to the types proposed for ^{252}Cf .

Technetium and Fluorine Studies

Work with the short-lived radionuclide technetium-99m as a tracer of scanning agents has been continued, and animal studies with the even shorter-lived radionuclide fluorine-18 have been started. A major effort has been put into the clinical evaluation of the use of $^{99\text{m}}\text{Tc}$ pertechnetate not only as a thyroid scanning agent but also as an indicator of thyroid function. The results of these studies have shown that $^{99\text{m}}\text{Tc}$ pertechnetate offers two advantages over the commonly used iodine isotope, ^{131}I , for *in vivo* thyroid function tests: the diagnostic accuracy of the test is greater, and the radiation dose absorbed by the thyroid gland is smaller by two orders of magnitude. The latter consideration is the result of simple calculations, but the former is not so readily perceived. Technetium and iodine belong to the same periodic group of elements, but only iodine is used in the synthesis of hormones by the thyroid gland. The transfer mechanism of iodine from the blood to the thyroid – usually referred to as the trapping mechanism – cannot, however, distinguish between these two elements. The next step in the iodine metabolism (binding of iodine) does make a distinction between these two elements. As a result, technetium can be used to measure only one function of the thyroid gland, while iodine measures several – trapping, binding, storage, and release – at the same time. The clinical results have given indication that pertechnetate uptake reflects the blood level of the normal thyroid stimulating hormone, TSH, and that of the ab-

normal long-acting thyroid stimulator, LATS. It is this specificity of the pertechnetate uptake that results in better separation of normal from abnormal thyroid function. ^{18}F -fluorophenylalanine has been synthesized and its distribution in the *p*- and *m*-configurations has been studied in several

species. The concentration in the pancreas has been 5 to 6 times that in the liver of mice, rats, and dogs. This agent would appear to be useful for imaging of the pancreas and parathyroids. It may have other applications as well.

SUPPORTING ACTIVITIES

Technical Operations and Services

The technical services and facilities essential to the Laboratory's research programs are provided by a number of organizational units whose operations are described below under appropriate headings.

REACTOR OPERATIONS

High Flux Beam Research Reactor

The High Flux Beam Research Reactor (HFBR) operated under design conditions throughout the year. Failure of D₂O flow baffle plates in the primary heat exchangers resulted in the HFBR's being shut down throughout the month of January for repairs to the heat exchangers. All experimental facilities were used during the year.

Operation. Operation of the HFBR resulted in the accumulation of 9056.36 MWd for the year. The total power accumulated to date by this reactor is 39,106.36 MWd. In the course of the year, eleven full operating cycles were completed. Routine operation was interrupted by four unscheduled shutdowns. The first three, on Nov. 1 and 26, 1969, and Feb. 5, 1970, were caused by electrical power failure, and their respective durations were 35, 32, and 18 min. The fourth, on Feb. 6, 1970, was the result of a spurious trip of the nuclear safety system and lasted for 17 min. During the scheduled shutdown periods, 168 used fuel elements (12 half-cores) were discharged from the reactor and replaced with new elements. Seven shipments (98 elements) of spent fuel were made to the Atomic Energy Commission's Savannah River Plant, Aiken, S.C.

The isotopic purity of the reactor system D₂O was reduced by 0.027% during the year's operation, and the tritium content rose to a new high of 2.3 Ci/liter, as shown in Figure 1. On July 1, 1969, the isotopic purity was 99.452%. On June 30, 1970, it was 99.425%. Fourteen drums containing a total of 6885.5 lb of degraded D₂O were shipped to the Savannah River reprocessing plant.

Failure of Primary Heat Exchanger Baffle Plate.

Small pieces of weld material were found in the primary system. These chips resulted from the failure of fillet welds on the D₂O flow baffle plates in

the hemispherical head of both primary heat exchangers. Repairs were made and no more chips were found in subsequent testing and operation.

Material Surveillance Program. Auxiliary control-rod blade A-7 and the follower rod were examined at the hot cell after having been in the reactor for ≈ 2 years of full power operation (29,194 MWd), or a maximum fluence of 1.5×10^{21} . Examination and testing of the aluminum follower rod showed a slight increase in strength but no significant loss in ductility. Metallographic and electron microscopy revealed no severe radiation damage. No embrittlement or swelling of the control-rod blade was detected, and all dimensions were within manufacturing tolerances. Metallographic analysis showed the bond between europium oxide and stainless steel cladding to be in good condition. The thermal neutron exposure at several locations in the control-rod blade was determined. The results indicate that the neutron exposure is not as sharply peaked at the blade tip as anticipated.

Reactor Systems Improvements. Installation of the tritium holdup panel was completed. With this panel, rapid and complete isolation of primary and secondary water systems can be effected from the control room. The secondary cooling water pumps can be started and shut off from this panel.

Figure 1. Degradation of D₂O purity and tritium build-up at the HFBR versus operating time.

Table 1
Distribution of HFBR Support From Scientific Programs

Research budget	Use charges					
	Fiscal 1970		Fiscal 1969		Fiscal 1968	
	Amount, \$	% of Usage	Amount, \$	% of Usage	Amount, \$	% of Usage
Physics Department						
Neutron physics	438,492	33	627,440	44	552,000	44
Structure of solids	425,568	32	228,160	16	201,000	16
Neutron diffraction studies	92,292	7	171,120	12	150,996	12
Subtotal	956,352	72	1,026,720	72	903,996	72
Chemistry Department						
Nuclear structure and inorganic chemistry	371,568	28	399,280	28	351,996	28
Total	1,327,920	100	1,426,000	100	1,255,992	100

Table 2
Usage of HFBR Vertical Irradiation Thimbles, Fiscal 1970

User	Reflector			Core edge		In-core		Total
	V-10	V-11	V-12	V-13	V-14	V-15	V-16	
Applied Science	1	6			1	1	13	22
Chemistry	29	5						34
Medical		3						3
Physics					5	1		6
HFBR materials surveillance experiment				22				22
Outside organizations		41				12	19	72
Total	30	55		22	6	14	32	159

Table 3
Irradiations at the MRR, Fiscal 1970

User	In-core	Core edge	Pneumatic tube	Radial hole	Broad beam	Patient facility	Animal facility	Total
Applied Science			40	10		7		57
Biology							354	354
Chemistry	1	21	52			14		88
Instrumentation and Health Physics		1	10			4	1	16
Medical		1	55			55	124	235
Physics		9	24					33
Reactor			12					12
Outside organizations		1	6	12	1	6		26
Total	1	33	199	22	1	86	479	821

Enclosure of the experimental facilities system area has been completed as part of the program to improve building ventilation.

A system providing continuous vibration monitoring of inaccessible rotating equipment during operation has been installed.

Experimental Facilities. All the horizontal beam holes have been occupied during the year by experiments that are operating routinely. Since the users of these beam holes are the principal users of the reactor, Table 1 indicates the distribution of the support from these scientific program groups.

A long-term irradiation in the V-16 in-core irradiation thimble for the Westinghouse Electric Corp. (Electron Tube Division) was completed. It was a life-test on miniaturized nuclear detectors in the core of the HFBR.

Many irradiations of samples of lunar material from the Apollo 11 and 12 missions were performed for scientists at Argonne National Laboratory and the University of Chicago.

The usage of the vertical irradiation thimbles is summarized in Table 2.

Operating Costs. The costs of operating the reactor decreased during fiscal 1970 from those experienced in 1969. One factor in this decrease is the reduction in the size of the operating crew as a result of the completion of various items of automated equipment. Figure 2 indicates the cost experience for several years past, as well as the predicted costs for fiscal 1971 and 1972. During fiscal 1972 the reactor is expected to be operating with improved fuel elements designed to allow for $\approx 10\%$ more operating time.

Medical Research Reactor

Operation. The Medical Research Reactor (MRR) was operated on 165 days during the year and 1307.099 MWh of operation were accumulated. The total integrated energy to date is 7031.158 MWh. During the year, 821 irradiations were made; 26 of these were for outside organizations. A breakdown of use by facility and user is shown in Table 3.

The last remaining fuel space was utilized in March 1970 when the 30th fuel element was added to the MRR core loading. The addition was necessary to compensate for fuel burnup due to increased reactor use and provided an excess reactivity level of $4.25\% \Delta k/k$.

Thirty fuel elements had been obtained during fiscal 1969 in anticipation of future needs. These fuel elements, designed for a reactor owned by the

Figure 2. Costs associated with operating the HFBR.

Figure 3. Use of the MRR.

State of Pennsylvania, had become surplus and were obtained at essentially no cost. The machining of the nose piece required to adapt these elements for use in the MRR was accomplished on site.

The original MTR-type fuel elements with which the MRR was loaded in 1959 are still in use and have caused no problems. Additional fuel elements have been added as dictated by reactivity requirements. However, some of these elements are expected to reach 20% burnup in fiscal 1971 and will be replaced, since an upper limit of 20% burnup is specified in the AEC limits for this reactor.

Four unscheduled shutdowns of the reactor occurred during the year. Two were caused by control-rod magnet failure and one was caused by an electrical power failure. The fourth was initiated by the reactor operator because of failure of a primary water temperature monitor and in accordance with standard operating procedures.

The use of the MRR, from start-up of the reactor to date, is indicated in Figure 3 in terms of MWh of operation and number of runs.

Brookhaven Graphite Research Reactor

The Brookhaven Graphite Research Reactor (BGRR) was last operated in June 1969, which brought the total energy produced by this reactor to 99,857.8 MWd. It is highly unlikely that it will be operated again. In December 1969 a proposal for decommissioning the reactor was presented by the Reactor Division to the Laboratory Director. This proposal noted the magnitude and permanence of the entire structure. The reactor shield is so massively constructed of such nondestructible

materials that it should be left intact, to provide a minimum-volume, long-term storage vault for all the reactor's radioactive internals. Special consideration was given to the matter of the energy stored in the graphite moderator and reflector. The graphite has been periodically annealed throughout its life so that the energy stored has been greatly minimized. A recent determination indicated that the energy that might be released by heating to 350°C was <20 cal/g, the minimum sensitivity of the determination method. Although there is some stored energy that would be released at higher temperatures, the amount is small compared with the energy input required to reach the release temperature.

The proposal to decommission the reactor was reviewed by the Trustees of Associated Universities, Inc., and later by representatives of the AEC, and on May 18, 1970, the Laboratory was authorized by the Manager of the Brookhaven Office of the AEC to decommission the BGRR in accordance with these plans.

All experiments, with the exception of the Chemonuclear Loop, have been removed from the face of the reactor. The experiential holes have been inspected, their contents catalogued, and the holes sealed. The control rods will be sealed in the graphite structure after they have been disconnected from their drive mechanisms. Reactor fuel will be unloaded during the winter months and prepared for shipment to the AEC's Savannah River processing plant. Since shipment of fuel is best limited to the warm months, because of difficulties presented by freezing temperatures, at least two summers, and possibly a third, will be required to complete decommissioning.

Procurement of Special Materials and Services

The procurement for the scientific departments of all radioactive and stable isotopes, as well as special materials controlled by the AEC, is a responsibility of the Isotopes and Special Materials Group. In this connection, 278 purchase orders were placed for radioisotopes, 33 for stable isotopes, and 46 for special materials. Against these orders, ~406 shipments were received and processed. The totals for orders placed and shipments received were slightly higher than those for the previous fiscal year. Of the orders placed, 35% were for the Medical Department, 17% for Biology, 17% for Chemistry, 17% for Physics, 9% for

Table 4

Summary of Services to Outside Users
(Handling and other charges included.)

	Fiscal 1970		Fiscal 1969		Fiscal 1968	
	Number	Volume, \$	Number	Volume, \$	Number	Volume, \$
Reactor irradiations	90	55,083	43	19,564	166	18,341
Processed radioisotopes	72	15,123	43	8,052	67	12,401
⁶⁰ Co and ¹³⁷ Cs sources	4	*	9	*	4	*
Cyclotron irradiations	0	0	1	230	0	0
Total	166	70,206	96	27,846	237	30,742

*AEC transfers - ⁶⁰Co and ¹³⁷Cs not produced by Brookhaven.

Applied Science, and 4% for Instrumentation and Health Physics. These percentages are essentially the same as those for the past two years.

The Isotopes and Special Materials Group is also responsible for annual inventories of radium sources and purchased stable isotopes and for negotiations for the loan of valuable isotopes. The number of radium sources on hand remained at 34, with a total activity of 5.86 curies and a total value of $\approx$ \$39,500. The inventory of purchased stable isotopes valued at \$32,800 shows an increase from last year's value of \$29,350, since the cost of purchases during the year (\$9719) exceeded consumption (\$6260). The number of stable isotopes on loan decreased from 29 to 24, with a decrease in value from \$1,549,310 to \$908,583.

On Nov. 26, 1969, IAEA inspection No. 16 was made of Facility BZB (Graphite Research Reactor). On March 16, 1970, IAEA inspection No. 17 was made of Facilities BZB and BZC (Medical Research Reactor). Both inspections were performed by new inspectors and were relatively short and cursory inasmuch as the Graphite Research Reactor has been on shutdown status all year.

Irradiation Services and Isotope Production

Table 4 is a summary of irradiation services to outside organizations during the past three years. In general, the volume of these services has been decreasing each year because of the AEC's policy of noncompetition and the increasing availability of similar services commercially. During this fiscal year, however, the volume of reactor irradiations unexpectedly increased; it may or may not remain at this level. The associated increase in dollar vol-

Table 5

Source and Special Nuclear Materials on Hand
at End of Year (in kilograms)

	Fiscal year		
	1970	1969	1968
Facility BZA			
Natural uranium	352	358	361
Depleted uranium	61,759	28,114	23,766
²³⁵ U > 75%	331	811	860
²³⁵ U < 75%	3	612	6,244
²³³ U	0	0	23
²³⁹ Pu	59	58	58
Thorium	84	85	817
Heavy water	43,156	52,351	49,378
Facility BZB (Graphite Reactor Fuel)			
²³⁵ U > 75%	67	67	79
Facility BZC (Medical Reactor Fuel)			
²³⁵ U > 75%	5	5	5

ume reflects the higher rates for services performed in the MRR and the HFBR since the shutdown of the BGRR.

Source and Special Nuclear Material Accountability

In Table 5 a three-year summary is presented of the amounts of source and special nuclear (SS) materials on hand at Brookhaven at the end of each fiscal year. Based on dollar values published by the AEC, the inventory of SS materials as of June 30, 1970, represents a value in the range of \$6.6 million. The large decrease of \$9.2 million from the previous year was mainly the result of re-

turning 480 kG of highly enriched uranium and 609 kG of slightly enriched uranium to AEC production channels. Most of these materials had become excess during the year with the closing of the Critical Experiment Facility. The decrease in the amount of heavy water is temporary, since it was caused by the return of some degraded water that will be replaced early next year. While there was a large increase in the amount of depleted uranium for use in shielding, the value of this material is too low to significantly affect the total inventory value.

Excluding the depleted uranium and heavy water, about 8.5 metric tons of SS material have been removed from the site in the past two years. An additional 216 kG of enriched uranium and 55 kG of plutonium, both alloyed with aluminum, are scheduled for return to the AEC for reprocessing next year. At that time the bulk of the remaining SS materials will be in the three reactors and in shielding material at the Alternating Gradient Synchrotron (AGS).

Early this year a contract was initiated with the National Lead Company for fabrication of 420 HFBR fuel elements to be delivered during the next three years. These elements will have a slightly longer fuel plate and about 15% more uranium than the fuel elements now in use. Since the elements on hand are not sufficient for operation beyond next year, delivery of the new elements is necessary to ensure continuous operation.

The annual audit of SS materials at Brookhaven and the associated accounting records was performed by the Brookhaven Office of the AEC from Feb. 9 to 25, 1970. The physical inventory effort required for this audit was greatly reduced as a result of the implementation of the program of sealing unused materials. The results of the audit were satisfactory, and there were no recommendations.

HEALTH PHYSICS

Radiation safety features of the Physics Department's Tandem Van de Graaff Accelerator were reviewed by the Laboratory Safety Committee and extensive surveys were made during the start-up period. The committee also conducted a similar review for the AGS prior to start-up after a long shutdown period. A section on radiation safety for particle accelerators and another on x-ray diffraction equipment were added to the Safety Manual. The rest of the Health Physics portion of the manual was extensively revised and was reissued. A

first draft of a Health Physics Emergency Procedures Manual was completed.

Although activities of the Building Survey Group were mostly routine, there were special exposure control problems in connection with repairs being made to a heat exchanger at the HFBR, during extensive conversion work by outside contractors at the AGS, and in connection with the planning and construction of a hot laboratory facility for sizable quantities of α and α - γ emitters. Other building survey activities of note were concerned with upgrading the access-control system for the metallurgy cells at the Hot Laboratory and decontamination of the sample preparation cell at the High Intensity Radiation Development Laboratory.

The normal 10-wk on-the-job training program in applied health physics was provided for a group of 17 AEC, PHS, and IAEA Fellows from ten schools. The diversity in the preparation afforded by the various schools has made it desirable to expand the scope of activities at BNL. For example, this year a program was instituted with Meadowbrook Hospital to furnish instruction on radiation protection for radiation therapy, and the student lecture series emphasized public health aspects of health physics.

Synchrotron Monitoring and Dosimetry

A battery-operated model of the universal dose-equivalent meter described last year has been built and tested at a variety of reactor and AGS locations. Comparison of the results with those obtained with the Rossi LET spectrometer showed differences of $<20\%$. It was found that this type of chamber is grossly in error for strongly divergent fields but that such errors are $<10\%$ when the source-to-detector distance is >4 times the detector diameter.

Use of a sealed-off chamber in the dose-equivalent survey meter has required a study of contaminants released by the plastic walls of the chamber into the tissue-equivalent counting gas. The principal contaminants found were water vapor and oxygen, the former by far the more important. Use of a few grams of P_2O_5 desiccant reduces the resulting change in pulse height to a small value that can be compensated for by periodic adjustments to the chamber collecting voltage. This effect can be further minimized by an extended period of outgassing at $70^\circ F$ prior to filling and use.

the radial distribution of dose around the tracks of ionizing particles. Analysis of data obtained with this chamber has been completed and the results are proving to be useful in various theoretical studies such as that described in the preceding paragraph.

Waste Disposal and Reclamation

Preliminary engineering studies have been made of possible methods for removal and disposal of the radioactive sludge that has accumulated in the bottoms of two 100,000-gal waste storage tanks at the liquid waste control and storage area. Removal hydraulically as a slurry and reduction in volume prior to shipment to West Valley, N.Y., will probably be the most economical procedure, but much more work will be required before a method can be chosen and removal of the sludge started.

Data relating to the liquid waste system are presented in Table 6. The amount of gross β activity, other than tritium, leaving the site in the stream to which the effluent is discharged totaled 14.7 mCi during the fiscal year. The average concentration was 1.4×10^{-8} μ Ci/cc, which is 1.3% of the applicable AEC standard. Tritium amounting to 25.1 Ci was discharged at an average concentration of 2.0×10^{-5} μ Ci/ml, or 0.7% of the applicable standard. With the BGRR shut down, the discharge of ^{41}Ar and ^{131}I activity from the BGRR-HFBR stack was effectively terminated. The only significant remaining stack effluent was 53 Ci/mo

of ^3H , originating at the HFBR. Twenty-three vaults of solid waste were shipped to the burial site at West Valley.

Environmental Monitoring

The design of the new plastic scintillator γ monitor was completed, and units have been satisfactorily tested at environmental monitoring stations at the site boundary. With the cessation of operation at the BGRR and the associated γ emission, the one remaining off-site monitoring station at Shoreham (5.4 miles north of the BGRR stack) was decommissioned.

During fiscal 1970 the highest external radiation level at the site boundary occurred at a point 0.64 miles north of the Gamma Forest source and averaged 2.08 mR/wk. This may be separated into two components of 1.75 and 0.33 mR/wk, due to background and the forest source, respectively. The permissible level above background is 500 mR/yr, or an average of 10 mR/wk. The values just cited are for the new north boundary, which is 1275 ft north of the old boundary for which values have been reported in the past. At the new site boundary the radiation level due to the forest source has been reduced to about 20% of that at the old boundary, which averaged 1.59 mR/hr during fiscal 1970.

Samples of air particulates, including both longer-lived natural and fallout isotopes, averaged 0.24 pCi/m³ of gross β activity, while the average activity in precipitation was 0.22 nCi/m²/mo.

Personnel Monitoring

Personnel monitoring service was provided for 2723 persons during calendar 1969, about the

Table 7

Distribution of Exposures of Individuals Receiving Regular Personnel Monitoring Service

Exposure range, Rem	Calendar 1969	Calendar 1968
0.00-0.49	2470	2445
0.50-0.99	151	163
1.00-1.49	32	82
1.50-1.99	34	32
2.00-2.49	19	22
2.50-2.99	8	8
3.00-3.49	9	20
3.50-3.99	0	10
4.00-4.49	0	13
4.50-4.99	0	5
5.00 and over	0	0
Total	2723	2800

Figure 4. BNL safety record.

same number as in 1968. The distribution of whole-body exposures to penetrating radiation for those regularly monitored is shown in Table 7. All exposures were <3 Rem per 13-wk period. The total exposure for all individuals monitored was 431 Rem, or 35% less than the 1968 total. The maximum individual total for the year was 3.48 Rem, compared with 4.88 Rem the previous year. There was a substantial reduction in exposure at the AGS, but two-thirds of the Laboratory total was incurred at the AGS by 30.5% of all those monitored at the Laboratory. The average exposure per worker monitored dropped from 235 mRem in 1968 to 158 mRem in 1969. It may be noted from Table 7 that there were no exposures >3.5 Rem, whereas there were 28 over this value during the previous year.

A FORTRAN program for use in reducing data from the pocket criticality dosimeters has been written for the CDC 6600 computer.

Laboratory Safety

The BNL injury frequency rate continued at an extremely low level during calendar 1969, reflecting the favorable accident experience together with commensurate savings in accident costs. (See Figure 4.)

There were but two reportable instances of fire or other property damage during 1969: a small kitchen-range fire in a men's residence, and water damage from the flooding of a transformer room during a rainstorm. Total losses amounted to only \$3050.

During 1969 major accomplishments included a new water supply management system for fire protection, initiation of installation of improved fire detection apparatus for the computer centers, completion of plans for use of high expansion foam to protect a large bubble-chamber installation, and completion of a comprehensive review of all BNL facilities to provide a priority list for fire and safety projects.

MECHANICAL ENGINEERING

During fiscal 1970 the number of personnel in the Mechanical Engineering Division was reduced from 187 to 168. Assignments to the various BNL departments are listed in Table 8. The Central Design Group was disbanded because of decreased use by all but the major users of mechanical engineering support, and the Safety Group is now organizationally part of the Mechanical Engineering Division.

Table 8
Assignment of Mechanical Engineering Division Personnel as of June 30, 1970

	Engineers	Designers and draftsmen	Secretarial and clerical
Accelerators			
Advanced accelerator development	3	1	
Alternating Gradient Synchrotron (AGS)	8	20	2
AGS conversion			
Magnet ring	6	8	
Linear accelerator	7	11	
Experimental planning and support			
Floor operations	7	3	
Cryogenics and design	9	10	
Administration	1		
Applied Science	4	6	
Central Design	1		1
Chemistry	1		
Physics			
Bubble chambers	14	15	
General	8	17	
Safety	5		
Total	74	91	3
Total personnel - 168			

In the Bubble Chamber Section work was done for the Physics Department in connection with the initial operation and improvement of the 7-ft bubble chamber, planning for conversion of this bubble chamber to a larger facility, modifications to improve the operation of the 80-in., 31-in., and 30-in. bubble chambers, and planning for the new H-10 Experimental Area and the moving of the 80-in. and 7-ft bubble chambers.

The major effort of the group involved the 7-ft bubble chamber. The first cool-down of this chamber began on May 8, 1969, and the chamber was filled with hydrogen on May 15, 1969. Attempts at expanding the chamber were unsuccessful, and difficulties were experienced with some of the chamber components. Changes were then made in the expansion system, optical baffle, vacuum system for the helium refrigerator, transfer lines, vacuum tank, and the helium refrigerator.

A second cool-down started on Oct. 9, 1969, and the magnet was cooled to operating temperature

and run at 10 kG with gas in the magnet Dewar. Because of an inadequate supply, the Dewar was only partially filled with liquid helium. The chamber was expanded on Oct. 29, 1969, and the first tracks of cosmic rays were obtained.

As a result of this operation the following changes will be made before the next cool-down. The fixed baffle covering the expansion area caused spurious boiling and will be removed. The bubble-catcher skirt that covers a chamber-cooling loop will be shortened, and a large tube will be attached to the inner edge to provide a smooth path for hydrogen flow and reduce boiling. The 5-in. spool valve controlling the hydraulic actuator for the expansion system was redesigned and tested, and an inflatable, indium-coated stainless steel tube seal will be installed in the magnet Dewar flange. In addition, the helium liquefier and compressor were overhauled and tested to verify their cooling capacity.

Specifications have been written for new hydrogen and helium liquefiers to make the 7-ft bubble chamber or its larger version satisfactory for continuous operation. The capacity of the hydrogen refrigerator will be 7 kW at 20°K, and that of the helium liquefier, 700 W at 4.5°K. Delivery is expected in the second half of 1971.

Since the 7-ft bubble chamber was designed as a test facility to evaluate concepts for large bubble-chamber designs, the initial operation was valuable in obtaining much engineering information on such matters as the use of fiber-glass reinforced plastic for the expansion piston. This electrically and thermally nonconducting material is necessary to eliminate eddy current heating due to movement of the piston in the bubble chamber's magnetic field and also to provide insulation between the liquid hydrogen in the chamber and the buffer volume beneath the piston. The piston (see Figure 5) has a 1-in.-thick fiber-glass conical and cylindrical section attached to a fiber-glass shaft by a preloaded tapered joint. This joint is held under compression by tension-wound glass filaments in order to transmit the 100,000-lb force from the shaft to the piston. Stainless steel bearing sleeves are mounted on the piston shaft for bearings and seals.

Another area of engineering advance involved the development of a fast-acting 5-in. D-spool valve for driving the actuator of the expansion piston. Difficulties had been encountered with seizing of the spool after relatively few cycles. This was later ascribed to large side forces during maximum flow

Figure 5. 7-ft Bubble chamber expansion piston, made of fiber-glass reinforced plastic.

of the hydraulic fluid. The solution involved redesigning the spool to incorporate hydrostatic bearings to provide positive support for the spool at all times. The proper operation of the bearing system was determined in a test device that allowed 12,000 lb side thrust to be placed on a journal while it was supported by the bearing system. Under this load the journal moved 0.0015 in. sideways to leave 0.0005 in. clearance, which was adequate.

The whole hydraulic actuation system was simulated in the full-scale test shown in Figure 6. The actuator is attached to a 500-lb weight and a driven hydraulic cylinder and accumulators to simulate the bubble chamber's liquid hydrogen volume. The test was conducted successfully for several hundred thousand pulses of 2-in. and 3-in. stroke with a period of 0.050 sec.

Preliminary design studies have been made to determine the feasibility of enlarging the 7-ft bubble chamber to increase its usefulness for physics experiments. The exact size will be determined by the funds available at the time of detail design.

The cost of enlarging the 7-ft bubble chamber will be minimal because many existing components, such as the optical equipment, cameras, electrical and pneumatic controls, and instrumentation, are not strongly dependent on chamber size and could be used on a larger chamber with minimum modification. In addition, by cutting apart the existing assembly various components such as the chamber top section and optics ports and various flanges, legs, and feed-throughs can be reused. Further, the superconducting magnet material can be rewound with additional material, and much of the small hardware can be used in making the new magnet coil. The only major components to be fabricated would be a spherical vacuum chamber, a spherical chamber section for the hydrogen chamber to which the present top section would be welded, and a new magnet coil Dewar. Thus, about 80% of the components of the 7-ft bubble chamber, which cost $\approx \$3,400,000$, can be used. This work is planned for the period from mid-1970 to completion of the new H-10 experimental area in 1972.

The operating bubble chambers were also modified for greater efficiency and reliability. Since difficulty had been experienced in maintaining the hydrogen level and temperature in the top of the 80-in. bubble chamber, cooling loops were redesigned for better heat transfer, and a balsa-wood and fiber-glass facing was applied to the piston face to provide greater insulation.

To reduce film costs, improve film handling and processing efficiency, and increase multipulsing efficiency, changes have been made in the optical system of the 80, 31, and 30-in. bubble chambers. The camera systems of the 80 and 30-in. chambers were changed to allow use of 35-mm film to correspond with that used in the 31-in. chamber; the transport system has been improved with a cam-operated, fast-acting pressure vacuum valve to control film position on the platen; and the data system has been improved by changing the incandescent light system to photoemitting diode chips.

An analysis was made of the methods and costs involved in moving the 80-in. bubble chamber from its present location to the new H-10 area. Decisions will be made shortly concerning this possible major change.

Development work is proceeding on the use of hollow-core superconducting materials and twisted strip superconductors using a small 10-liter/hr

Figure 6. 7-ft Bubble chamber actuator and spool valve test. The upper section simulates the liquid hydrogen volume of the bubble chamber.

helium liquefier and 24-in. Dewar in the bubble chamber works area.

Work has continued on track-sensitive targets, which are transparent acrylic plastic cylinders mounted in the bubble chambers and containing a liquid different from the bubble chamber liquid. Tracks occur in both liquids, since they are expanded at the same time. The use of different materials (e.g., deuterium in the target and a neon-hydrogen mixture in the chamber) causes problems arising from the significantly different pressure and temperature relationships. The target being developed consists of a multiconvolution bellows system that permits independent control of the target pressure and simultaneous expansion of the target and chamber fluids. A cooling loop located inside the target controls the target fluid temperatures.

The General Physics Section of the Division performs work for all other groups in the Physics Department, as follows:

The bearing and motor development program for the fast-neutron chopper (HFBR beam hole H-2) was completed and the new support bearing drive motor system was installed in January 1970. Performance of the self-pumping, oil-lubricated bearings has been excellent at all speeds up to 15,000 rpm. As in the slow-neutron chopper, in which the oil-lubricated bearings have been in almost continuous operation for well over a year (9500 hr), the fast chopper should have better than a year of continuous operation before bearings must be replaced.

Considerable effort was expended in the design of experimental equipment for the solid-state spectrometer research program at the HFBR (beam holes H-4 to H-8). Some of the components designed include an angle divider, monochromator, and multipurpose goniometer. A new rotary plug has been designed, and its fabrication and installation at HFBR beam hole H-7 should be completed early in fiscal 1971. This plug provides a choice of three collimated beams and a shutter position. Initially 10, 20, and 40-min collimation will be provided.

Design work was started on a Fourier chopper, a recent development that eliminates the necessity for working with a monoenergetic neutron beam and uses Fourier analysis to separate the data. The Fourier chopper consists of a 5-in.-diam aluminum disk rotating at speeds up to 19,000 rpm. Radial slits are machined in a gadolinium foil which is opaque to neutrons and is bonded to the surface

of the disk. Timing information is provided by a photoelectric sensor that reads a pattern on the disk. The drive will be a single-phase, hysteresis-synchronous motor controlled by a two-band oscillator. Chopping frequency will be varied in bands from 0.5 to 50 kHz.

The cold neutron moderator project for HFBR beam hole H-9 has been progressing satisfactorily. Approval was obtained from the Reactor Safety and Cryogenic Safety Committees for the preliminary safety analysis report. The project staff has also been requested by the committees to formulate a "maximum credible accident test" program to evaluate the performance of certain components of the safety chain protecting the cold neutron moderator and its associated liquid hydrogen loop, as well as to determine the effects of a variety of accidents on the moderator, containment, and support structure. It is planned to conduct these tests early in fiscal 1971.

A preliminary design effort has been started for a cold neutron experimental facility to enable researchers to use the additional cold beams that will be available when the cold neutron moderator project is complete. The facility will consist of a primary radiation shield to reduce radiation levels and will provide openings for three beams. One of the beams will be directed to a chopper experiment through a double monochromator using pyrolytic graphite crystals, and the other beams will be conducted through internally reflecting beam pipes.

A tandem goniometer to be used for precision x-ray angular distribution measurements by researchers at the new Tandem Van de Graaff Facility is nearing completion. The device provides a controlled variable angular and radial position on two 6-ft arms pivoting about a central target. The arms, which must support concentrated loads of up to 6000 lb of counter shielding, are steel weldments for high rigidity and are supported on a hardened bearing track by ball transfer pads. Each arm has a positioner drive that uses two motors coupled to a drive pinion through a differential gear unit. One is a synchronous ac motor that functions as the slewing motor, and the other is a stepping motor, used for precision positioning close to the desired angular setting. Work continued on the design effort for the terminal ion source system, which should be installed soon.

Both accelerator systems of the Tandem Van de Graaff Facility have been assembled and have

Figure 7. Prototype cylindrical wire spark chambers. The one in the foreground is 30 in. in diameter and 36 in. high.

passed acceptance tests. An SF_6 recovery system has been designed as a modification of the present insulating gas system. SF_6 gas is added to the insulating gas mixture to improve voltage stability.

Support for counter experiments in high energy physics was extensive, with most of the work directed toward an AGS experiment to study multi-particle production in p - p interactions at 28 GeV/ c . The experiment involves two high-resolution spectrometers and one large, solid-angle spectrometer.

The Π spectrometer uses an array of cylindrical magnetostrictive readout spark chambers 12 to 37 in. in diameter and 40 in. high (Figure 7). The problems in constructing cylindrical chambers differ from those encountered in flat spark-chamber work. In the cylindrical chambers the conducting

wire grid is produced by mounting a 3-mil H-film and 1-mil aluminum laminate on a large drum. The H-film is coated with a film of epoxy, and 5-mil gold-plated copper wire is wound on it (40 wires/in.). Control of the $\frac{1}{4}$ -in. gap is achieved by bonding the foils to a phenolic honeycomb, which also adds rigidity. Preformed cylindrical steel strips at the top and bottom are joined to vertical aluminum stiffeners at the ends. The chambers are then nested in top and bottom plates separated by spacers, and the entire assemblage is mounted between the pole faces of a large magnet. Prototype chambers have been successfully fabricated and tested, and present schedules call for completion late in 1970.

Two large Čerenkov counters are being provided for this experiment. Each consists basically of a reinforced steel vessel of racetrack cross section, onto which are bolted thin-walled aluminum

semicylindrical beam windows measuring 3×7 ft. Design pressure is 100 psig with Freon 14 gas, and the design fabrication and testing aspects closely follow the relevant portions of the ASME Boiler and Pressure Vessel Code.

The magnetic finger device used for focusing π and K mesons has been successfully tested after some design modifications to the first inner finger and the addition of a vibration damping spacer. The fingers were pulsed 520,000 times at 12,000 V and 300,000 A, with no evident deterioration.

Assistance was provided to the Reactor Operations Division in the repair of the HFBR primary heat exchangers. Failure of the fillet weld joint between the baffle plate and the tube sheet was observed in both exchangers. Effective support of the plate along the edge adjacent to the tube sheet was provided by a pair of rods that transmit the plate loads to the hemispherical head. Other bracing was installed to increase the natural frequency of vibration of the plate. The exchangers were returned to full 40-MW service.

Several in-reactor irradiation capsules were completed during the year. One capsule, designed to measure the neutron capture-to-fission ratio in ^{239}Pu , was irradiated during the May cycle of the HFBR. A capsule for irradiating copper bicrystals in the HFBR at 500°C was designed for a study of radiation effects. A test capsule was successfully irradiated to verify the design.

The use of ozone in treating acid mine drainage is being investigated in the Department of Applied Science. The ozone, by enhancing the oxidation of ferrous ions in solution, aids the neutralization and precipitation steps of proposed chemical processing schemes. The study is being made for the Federal Water Quality Administration.

A program involving low and high-cycle fatigue testing of LMFBR materials of construction in sodium and steam environments is in progress. Environmental chambers for the test machines, including sodium supply loops, have been designed and are being fabricated.

Conceptual design studies were begun on multi-stage flash distillation vessels utilizing concrete-polymer materials. Design of a prestressed vessel 30 ft in diameter by 90 ft long to operate at 50 psig and 300°F was completed. The vessel is supported every 15 ft and is loaded internally with 2 ft of brine and light aggregate fill. A stress analysis was performed with use of finite element techniques, and the results indicate that a wall thick-

ness of 4 in. is feasible for this vessel. The use of concrete-polymer materials for bridge decking and luminaire structures is also being studied.

When the 200-MeV proton linear accelerator (linac) starts operation next year about 50% of the high energy protons accelerated will be dumped into a beam stop. The Brookhaven Linac Isotope Producer project will utilize this beam of waste protons to produce various nuclides. A preliminary design of the facility shows an 8-ft-diam by 33-ft-high water-filled shield tank which houses the target-handling equipment. The stainless steel vessel has been designed and is being procured. Fabrication drawings of the sample-positioning elevator are being prepared.

Design work on the trailer-mounted mobile gamma irradiator has been completed. Design of the crash frame for this irradiator has also been finished. The rodent irradiator was completed and delivered to the BNL Medical Department. The second and third Brookhaven portable cesium development irradiator units were shipped to India and Chile, respectively.

The BNL radioactive waste disposal shipping cask "Overpack" was modified to accept a $4 \times 5 \times 8$ -ft concrete box which is slightly larger than originally specified.

An electron beam collimator was designed for the Metallurgy Division, and the Nuclear Materials Group received assistance in security seal development and in the design of mechanical assemblies for the measurement of reactor fuels.

Several new test sections were designed for the Heat Transfer Group. A preliminary design was made for a two-diameter test section for the potassium heat transfer facility. With appropriate adjustment of flow rates, this section will allow separation of the velocity and Reynolds number effects in boiling inception studies. A rod-bundle test section was designed for the sodium loop. The initial unit will have a pitch-to-diameter ratio of 1.25. Subsequent units will have P/D ratios of 1.15 and 1.35. These sections are to be installed in the 1000°F side of the heat transport system. Appropriate valving will allow alternate operation of the close-packed bundle and the existing annular test section. Several shell and tube-sheet modifications were made to the mercury loop test sections.

A detector for ^{14}C β particles was designed for the Medical Department. The outer cosmic-ray shield is made from an $11\frac{1}{2}$ -in.-i.d. gun barrel. The inner annular ring shield will contain mercury.

The major work of the AGS Section has been connected with developing for the Accelerator Department apparatus to bring particle beams out of the AGS, with special emphasis on the slow external beam (SEB).

The 0° beam-line extension of the SEB to the C target has been completed. The extension brings the primary beam into the new East Experimental Building Addition for the first time. In addition to the magnets and power supplies required for beam transport, the array of equipment includes vacuum beam pipe and pumps, television stations with instrument boxes and actuators, radiation plugs and shields, and a target turret for the C target position.

The vacuum system consists of ≈ 450 ft of 6-in.-diam aluminum beam pipe. "Marman"-type quick-disconnect couplings are used on all vacuum joints to speed up component changes and reduce the time spent by technicians in radiation areas. Vacuum seals are of the metal C-ring type. All valves are bellows sealed; this eliminates the leakage problems associated with the older valves, in which packing seals were used. The control of this vacuum system is considered an extension of the ring vacuum control system, and similar equipment and procedures are used. For vacuum readout, use is made of the ion pump current, which is proportional to pressure, rather than ion gauges.

A remote-controlled, variable-aperture collimator has been installed in the slow beam line just after the beam emerges from the AGS. The function of this device is to clip the "halo," or tail, which is inherent in the extraction process, from the SEB and thus allow a clean beam to be delivered to the target. The device consists of two horizontal and two vertical jaws, 2×4 in. in cross section and 20 in. long, made from nonmagnetic stainless steel with tungsten inserts. The collimator is packaged in a vacuum box; each of the four jaws is individually controlled and may be skewed ± 4 mrad as well as translated 1.5 in. The jaws may be positioned remotely from the main control room or by the PDP-8 computer. Each jaw is driven by two Slo-syn motor drive assemblies. The radial displacement is measured by a potentiometer, and a differential subassembly with its integral potentiometer monitors the skew angle of each jaw. Dynamic O-ring seals have been eliminated, and torque is transmitted through the vacuum chamber walls to the jaws via a hermetically sealed harmonic drive gear reduction unit.

In addition, a remotely controlled, four-jaw radiation shield and two radiation plug devices have been built for the SEB extension. The shield has two horizontal and two vertical jaws that can be individually controlled and is similar in design to the variable-aperture collimator but lacks the skew angle feature. Each of the two radiation plugs is a stainless steel forging that is $8 \times 8 \times 48$ in. long and weighs 900 lb. The plug rides on hardened stainless steel shafts and ball bushings inside a vacuum box and is remotely controlled.

To facilitate SEB targeting in air, a 6-station, remotely controlled, automatic indexing turret was incorporated at target stations A and C. The turret can be indexed, clockwise or counterclockwise, to an adjacent target position in one machine cycle. The individual targets can be quickly replaced manually, or the entire 6-station turret head can be easily removed and replaced.

To obtain a more accurate beam profile, two emittance devices have been built and mounted on linear actuators. The first device consists of 24 beryllium signal plates stacked alternately between 25 tantalum bias shield plates. This array occupies the same space as the original 12-plate array. Therefore the proton beam interacts over twice as many signal plates, which permits a more accurate beam profile to be made. The second device consists of 24 fingers mounted on an insulated rotatable plate and shielded by 0.002-in.-thick aluminum bias plates. By optimizing the angle that the 24-finger array presents to the proton beam, the beam can be made to interact over the entire array. The array may be rotated remotely from the control room and retracted from the path of the beam when not in use.

A new radiation-hardened target airlock capable of supporting two standard target motors has been designed. The dynamic seals are of the bellows type where translation is required, and a harmonic drive where rotation and torque are to be transmitted through the vacuum wall.

In conjunction with the airlock development program, a new target-position readout system has been devised that will allow placement of the radio-sensitive target-position electronics package 20 ft upstream of the airlock in an area shielded from radiation.

Two vertical bump magnets 20 in. long with a 6×6 -in. aperture have been designed and are being fabricated. These magnets will produce an orbit deformation at the septum and ejector magnet

locations of the SEB in the ring and allow for greater extraction efficiencies if the vertical orbit drifts.

Design of an electrostatic septum for more efficient SEB extraction is complete. The deflector uses 0.001-in. tungsten wires spaced on 0.078-in. centers as the septum, and each wire is spring-loaded for equal tension. At 100 kV the 2-meter-long septum will deflect the beam 0.6 mrad. The septum will be placed upstream of the present 0.030-in. septum at F-5.

A 1-in. gap height-50% duty cycle ejector and a $\frac{5}{8}$ -in. gap height-50% duty cycle septum are being designed for postconversion SEB's. This was required because of the larger emittance and faster repetition rate of the converted AGS. Organic materials that would be subject to radiation will not be used in these magnets.

A beam-splitter system designed for the SEB will allow the beam to impinge simultaneously on two external SEB targets on the same machine pulse. It consists of a 0.002-in.-thick septum electrostatic splitter, a 0.020-in.-thick water-cooled magnetic splitter, and a 0.350-in.-thick superconducting magnetic splitter, for a total bend of ± 19.5 mrad. A full cross-section, $\frac{1}{6}$ -length model of the superconducting splitter magnet has been designed and fabricated for evaluation purposes.

The fast extraction scheme to the new North Bubble Chamber Area calls for the development of a full-aperture fast kicker and a $\frac{1}{16}$ -in.-thick septum ejector magnet. Design has been completed on a $\frac{1}{4}$ -length model of the fast kicker. This model will contain one of the four magnet sections of the final version and has been designed to expedite the rapid exchange of components for servicing or design evaluation. Tests on this model will include determination of the desirability of using fluorocarbon FC78 gas as a replacement for transformer oil.

The design of the fast external beam (FEB) septum ejector magnet assembly has been completed. The system provides for vacuum pumpdown and bakeout of the assembly prior to installation in the ring. A $\frac{1}{4}$ -length model of the magnet has been assembled for reliability tests and magnetic field measurements.

Final design has been started on a new magnet inflector for 200-MeV injection. It is capable of a 200-mrad bend of the injected beam and is designed for beam stacking in the vertical and horizontal planes.

A 13° bending magnet for the 200-MeV injection system was designed to direct the proton beam after it emerges from the high energy beam transport line-up into the inflector. The magnet coil halves are segmented into a main and a Vernier winding. The main windings are coupled in series with two of the inflector segments, which receive the same pulse and produce a similar deflection of 200 mrad. Up to a maximum of 28 mrad is provided by the Vernier coil, which may be varied to effect any minor changes required in steering.

The prototype "elliptical" quadrupole magnet has been thoroughly tested. This unit was primarily designed as a low-field correction quadrupole to shift the ν value in the AGS. The tests indicate that the magnet is capable of sustaining a higher current dc pulse. This increase in performance will allow its use with horizontal betatron frequency jump at transition in addition to its original function of low-field correction.

The Experimental Planning and Support Section has designed and fabricated, for the Accelerator Department, magnets for experimental beam lines, vacuum boxes, and vacuum systems, and has been involved in the redesign of the dc electrostatic beam separators.

Work is also continuing on the development of superconducting radio-frequency beam separators operating at 1.8°K. The major problem is the preparation of the resonant cavities of niobium, and in particular developing the proper interior surface. This necessitates very fine machining, chemical polishing, and annealing of the niobium at 2000°C and a vacuum of 10^{-9} torr. The cavities must then remain in a very clean atmosphere until used.

The Cryogenic Group of this Section has been involved in projects in the Accelerator Department and in other BNL departments. Three automatically operated liquid hydrogen target systems for beams at the AGS were installed and operated successfully. When using manually controlled liquid hydrogen targets, a day and night watch on each target had been required. With the automatic target filler a number of targets can be supervised by one watch group. The system automatically transfers liquid hydrogen from a 175 or 1000-liter supply Dewar to the target on signal from a liquid level sensor in the reservoir. A controller monitors the vacuum in the target and transfer line, as well as the reservoir and target

pressures. When preset limits have been exceeded the delivery of liquid stops, reservoir pressures are reduced to ambient conditions, an alarm is sounded, and the condition is indicated on an annunciator panel.

Some components have been received for the cryogenic apparatus being designed with the Physics Section for the cold neutron moderator (CNM). An assembly building being erected adjacent to the HFBR will initially be used for the operational test program of the CNM, but later will house the 3.5-kW helium refrigerator compressor. This refrigerator, one of the largest to date, is expected to be completed shortly.

Equipment is being designed and fabricated for use in a series of operational and safety tests on the CNM for the BNL Reactor Safety Committee. The safety tests are designed to subject the vacuum envelope of the CNM to the overpressure that could occur in the event of failure of the insulating vacuum, plugging and bursting of liquid hydrogen lines, or ignition of a solid air and liquid hydrogen mixture. Before AEC approval is granted it must be shown that such events cannot breach the moderator casing to affect the HFBR and that gaseous products can be safely vented outside the building.

A large project under way in cooperation with the Cold Magnet Study Group of the Accelerator Department involves preliminary design of a synchrotron of approximately the diameter of the AGS, to be housed in the AGS tunnel. The magnet system will operate at a minimum field of 40 kG, and therefore either a pulsed superconductor material or pure aluminum will be used for the magnet coil. One of the two groups involved in this work is concerned primarily with pure aluminum and a steel magnet structure; the other is primarily interested in a filamentary niobium-titanium superconductor in a copper matrix for the current-carrying conductor. This is arranged in an air-core configuration with a laminated steel shield. Both groups have engineering and design personnel working with them on the special problems of development and fabrication that are involved.

In addition, studies have been made of designs of cooling systems for large synchrotrons. For the superconductor system, liquid helium could be used, but there are many difficulties connected with vapor venting in a two-phase liquid gas system, circulation of the liquid helium over long distances, and the large temperature differential

required to remove the energy dissipated. A refrigeration cycle using two separate helium loops has been proposed. One loop, which provides the cooling, liquefies helium at 1.3 atm and 4.5°K in 48 separate subcoolers arranged in the AGS ring adjacent to 48 magnet Dewars, each ≈ 50 ft long. The other loop provides the heat exchange medium between the magnet Dewars and the subcoolers. Supercritical helium at 10 atm pressure enters the magnet Dewar at 4.5°K and exits at 5°K.

The aluminum conductor coil system uses a helium refrigerator to produce cold (10°K) helium gas at the Dewar entry, with the temperature increasing to 13°K at the Dewar exit. The system pressure is 10 atm.

In the Conversion Division Section work continued on the 200-MeV linac injector and the changes to be made to the AGS ring. Fabrication of the linac tanks was completed in February 1970. Assembly of drift tubes into the tanks had started with receipt of the first tank. Tanks Nos. 1, 3, 4, 5, and 6 are assembled and in place in the linac tunnel, and the rest of the tanks will shortly be in place. On March 24, 1970, a proton beam was accelerated through tank No. 1 to an energy of 10 MeV. Beam operation at 10 MeV will continue intermittently to improve the operation of the preinjector and tank No. 1.

Fabrication of the drift tubes is complete, and the drift-tube factory is continuing fabrication of quadrupoles and other elements of the low energy beam transport.

Occupancy of the new linac complex took place in the spring of 1970, and installation of rf components, water systems, vacuum systems, etc., is under way.

Design of 200-MeV beam analysis equipment and beam dump is being undertaken by the Linac Group. An experimental facility for the Chemistry Department and the Department of Applied Science is being designed to use those proton pulses from the 200-MeV linac that will not be injected into the AGS.

In the magnet ring area of the AGS the new vacuum chambers were completed, as was mechanical erection of the Siemens motor-generator power supply. The bus bar distribution system in the AGS ring was redesigned and placed on order. A prototype rf cavity was built, and as a result some fabricated sections were replaced by castings, at a considerable cost saving. All components are now on order.

The necessary special vacuum chambers for injection and external beam areas were designed and are being fabricated. New standard hardware for the 5 and 10-ft straight-section vacuum chambers was also designed and ordered.

New pickup electrodes were developed, and several prototypes have been built and are undergoing test. Early measurements indicate that one of the new designs is more economical to build and can be adapted to an elliptical cross section. It also has the best signal-to-noise ratio, as well as the best linearity characteristic. A final decision will be made shortly and procurement initiated.

Considerable effort was expended on the design and fabrication of prototype low-field correction coils, and a new cosine 20 current-distribution quadrupole for the 2-ft straight section has been built and measured.

In the Chemistry Department an advanced multidetector x-ray diffractometer system called AESOP (automatic equiinclination spectrometer operating in parallel) will be completed this year. Its design and development were reported previously.

Preliminary design work has been completed for an irradiation facility in the beam analysis tunnel of the AGS 200-MeV linac injector. This facility will use excess proton pulses from the linac to make available intermediate energy levels for producing short-lived, neutron-rich isotopes, as well as isotopes for use in organic hot-atom chemistry and medical applications. The facility will consist of a pneumatic "rabbit" to carry a thin target into the proton beam and an elevator to transport an internally cooled target from a loading station 20 ft above the proton beam down to the beam.

In addition, several cyclotron targets were designed to measure beam current, and a hydraulic accumulator was modified for gas-to-gas service to compress precise volumes of radioactive gases. The first phase for simplifying the preparation of AGS targets and punching postirradiated foils has been completed.

MACHINE SHOPS

The Central Shops Division maintains shops and inspection and quality control stations in six Laboratory buildings. The primary service provided is the fabrication of mechanical, welded, and formed metal parts for the construction or modification of scientific equipment. Services and repairs to Laboratory equipment and arrange-

Table 9
Contributions to Central Shops Workload
(% man-hours)

	Fiscal year		
	1970	1969	1968
Accelerator	49.2	38.8	26.3
Applied Science	8.6	12.6	18.1
Biology	1.5	2.2	1.7
Chemistry	2.7	3.4	3.5
Instrumentation and Health Physics	0.8	0.7	0.8
Medical	1.3	2.9	2.2
Physics	30.3	33.0	39.8
Reactors	2.9	3.3	5.4
Miscellaneous	2.4	2.8	1.5
Outside contracts	0.3	0.3	0.7

ments for off-site services and vendor fabrication as required are also functions of the Division. The staff of supervisors and technical personnel administering these services represent an average of 13 years of service with Brookhaven.

Distributed shop time to the various Laboratory departments during fiscal 1970 totaled 148,257¾ man-hours. Table 9 gives the distribution for the year and a comparison with fiscal 1969 and 1968. Services provided, including those of employees on loan to scientific departments, totaled 8570¼ man-hours. Inspection services provided by the Division's Inspection and Quality Control Section, for which there is no direct charge, included 100% inspection of parts fabricated by the Division, assistance in setting up scientific equipment, tool calibration, vacuum and hydrostatic leak detection, and inspection of off-site fabrication.

To cope with demands for the handling of larger and heavier pieces of material, building modifications in the Heavy Machine Shop included a traveling overhead crane and the foundation for a vertical boring and turning mill of increased capacity. Figure 8 shows the newly acquired mill, the Laboratory's largest machine tool. The Division's fifth numerically controlled machine, a vertical continuous-path machining center (see Figure 9), was also installed in the latter part of fiscal 1970. This valuable asset to the Machine Shops will now provide continuous-path milling, a very desirable feature for the present precise and complicated machining required for BNL research equipment.

Figure 8. The Laboratory's largest machine tool. The unique design of this vertical boring and turning machine permitted installation within the existing building of the Heavy Machine Shop.

Figure 9. The vertical machining center, latest addition to the Central Shops' numerically controlled machining. A feature of this machine is continuous-path and circular milling, a tape-controlled function that will increase the Division's fabrication capabilities.

A program was formulated in 1968 to restore some of the Laboratory's older pieces of shop machinery to new accuracy and in many instances to up-date them by installing modern measuring and feed control equipment. This year the program provided for the rebuilding of three machines off site and rebuilding and modernizing of seven machines on site.

TECHNICAL INFORMATION

The last phase of the construction and renovation program to expand and modernize the Research Library was completed during the fall. The relocation of the staff, the additional reading space, and the increase in shelving have resulted in a quieter, more spacious, and better organized facility.

A full year of association with the Long Island Library Resources Council (LILRC) has brought about a marked change in the Library's interlibrary loan operations. Forty percent of the material not found on the Library's shelves is now obtained by the Council from Long Island libraries. Last year only 12% of the loan requests were filled by local institutions. With respect to requests for loans of books and journals in the BNL collection, the service provided by the Library to Long Island libraries rose from 17% to 48% of the total loans negotiated through LILRC. For BNL, participation in the LILRC interlibrary loan network has resulted in faster delivery of borrowed items and the elimination of transportation charges.

As a further index of the Laboratory's decreasing requirements for classified information, one of the two staff members who operate the Classified Library now provides part-time assistance in the Research Library. A vigorous program of destruction, declassification, and return has resulted in reducing the holdings from the Dec. 31, 1968, total of 11,600 classified reports to 6713 as of last Dec. 31.

A total of 1022 scientific and technical manuscripts resulting from BNL-supported research were processed during the year for publication in the open literature. The film library negotiated 369 loans of 16-mm motion pictures on nuclear topics to local schools, civic groups, and research institutions.

The Patent Office reported 26 inventions during the course of the year. A summary of its activities during fiscal 1970 and the two previous years is given in Table 10.

Table 10

	Fiscal year		
	1970	1969	1968
Patent clearances	1145	1208	1218
Records of invention	26	16	38
Patent applications	7	22	18

INTERNATIONAL COOPERATION

The spirit of international cooperation in science is greatly fostered by the many arrangements whereby foreign scientists visit and come to work at Brookhaven and Laboratory scientists attend overseas meetings and conferences. In addition, the Laboratory has been involved in several formal programs of scientific cooperation. Those currently active include arrangements with the Italian Laboratorio di Fisica Nucleare Applicata del Centro di Studi Nucleari della Casaccia, the Norwegian Institutt for Atomenergi at Kjeller, the Greek Nuclear Research Center, and the Puerto Rico Nuclear Center.

The first of these programs, arranged as an appropriate activity under the U.S.-Italian Agreement of June 19, 1967, for scientific cooperation became formally effective in March 1969. In general, the cooperative work is concerned with the study of the structure and dynamics of magnetic spin systems, with neutron scattering employed as the principal experimental tool and nuclear magnetic resonance used in complementary studies. The program has been actively implemented with brief visits by Brookhaven scientists to the Casaccia Nuclear Studies Center for discussions of the experimental program and for collaboration on theoretical problems. The exchange of scientific staff was initiated with the assignment of an Italian theoretical physicist to work at Brookhaven for six months. He is doing research on magnetic form factors of transition metal ions. Following his visit, an Italian experimentalist is expected to visit Brookhaven for an extended period.

The arrangement with the Norwegian Institutt is a new program, instituted last March. It will involve cooperative studies on solid-state phase transitions employing neutron scattering techniques.

Under the auspices of the Atomic Energy Commission's Division of International Affairs, a co-

operative program between BNL and the Greek Nuclear Research Center (Demokritos) has been maintained since 1965. As part of this program, visits are arranged between staff scientists of both institutions for discussion of problems of mutual interest and exchange of information. BNL has also supplied several items of equipment, on a loan basis, to Demokritos to expedite their research activities. Because of budgetary restrictions, the program was sharply cut back this year. Nevertheless cooperative consultations, particularly with respect to the installation and use of a Van de Graaff laboratory for low energy nuclear physics, were carried out. Several Greek students and technicians from Demokritos, near Athens, received training in a summer session at Brookhaven. An

International Atomic Energy Agency fellowship was awarded to a Demokritos staff member for research at the BNL High Flux Beam Research Reactor during fiscal 1970.

Contact between Brookhaven and the Puerto Rico Nuclear Center is now maintained principally through joint or complementary research projects. The principal areas of common interest have continued to be neutron diffraction and organic semiconductors. Although now at a level much reduced from that of the early days of the cooperative program, an exchange of visiting scientists for short periods has continued. This exchange is still very useful in overcoming the problem of Puerto Rico's relative isolation and in contributing to the effectiveness of joint research efforts.

Administration and Operations

The management operations reviewed in this section have been designed to facilitate and encourage the research activities of the Laboratory's scientific staff.

PERSONNEL

Scientific Staff and Students

For the second consecutive year, the number of regular staff members at Brookhaven decreased during the 12 months ending May 31. Turnover remained at a significantly high level; 40 scientists were appointed to the staff, and 33 terminated their appointments. Comparative year-end statistics for 1970 and 1969 are shown in Table 1.

The number of salaried visitors at the Laboratory decreased to the lowest total since 1960. This

was due primarily to a reduction in the number of postdoctoral Research Associates, which also reached a 12-year low. During the year 34 recent graduates began postdoctoral research investigations and 37 completed their terms. Of the latter, four were promoted to the regular staff.

In contrast to the decrease in the number of salaried appointments, the number of scientists and students holding nonsalaried appointments continued to increase. More than 800 individuals in this category participated intermittently for periods of up to several weeks at a time.

May 31, instead of June 30, was used in Table 1 to exclude from the statistics those who work at Brookhaven only during the summer months. The same date was used in Table 2 to include participants in only one summer program.

Table 1

Scientific Staff and Students on May 31, 1970 and 1969

	Regular staff		Visitors			
			Salaried		Nonsalaried	
	1970	1969	1970	1969	1970	1969
By appointment category						
Staff						
Senior Scientist	91	88	1	1	73	76
Scientist	200	189	5	7	151	160
Associate Scientist	134	139	4	5	201	198
Assistant Scientist	32	48	8	8	95	90
Senior Research Associate	—	—	5	4	1	—
Research Associate	—	—	59	67	100	93
Students						
Junior Research Associate	—	—	4	4	160	174
Research Assistant	—	—	0	0	105	131
Total	457	464	86	96	886 ^a	922 ^b
By academic degree						
Ph.D. or M.D.	325	333	78	89	600	584
Master	59	57	3	3	122	122
Bachelor	67	68	5	4	148	202
No degree	6	6	0	0	16	14

^a60 of these appointees were at BNL on a full-time basis as of May 31, 1970.

^b72 of these appointees were at BNL on a full-time basis as of May 31, 1969.

Table 2

Classification of Visiting Scientists and Students Participating in BNL Program
for One Month or More, June 1, 1969 - May 31, 1970

	Guests and salaried visitors				1969 Summer program		Totals	
	3 Months or more		Less than 3 months		Salaried	Guest	Individuals	Institutions
	Salaried	Guest	Salaried	Guest				
University staff	22	66	1	63	62	47	261	117
Thesis students	7	33	0	20	0	5	65	28
Student research assistants	6	22	1	9	108	55	201	94
Subtotal	35	121	2	92	170	107	527	170 different
Industry	1	5	0	1	0	1	8	8
Other institutions	10	24	2	8	8	7	59	34
Total	46	150	4	101	178	115	594	210 different

Table 2 lists the numbers of visiting scientists (salaried Research Associates excepted) and students who worked at the Laboratory for cumulative periods of one month or more. The total of 594 individuals compares with the all-time high of 644 reported two years ago.

Summer Program for 1970

Arrangements have been made for 266 visiting scientists and students to work at the Laboratory during the summer of 1970. Of this number, 138 are staff members of colleges, universities, and other institutions, and 128 are students.

Special groups include 76 undergraduate participants in the Laboratory's 19th annual summer student program, 15 Health Physics Fellows, 19 graduate students in the second Brookhaven summer school in theoretical elementary particle physics, two summer semester students in the Boston University-BNL Honors Program, and 26 participants in the BNL Summer Study on AGS Utilization.

Employment, Training, and Education

In February of fiscal 1970 the Laboratory was informed that its operating funds for fiscal 1971 would be reduced. This, coupled with marked increases in operating costs, necessitated a reduction in force which began in April.

Reductions among the staff categories were closely proportionate to the size of each category. The selection criteria used to effect the reduction

were chosen to maintain staff competence by retaining the best qualified employees on the basis of their prior service and work records. In all, 203 employees were scheduled for layoff. This number was reduced by 59 voluntary resignations during the layoff period and by the transfer of 19 employees to other positions within the Laboratory. As of June 30 the Laboratory work force, exclusive of guests, research collaborators, and temporary appointees, numbered 2943, a net loss of 318 employees during fiscal 1970 (see Table 3).

Training and educational activities at the Laboratory took on new dimensions with the introduction of two apprenticeship programs. These new programs are designed to upgrade unskilled employees in the craft and electronics fields. Six employees were selected to participate in the four-year Craft Apprentice Program, and six were selected for training in electronics under the Technician Apprentice Program. The two programs, which both commenced in September, involve on-the-job training and related formal instruction leading to qualification for journeyman positions at the Laboratory.

For the most part, programs dealing with the training of disadvantaged young people continued as in prior years. The High School Cooperative Education, College Work Study, and Brookhaven Semester programs provided on-the-job training and education for 94 young people during the year. The one distinct change in this area concerned the restructured Youth Opportunity Pro-

Table 3
Employment Statistics*

	June 30, 1970	June 30, 1969
Scientific staff**	511	545
Scientific		
professional staff	321	376
Nonscientific staff	2111	2340
Total	2943	3261

Turnover data	Number	1970 Annual rate (%)	Number	1969 Annual rate (%)
<u>Accessions</u>				
Scientific staff**	81	16	77	14
Scientific				
professional staff	34	11	30	8
Nonscientific staff	138	7	201	9
Total	253	9	308	9
<u>Separations</u>				
Scientific staff**	115	23	87	16
Scientific				
professional staff	89	28	47	13
Nonscientific staff	367	17	250	11
Total	571	19	384	12
<u>Net Accessions</u>				
Scientific staff**	-34	-7	-10	-2
Scientific				
professional staff	-55	-17	-17	-5
Nonscientific staff	-229	-11	-49	-2
Total	-318	-11	-76	-2

*Figures do not include 20 temporary summer non-student employees. Guests and temporary student employees are included in Table 2.

**Includes Research Associates and visitors.

gram, which was renamed the Youth on Campus Program.

After several years of participation in the Youth Opportunity Campaign, it became obvious that merely providing employment for disadvantaged young persons was more of an economic than a social contribution, and that vocational guidance and training were as essential to the improvement of their status as the opportunity to earn money. Equally obvious was the fact that placing the typically disadvantaged young person in an unfamiliar setting, with people with whom he had no

easy rapport, might counteract attempts at effective guidance and training.

Because of the conclusions drawn from these past experiences, the Laboratory expanded the scope of the program to include an educational process that would enable the participants to receive vocational guidance and to develop skills in a relaxed, informal atmosphere. To accomplish this, a short-term special staff consisting of a professional guidance and industrial arts teacher, a secretarial science teacher, and a vocational psychologist was recruited for the program.

Working closely with the supervisors of the young people, the staff formulated a program of special classes, individual counseling, and development of skills within the framework of actual job situations.

The program lasted 8 weeks, and for the 38 young people involved it proved to be a meaningful training experience. For the Laboratory, it was another significant stride forward in its affirmative action effort.

Labor Relations

The Laboratory negotiated two labor agreement during fiscal 1970. Early in July, negotiations were held with the International Brotherhood of Electrical Workers (IBEW) on the inclusion of ten telephone operators in the bargaining unit. The National Labor Relations Board had previously certified the IBEW to represent this group of employees.

New contract negotiations were commenced with the Oil, Chemical, and Atomic Workers Union. This union represents 21 employees in the Reactor Division and the Department of Applied Science. Initially, the Union announced that it was seeking a substantial wage increase and a new type of labor contract, presumably a one-year agreement to replace the existing open-end agreement. After lengthy negotiations, it was eventually agreed that the present contract would be continued. No wage increases were involved inasmuch as the resumed contract provided for merit raises on a basis similar to that for the nonunion technicians.

There were two cases brought before the National Labor Relations Board. One concerned a petition filed by the IBEW to represent 13 technicians in the Accelerator Department. After hearing arguments by both sides, the Board dismissed

the Union's petition on the grounds that the employee group sought was an "inappropriate unit."

The other NLRB case was an unfair labor practice charge filed by an employee who claimed he had been unjustly terminated because he refused to have his union dues checked off. The labor agreement covering this employee requires the Laboratory to terminate anyone who does not tender his dues. The NLBR found no basis for the employee's claim and dismissed the charge against the Laboratory.

There was one arbitration case during the year which was submitted by the IBEW. This case concerned an alleged contract violation in which the Laboratory promoted a better qualified employee over an employee with greater seniority. The arbitrator found no contract violation on the part of the Laboratory and allowed the promotion to stand.

Employee Services

There were no significant changes in benefits under the Group Insurance Program this year. However, the employees' share of the program's cost was lessened to some extent as a result of reductions in the medical insurance premiums. Since July this insurance has been provided at no cost to each individual employee, whether active or retired. Employees are still required to pay a premium for their dependents' medical insurance, except in the case of spouses who are eligible for Medicare.

Twenty-four employees reached age 65 and retired during the year. This was the largest number of retirements in Laboratory history. Twenty-year service awards were presented to 49 employees and ten-year service awards were given to 132.

PLANT ENGINEERING AND PLANNING

Plant Engineering and Planning has completed its third year as a department in its own right. During this year further restructuring has taken place to ensure the most efficient utilization of personnel remaining after force reductions. As now organized, the Department discharges its functional and professional responsibilities through staff planning, engineering, and administrative groups and four line operating divisions: Electrical, Mechanical Utilities, Architectural and Structural, and Site. Each operating division is vertically structured under a superintendent responsible for all functions, from concept through design,

construction, operation, maintenance, and repair. The Division Superintendents report functionally and administratively to the new Deputy Manager/Plant Engineer.

Administrative Staff

This group reports to the Department Manager and Deputy Manager on all matters affecting dollar amounts, work orders, and reports. The effort to utilize the 360 computer, with assistance from the Administrative Data Processing Group, has progressed during the year with the adoption of new accounting and reporting systems. A program for reporting maintenance, facility, and technical support backlogs has been devised in concert with Administrative Data Processing. A systematic planned maintenance schedule for all divisions is now in effect and will be a regularly reported program in fiscal 1971. The major operation and maintenance efforts of the Department accounted for by this group are summarized in Tables 4 and 5.

Engineering Staff

Projects initiated during fiscal 1970 amounted to \$785,000 under the General Plant Projects Program. There were about 100 of these additions to or modifications of facilities, as well as miscellaneous site improvements. A concerted effort was made during the year to eliminate fire and safety hazards as recommended by the AEC's Brookhaven Office and the Laboratory Safety Services Office. General plant projects exceeding \$50,000 included the fire protection system for the main control room of the Alternating Gradient Synchrotron (AGS); heating, ventilating, and air conditioning improvements at the Medical Research Center; building modifications, Plant Engineering and Planning; and building modifications for the PDP-10 computer, Department of Applied Science.

The Engineering Staff coordinates the issuance of accelerator and reactor additions and modifications (ARAM) program proposals, as well as the reporting of progress during construction. On a number of these projects the staff members administered the entire design and construction effort.

Early in 1970 the group began preparing the data sheets for the construction projects in the budget request for fiscal 1972. Work included site selection, preliminary building plans, cost estimates, and descriptions for the projects listed below (total estimated cost, \$10,000,000).

Table 4
Manpower Utilization

Type of work	Fiscal 1970		Fiscal 1969	
	Productive man-years	Percent of total work	Productive man-years	Percent of total work
Maintenance, repairs, and utilities operations	139	41.4	153	43.2
Major maintenance programs	2	0.6	—	—
Facility improvements	8	2.3	6	1.7
Research program support	99	29.5	105	29.7
Building janitor services	81	24.1	83	23.4
Decontamination	1	0.3	1	0.3
Hot Laundry operation	6	1.8	6	1.7
Total	336	100.0	354	100.0

Table 5
Costs of Supplies, Materials, and Contracts

	Fiscal 1970	Fiscal 1969
Maintenance and utilities materials	\$ 359,085	\$ 334,653
Major maintenance materials and contracts	180,250	144,960
Building janitor supplies	57,862	63,895
Decontamination	499	518
Hot Laundry	11,287	10,903
Fuel oil	461,977	421,644
Electricity	1,513,812	1,713,145
Total	\$2,584,772	\$2,689,718

Electron accelerator
Bio-medical conjunct facility
General plant projects, fiscal 1972

During fiscal 1970 the Engineering Staff continued to assist the Physics Department in delineating the scope of future large-scale bubble-chamber facilities and building construction. Assistance to the Accelerator Department continued in connection with the evaluation of Title II and Title III design for the AGS conversion. Two staff members have continued on a full-time basis to aid AGS personnel in the execution of the work.

Planning Staff

Long-term requirements of site engineering, operation, maintenance, and scientific program support continue to be investigated by this group. The computer model of the site water-distribution system has proved valuable in discovering deficiencies in volume, pressure, and quality. Enough information was generated by runs of this model

to allow engineering of corrective changes, which will be made in the future, and the presentation of a paper on this system to the American Society of Mechanical Engineers. An investigation of the site's present and future energy requirements continues.

PLANT PROTECTION AND SECURITY

The Plant Protection and Security Division continued to perform its assigned functions during fiscal 1970.

Although the scope of the Security function at the Laboratory has contracted substantially since Brookhaven's early days, the Laboratory continues to maintain an active security clearance program. At the end of fiscal 1970, about 325 employees and affiliates held active "Q" clearance, while more than 225 held active "L" clearance. These clearances are required in connection with classified documents at the Laboratory; they also ensure Brookhaven scientists and technical personnel full

access, when necessary, to classified data at the Laboratory and at other laboratories and institutions in the Atomic Energy Commission's complex.

The physical growth of the Laboratory and the expansion of its research programs have necessitated ever-increasing emphasis upon the Laboratory's plant protection program. Adaptation of industrial plant protection techniques and practices to the specialized requirements of Brookhaven has had gratifying results in effectiveness of operations and economy of manpower, particularly in the light of mandated personnel losses. The number of Laboratory employees, coupled with a substantial increase in the number of persons visiting the Laboratory, has given rise to automobile traffic and parking problems, which have been effectively resolved.

The Laboratory's professional Fire Group has maintained its excellent record in meeting potentially dangerous fire situations at the Laboratory. An active fire-inspection and fire-prevention program is a continuing and important aspect of the Fire Group's activities. Close liaison with scientific and technical personnel engaged in research experiments and other activities presenting potential fire hazards is regularly maintained, with excellent results. Fire-fighting equipment has been increased and modernized, mutual-aid fire-fighting agreements with nearby communities have been continued, and training of Fire Group personnel has been accelerated.

Responses to fire alarms during the past three fiscal years are tabulated below.

	1970	1969	1968
Responses on site	178	224	195
Responses off site	2	2	6
Investigations	48	43	60
Total	228	269	261

BUSINESS MANAGEMENT AND ADMINISTRATION

Purchasing

Much time was spent by the Purchasing Manager's Office during the year in two significant areas. The first was the publication of Chapter 9-59 of the AEC Procurement Manual. This chapter consolidates in one section of the manual all procurement regulations that are relevant to AEC prime contractors, such as Brookhaven. Many of the procedures in the Laboratory's Pur-

chasing Division Manual were revised to meet the intent of the revised regulations, most of which are mandatory under Federal statutes.

The other significant area is concerned with the Laboratory's Equal Employment Opportunity-Affirmative Action Compliance requirements and standards. The purpose of these requirements is to implement the Civil Rights Act of 1964 or Presidential Executive Order 11246 in securing the rights of minorities to work under government-funded contracts. These standards and requirements have been issued in the BNL Purchasing Division Manual.

Supply and Materiel

The establishment of nomenclature for the AGS groups has been completed and a catalogue compiled. This entire effort should be fully computerized by the end of September 1970.

The Property Management Section of the Supply and Materiel Division is now participating in the newly formed AEC Used Nuclear-Type Equipment Grant Program, which makes equipment that qualifies available to educational institutions for instructional purposes.

Property Management, in conjunction with the Fiscal Division and the Budget Office, has requested that the capitalization value of fixed assets be raised from the new \$100 figure to $\approx$ \$300 to \$500, depending upon AEC approval.

The Division is in the process of closing the two remaining outlying stockrooms. Of the two persons now assigned to these areas, one man will be servicing these two stockrooms daily, plus one additional area, which was closed previously. The other will be reassigned within the Division, where needed.

In addition, to achieve the most efficient utilization of manpower, the Division is making arrangements for all inventory "stock" materials to be delivered directly to the stockroom storing those items instead of first passing through the Receiving Section. In this way double handling will be eliminated.

Systems and Data Processing

During the past fiscal year the Systems and Data Processing Division has concentrated its efforts in three specific areas: (1) completion of outstanding conversion projects, (2) consolidation and reassessment of all computer processes, and (3) development of a totally integrated manage-

ment information system. These efforts, which are centered around a third-generation IBM 360 Model 30 computer, take into account the Division's long-range plans, as well as the more immediate management information requirements of the Laboratory.

Successful installation of a more detailed accounting and budget control system and a totally computer-oriented budget forecasting system highlighted the concluding stages of the Division's conversion efforts. The Univac SS/90 computer was classified "excess" in July 1969. The development of a standard input system has been one of the key factors in generating Laboratory-wide confidence in the Division's computer-generated products. The input system has made possible firm control over the quality of output for all areas of application, and its use has resulted in a marked improvement in accuracy and timeliness of output. During the entire conversion period the Division exercised extreme care in its attempts to incorporate tighter controls and sound business practices.

With this milestone passed, emphasis in the Division shifted to the development of an organized schedule of reassessments and consolidations. These postconversion objectives, which consider the more exact requirements of user groups, will enhance the effectiveness and efficiency of the services offered by the Division. Priorities in this area include the initiation of exception-process techniques that will highlight items of immediate concern coincident with a reduction in the number of computer products produced. This significant undertaking is being aided by the adoption of a new analytical reporting system that will provide the Division with an interpretative capability for all manpower and machine expenditures relevant to each computer system.

The acquisition of the IBM 2314 Direct Access Storage Facility enhanced the Division's plans for a communications-oriented Management Information System. This facility, with a storage capacity eight times that of the former configuration, will provide an immediate access capability of a broader data base for each existing system. Other tangible benefits relate to the operating environment. Less magnetic tape handling and less controlling, as well as a reduction in magnetic tape requirements, will be among the major advantages. Job setup time and operator intervention will be drastically reduced, which will lessen the work load of all day-to-day operations. Above all,

this facility provides a very real basic capability for the Division's realization of many new effective and efficient computer systems.

In fiscal 1970 the Division also satisfied over 175 requests from users for extensions and/or revisions to systems, programs, and operational practices.

Technical Photography and Graphic Arts

Throughout the year the Technical Photography and Graphic Arts Division has concentrated on finding new ways of providing the Laboratory with improved services. Technical personnel specializing in one field have been trained in new techniques, outside their specialty, to promote greater flexibility within the Division.

The acquisition of 3500 additional square feet of space has resulted in the expansion of the Quick Copy Service Center and the renovation of quarters to house chemical analysis equipment, optical test benches, a Calcomp-generated film processor, densitometers, a comparator, and other quality control instruments. More automated equipment was installed, including an additional stabilization processor which develops and fixes a photographic print in 23 seconds. Videotape equipment acquired during the year is being used to record lectures, seminars, and demonstrations, including the sessions of the six-week Summer School in Elementary Particle Physics held by the Physics Department in 1969.

While the AGS was shut down for conversion, the machines used to process bubble-chamber film were overhauled and modified by building additional automation into their chemical supply and storage systems. A semiautomatic roll paper printer-processor, used to produce multiple prints from the same negative, was also modified to increase its efficiency.

Some of the copying equipment was replaced with new machines that are 50% faster in operation and feature automatic feeding of originals, collating of copies, improved image quality, and lower cost per copy. Equipment that automatically inserts material into envelopes and seals them prior to postage metering was installed.

A retrieval system for photographic negatives was started with a library of negatives made during the period July 1967-January 1970. The library will be expanded by keeping it current and eventually including negatives from the years prior to July 1967. Another new technique developed during the year was that of photographing

the ocular fundus, in connection with a study at the Medical Research Center on the cause and control of hypertension. Patients were photographed at regular intervals, with both conventional and infrared color films, to record any changes in their condition. Graphic displays on the screen of the cathode tube of a Cal-comp electronic digital plotter were photographed and processed in a newly installed processor to a partial reversal. Film thus processed can be mounted and projected as slides or can be printed photographically without the need for an internegative. Almost all the graphical and tabular material for the Third Edition of BNL-400, *Angular Distributions in Neutron-Induced Reactions*, was reproduced by this technique, which resulted in the saving of several steps in the printing process.

STAFF SERVICES

The general level of activity in the Staff Services Division continued high during fiscal 1970. The Division provides the following services and assigned functions for the Laboratory staff and visitors: housing, travel, telecommunications, mail and wire service, transportation, motor vehicles, food services, and special staff services. All these activities continued essentially as before.

Completion of the rental rate survey of on-site housing, pursuant to Bureau of the Budget Circular No. A-45, resulted in increased rentals, effective Jan. 1.

The Travel Office processed 8040 trips, compared with 7940 during fiscal 1969.

A pool of 26 vehicles, two more than last year, is available on a trip basis for official business.

CONFERENCES, PUBLIC INFORMATION, AND EDUCATION

Four AUI Distinguished Lectures were held during the year. The first one was delivered on Oct. 2 by Professor Kenneth E. Moyer; the title of his lecture was "Some Implications of Recent Brain Research." The second was given on Nov. 12 by former Secretary of the Interior Stewart L. Udall, with the title "Agenda for Tomorrow." Dr. Alvin M. Weinberg, Director of Oak Ridge National Laboratory, gave the third lecture, entitled "National Environmental Laboratories?" on Feb. 26. The fourth lecture was delivered on

April 2 by Richard L. Garwin; his subject was "Strategic Arms Limitation."

A new Brookhaven Distinguished Lecture series was initiated by the AUI Trustees. In January, Professor Francis E. Low of MIT presented several lectures; in April, Professor T.D. Lee of Columbia University presented four seminars; and on April 19 Dr. John C. Kendrew of Cambridge University spoke.

The Laboratory cooperated with the State University of New York at Stony Brook on the Eighth International Congress of Crystallography, held at Stony Brook, Aug. 13-21. In conjunction with the congress, daily tours through BNL were organized for attendees. Many of the scientists at the congress also attended a topical meeting on Chemical and Physical Aspects of Neutron Diffraction, which was held at Brookhaven on Aug. 22 and 23.

A number of conferences and meetings took place during the year. The most important ones were: Seminar on Irradiator Source Activity Standardization, July 8-9; Affirmative Action Conference, July 24-25; Neutron Cross Section Working Group Meeting, Aug. 11-13; Meteorology AEC Review Committee and Program Leaders' Conference, Aug. 18-20; Third American Electromagnetic Isotope Separator Symposium, Sept. 16-17; Cross Section Evaluation Working Group Meeting, Sept. 24-26; Brookhaven Semester Conference, Oct. 9-10; Atmospheric Diagnostics Program Information Meeting, Oct. 16; Nuclear Materials Safeguards Committee Meeting, Jan. 23; Executive Committee of the Chemical Section of the National Safety Council, Feb. 10-11; AEC Advisory Panel on Accelerator Radiation Safety, March 17-18; Electrochemical Carbon Meter Meeting, March 23; Cross Section Evaluation Working Group Meeting, March 24-25; ASME Nuclear Codes and Standards Review Subcommittee Meeting, April 14; AEC Laboratories Wage and Salary Conference, April 23-24; Sixth Seminar on Medical Planning and Care in Radiation Accidents, April 26-29; AEC High Energy Program Review, May 13-14; AEC-Sponsored Cesium Discussion, May 19; Atomedic 1970, May 20-21; Members of Columbia University Medical Department and AEC, May 25-26.

On Oct. 7 and 8 a sample of lunar rock collected on the Apollo 11 flight was exhibited to about 2000 BNL employees. On Oct. 10 and 11 the same sample was on display to the general public and was seen by some 5000 persons.

The 16th High School Visitors' Day, held on Oct. 18, was attended by 5000 students from 199 schools. The 20th Visitors' Day was held on Oct. 25, with 4500 persons, including students from 22 colleges, in attendance. The 14th Science Youth Day commemorating Thomas Alva Edison's birthday was held on Feb. 11 and was attended by 123 students and 25 teachers from 30 Suffolk County high schools. The general topic for this program was "Biology Today."

In addition to 500 foreign individuals who visited the Laboratory during the year, nine foreign groups were received. One of these was a group of Ministers of Science that had been invited to witness the launching of Apollo 11 at Cape Kennedy. On their visit to BNL on July 14 they were accompanied by AEC Commissioner W.E. Johnson and several AEC staff members.

During the year 59 teachers attending two National Science Foundation teachers-in-training seminars were given talks on the Laboratory's research program and were shown the major facilities.

As in past years, many staff members delivered speeches to local civic, church, school, and other educational audiences. Nine lectures in the BNL Lecture Series were given by staff members, who discussed the various aspects of their research.

Three Brookhaven staff members were honored with important awards. Dr. George C. Cotzias, Head of the Medical Department's Physiology Division, was named winner of the 1969 Albert Lasker Award for clinical medical research, for his dramatic demonstration that large, daily dosages of L-dopa can reverse most of the crippling effects of Parkinsonism. Dr. Eugene P. Cronkite, Chairman of the Medical Department, received the 1969 Alfred Benzon Award for his work in hematology. Dr. Joseph M. Hendrie, Associate Head of the Engineering Division, Department of Applied Science, was named one of five recipients of the AEC's E.O. Lawrence Memorial Award for 1970. Dr. Hendrie's citation reads: "For his outstanding contributions to the physics and engineering of versatile research reactors, and for important contributions and recognized leadership in promoting the safety of large power reactors."

Appendix A

PUBLICATIONS, JULY 1, 1969 - JUNE 30, 1970

This list includes official Laboratory publications, abstracts of papers which were or will be presented at scientific meetings, and publications by staff members, consultants, and guests. All these listings result from work done at the Laboratory; they were submitted during the review period.* Abstracts are indicated by (A); letters to the editor, (L); and notes, (N). Acceptance for future publications is designated by (in press).

GENERAL PUBLICATIONS

Annual Report, July 1, 1969. BNL 50169 (AS-23).
Annual Report, Department of Applied Science, Dec. 31, 1969. BNL 50205 (S-72).

Conference Reports:

Brookhaven Symposia in Biology No. 22, Diversity and Stability in Ecological Systems. BNL 50175 (C-56).

Time and Dose Relationships in Radiation Biology as Applied to Radiotherapy, NCI-AEC Conference, Carmel, Calif., 1969. BNL 50203 (C-57).

Summer School in Elementary Particle Physics, Theories of Interactions at High Energies, July 22-Aug. 29, 1969, R.F. Peierls, Editor. BNL 50212 (C-58).

Brookhaven Lecture Series:

75. *The Molecular Basis for Enzyme Action: Current Views,* E. SHAW. BNL 50174 (T-533).

77. *The Small Distance Frontier,* G.B. COLLINS. BNL 50210 (T-556).

82. *Modern Alchemy With Accelerators,* J.B. CUMMING. BNL 50211 (T-557).

84. *Marked Money in the Carbohydrate-Fat Economy,* W.W. SHREEVE. BNL 50191 (T-544).

86. *The Slow External Beam at the Brookhaven AGS,* M.Q. BARTON. BNL 50225 (T-565).

High-Temperature Liquid-Metal Technology Review:

Vol. 7, No. 4, Aug. 1969. BNL 50204 (PR-40).

Vol. 7, No. 5, Oct. 1969. BNL 50215 (PR-41).

Vol. 7, No. 6, Dec. 1969. BNL 50223 (PR-42).

Vol. 8, No. 1, Feb. 1970. BNL 50236 (PR-43).

Vol. 8, No. 2, Apr. 1970. BNL 50248 (PR-44).

Vol. 8, No. 3, June 1970. BNL 50258 (PR-45).

Miscellaneous:

Angular Distributions in Neutron-Induced Reactions, Vol. 1, Z = 1 to 20, D.I. GARBER, L.G. STRÖMBERG, M.D. GOLDBERG, D.E. CULLEN, AND V.M. MAY. BNL 400, 3rd Ed., [EANDC(US)-138 "U"].

*Also included are those listings from the last annual report [BNL 50169 (AS-23)] for which complete reference information was not then available.

The Atmospheric Diagnostics Program at Brookhaven National Laboratory, Second Status Report, W.D. TUCKER, Editor. BNL 50206 (T-553).

Determination of Metallic and Non-Metallic Trace Impurities in Sodium Metal, C. AUERBACH, Editor. BNL 50229 (T-568).

Progress Report of the Sodium Technology Work Sponsored by the Division of Reactor Development and Technology, United States Atomic Energy Commission (Official Use Only):

Quarterly, July 1-Sept. 30, 1969. BNL 50207 (T-554).

Annual, Jan. 1-Dec. 31, 1969. BNL 50219 (T-561).

Quarterly, Jan. 1-March 31, 1970. BNL 50243 (T-578).

Weekly Bulletin 23, No. 5-52; 24, No. 1-4.

Weekly Selected Reading List 22, No. 8-52; 23, No. 1-6.

STAFF PUBLICATIONS AND ABSTRACTS

Accelerator Department

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ADAIR, R.K. - See also WANDERER, P. J. JR.

AGGUS, J., KEANE, J., AND GRAND, P. Linac tank installation and tune-up for 200-MeV linac. (A) Presented at National Accelerator Laboratory Conf. Proton Linear Accelerators, Batavia, Ill., Sept. 28-Oct. 2, 1970.

AGS STAFF, Performance of the slow external beam at the Brookhaven AGS. In *Proc. 7th Int. Conf. High Energy Accelerators, Yerevan, USSR, Aug. 27-Sept. 2, 1969* (in press).

AMARI, R. - See SLUYTERS, T. J. M.

ANKENBRANDT, C.M. - See WANDERER, P. J. JR.

BARON, A.I. AND VOGEL, U. A method for the calibration of pick-up electrodes. Submitted to *Rev. Sci. Instr.*

BARTON, M.Q. *The Slow External Beam at the Brookhaven AGS, Brookhaven Lecture Series No. 86, Sept. 24, 1969.* BNL 50225 (T-565).

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- BATCHELOR, K., BITTNER, J., CHASMAN, R., FEWELL, N., SLUYTERS, T., AND WITKOVER, R. Beam performance of the 10-MeV section of the 200-MeV linear accelerator at Brookhaven National Laboratory. (A) Presented at National Accelerator Laboratory Conf. Proton Linear Accelerators, Batavia, Ill., Sept. 28-Oct. 2, 1970.
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- SMITH, J. - See BROWN, R.W.
- SMOLUCHOWSKI, R. - See DIENES, G. J.
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- UTO, H. - See YUAN, L.C.L.
- VANDERBURG, V. - See KALBFLEISCH, G.; KIANG, R.; STRAND, R.C.
- VANNESTE, L. - See BRUNHART, G.; POSTMA, H.
- VINEYARD, G.H. - See WATSON, R.E.
- VON WITSCH, W. - See EMERSON, S.T.; FRIEDES, J.L.; SIMPSON, W.D.
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Aug.	1969	BNL 50192 (T-545)
Sept.	1969	BNL 50200 (T-550)
Oct.	1969	BNL 50202 (T-551)
Nov.	1969	BNL 50209 (T-555)
Dec.	1969	BNL 50214 (T-558)
Jan.	1970	BNL 50217 (T-559)
Feb.	1970	BNL 50222 (T-563)
Mar.	1970	BNL 50227 (T-566)
Apr.	1970	BNL 50234 (T-571)
May	1970	BNL 50240 (T-575)
June	1970	BNL 50247 (T-581)

Appendix B

OFFICERS AND SCIENTIFIC AND PROFESSIONAL STAFF

Maurice Goldhaber, *Director*
 George H. Vineyard, *Deputy Director*
 Victor P. Bond, *Associate Director*
 Rodney L. Cool, *Associate Director*
 R. Christian Anderson, *Assistant Director*
 William J. Catacosinos, *Assistant Director**
 Vincent R. O'Leary, *Assistant Director*
 Samuel M. Tucker, *Assistant Director*
 (retired June 30, 1970)
 Gerald C. Kinne, *Assistant to the Director*

G. Kenneth Green, *Chairman*, Accelerator Department
 Yoshio Shimamoto, *Chairman*, Applied Mathematics Department
 Warren E. Winsche, *Chairman*, Department of Applied Science
 Harold W. Siegelman, *Chairman*, Biology Department
 Gerhart Friedlander, *Chairman*, Chemistry Department
 Horner Kuper, *Chairman*, Instrumentation and Health Physics Department
 Eugene P. Cronkite, *Chairman*, Medical Department
 R. Ronald Rau, *Chairman*, Physics Department
 Irving J. Polk, *Head*, Mechanical Engineering Division
 Robert W. Powell, *Head*, Reactor Division

Henry C. Grahm, *Budget Officer*
 Lewis R. Burchill, *Controller*
 Dennis Puleston, *Information Officer*
 Charles F. Dunbar, *Legal Counsel*
 (retired December 31, 1969)
 N. Peter Rathvon, Jr., *Legal Counsel*
 Joseph S. Washburne, *Personnel Manager*
 Maxwell M. Small, *Manager*, Plant Engineering and Planning
 Norbert J. Dernbach, *Public Relations Officer*
 Edward J. Burke, *Security Officer*

Accelerator Department

G. Kenneth Green, *Chairman*
 Roger R. Adams
 Christopher Agritellis*
 Theodore Alper*
 Gregory P. Bagley
 David A. Barge*
 Mark Q. Barton
 Kenneth Batchelor
 Gerald W. Bennett
 Arnold Benton*
 David Berley
 Richard A. Beth
 John W. Bittner
 John P. Blewett

Leroy N. Blumberg
 Richard B. Britton
 Hugh N. Brown
 Theodore Carides*
 Renate W. Chasman
 Peter J. Clarke*
 Johannes Claus
 Jack A. Cockrill*
 George W. Cornish, Jr.
 James G. Cottingham
 Joseph A. Curtiss
 John J. Dabrowski
 Per Fridtjof Dahl
 Gordon T. Danby
 Donald A. Davis
 Edward W. Dexter
 Emory G. Egler
 Stephen E. Eiseman

Arnold V. Feltman
 Norman M. Fewell
 Horst W. J. Foelsche
 Eric B. Forsyth
 John D. Fox
 Robert S. Frankel
 Martin Fruitman
 John J. Gabusi
 William Gefers
 Salvatore T. Giordano
 Joseph W. Glenn, III
 Eileen C. Gran*
 David L. Greenberg
 Harald Hahn
 Henry J. Halama
 William E. Harrison, Jr.
 Frank G. Heimbürger
 John C. Herrera

*Terminated before July 1, 1970.

Garrett A. Hughes
 Robert S. Hulliger
 John W. Jackson
 David D. Jacobus
(retired February 16, 1970)
 Kurt Jellett
 Ralph R. Kassner
 John T. Keane
 Vincent J. Kovarik
 John H. Lancaster
 Ronald F. Lankshear
 Robert A. Larson
 Donald M. Lazarus
 Robert J. Lenuzza
 Gerald S. Levine
 Su Tang Lin
 Isador J. Livant
 Walter Livant*
 Robert E. Lockey
 Vincent S. LoGrasso
 Robert A. Loper
 Edward A. MacDougall
 Harvey McChesney, Jr.
 Austin J. McGearry
 Alfred D. McInturff
 Lowell McLean
 Andrew J. McNerney
 Peter A. Montemurro
 Melvin Month
 William H. Moore, Jr.
 Gerry H. Morgan
 Ronald J. Nawrocky
 Ernest Okress*
 Arthur N. Otis, Jr.
 George Parzen
 Jens C. Pettersen*
 Martin Plotkin
 Icarus E. Pyros
 Eugene C. Raka
 George Rakowsky
 Raymond H. Rheaume
 Alvin H. Rosenfeld
 William B. Sampson
 Ralph T. Sanders
 Joseph F. Sheehan, Jr.
 Theodorus J.M. Sluyters
 Lyle W. Smith
 Anastasios Soukas
 Joel W. Spinner*
 Julius Spiro
 Robert C. Talsma
 Frank J. Thornhill
 Timothy E. Toohig*
 Arthur Tranis
 Clarence M. Turner
 Arie van Steenberg
 Uriel Vogel*
 Ching Lin Wang
 Robert J. Warkentien
 Arnold R. Watts

*Terminated before July 1, 1970.

Irwin Weitman
 George W. Wheeler
 Richard L. Witkover
 Samuel P. Yamin*
(postdoctoral appointment)

Applied Mathematics Department

Yoshio Shimamoto, *Chairman*
 Barry S. Arbeit
 George A. Baker, Jr.
 Lydia Bargiuk
 Carmen M. Benkowitz
 Harold C. Berry
 Kenneth J. Brightman*
 Ludvik Burgar
 Graham H. Campbell
 Hong-bo Chiang
 Henry W. Davis
 John E. Denes
 John E. dePillis*
(on leave from Univ. of California)
 John W. Essam
(on leave from Westfield College, Hampstead, London, England)
 Jerry M. Friedman
 Kurt Fuchel
 Bernard D. Garfinkel
 Bernard D. Gaunt*
(on leave from King's College, Univ. of London, England)
 Michael D. Goldfarb*
 Charles I. Goldstein
 Arthur D.S. Harris
 Heinrich Heesch*
(on leave from Technische Hochschule, Hanover, West Germany)
 Sidney Heller
 Margaret F. Hind*
 Richard S. Horwitz
 Joseph Kahane*
 Anatoly Kandiew*
 Burton S. Kleinman*
 Leslie L. Lawrence
 Raymond E. Lawrence*
 Marc Leopold*
 Irwin Lewis
 Robert B. Marr
 Bruce A. Martin
 Noboru Nakanishi
(on leave from Kyoto Univ., Kyoto, Japan)
 Lorraine J. Osterer
 Larry S. Padwa
 Ilse H. Perlman*
 Arnold M. Peskin
 Clarence C. Pittenger
 Dysart A. Ravenhall
 Stuart S. Rideout
 Robert N. Salerno
 Niels F. Schumburg
 Arthur B. Scott
 Susan M. Sevia

Sharon Spark
 Colin D. Stewart
 Morris M. Strongson
 Melvin Tainiter
 James K. Thurber*
 Ralph A. Trondle
 Carol A. Wawrzusin*
 Robert H. Whisker

Department of Applied Science

Warren E. Winsche, *Chairman*
 Anthony Adin*
 George Adler
 Arnold L. Aronson
 Clemens Auerbach
 Allan Auskern
 David S. Ballantine*
 Charles B. Bartlett*
 Helen B. Bauman*
 Mendel Beer*
 Morris Beller
 Mulki R. Bhat
 Fritz Bloch
 John S. Bookless
 Joseph S. Bryner*
 William J. Cahill*
 Albert W. Castleman, Jr.
 John Chen
 Jack Chernick
 Joe G.Y. Chow
 Peter Colombo
 John F. Conant*
 Robert W. Conn
(postdoctoral appointment)
 Helen R. Connell
 Anita J. Court*
 Dermott E. Cullen
 John H. Cusack
 David J. Diamond
 Joan M. Dickey*
 Russell N. Dietz
 Robert F. Doering
 Roy F. Domish
 John J. Dorning, Jr.
 Kenneth W. Downes*
 Raymond F. Drager*
 Marvin K. Drake
 Orrington E. Dwyer
 Horoshi Ebihara
(on leave from Japan Atomic Energy Research Institute, Ibaraki)
 William C. Eckelman
 James J. Egan
 Lester G. Epel
 Jack Fajer
 Peter T. Fallon
 Helen H. Farrell
 Stephen W. Feldberg
 Albert H. Fleitman
 Jack J. Fontana
 Joseph Forrest

Bernard R. Fox*
 Leonard Galanter
 James M. Galligan
 Donald I. Garber
 Meyer Garber
 Jacob Gilat*
*(on leave from
 Israel Atomic Energy Commission, Yavne)*
 Althea Glines
 Norman N. Gold*
 Murrey D. Goldberg
 Rubin Goldstein
 Robert W. Goodrich
 Barry M. Gordon
 Leon Green
 Margaret W. Greene
 David H. Gurinsky
 Loranus P. Hatch
(retired June 30, 1970)
 Michael A. Helfant*
 Joseph M. Hendrie
 Raymond J. Heus
 William A. Higinbotham
 Frank B. Hill
 Manny Hillman
 Peter J. Hlavac
 Michael Hobdell*
(postdoctoral appointment)
 Frederick L. Horn
 William H. Horn
 Chia-Jung Hsu
 Peter Hubberstey
(postdoctoral appointment)
 Hugh S. Isaacs
 Robert J. Isler
 Ljebomir M. Jetic*
(postdoctoral appointment)
 Carl L. Johnson
 Richard Johnson*
 Sheldon Kalish
 Otto F. Kammerer
 Mary T. Kinsley
 George Kissel
 Carl J. Klamut
 Paul J. Klotz
 Herbert J.C. Kouts
 Theodore J. Kreiger
 William H. Kropp
 Lawrence E. Kukacka, Jr.
 Michael J. Lancefield*
(postdoctoral appointment)
 Daniel F. Leahy
 Elliot Lebowitz
 Gerald S. Lellouche
 Melvin M. Levine
 George C. Lindauer
 Hans Ludewig
 Donald R. MacKenzie
 Gerald A. Macri
(postdoctoral appointment)

Benjamin Magurno
 Bernard Manowitz
 George Markovits
(postdoctoral appointment)
 William Marcuse
 Victoria L. May
 James J. McNicholas*
 George E. Meinken
 Donald J. Metz
 Paul A. Michael
 Julius Milau
 Francis T. Miles
 Bertram Minushkin
 Sophie O. Moore*
 Said F. Mughabghab
 Anil K. Mukherji*
(on leave from Drexel Inst. of Technology)
 Albert C. Muller
 Leonard Newman
 Odelli Ozer
 Philip F. Palmedo
 Raymond J. Parsick
 Sol Pearlstein
 James P. Phelps*
 James R. Powell, Jr.
 Thomas F. Prach
 Glenn A. Price
 Augustus Prince
 Jacob Pruzansky
 Surendra N. Purohoit
 Chad J. Raseman
 James J. Reilly, Jr.
 Powell Richards
 Francis X. Rizzo
 Anthony Romano
 Wolfgang Rothenstein*
*(on leave from Technion,
 Israel Inst. of Technology, Haifa)*
 Alexander Sabosto*
 Jerome Sadofsky*
 Francis J. Salzano
 César A. Sastre
 Clifford H. Scarlett
 Donald G. Schweitzer
 Thomas V. Sheehan
 Louis M. Shotkin
 Robert M. Singer
 Peter Soo*
 Louis G. Stang, Jr.
 John R. Stehn
 Meyer Steinberg
 Thomas E. Stephenson
 Gerald Strickland
 Nils L.G. Strömberg*
*(on leave from Research Inst.
 of National Defense, Stockholm)*
 Sylvester C. Suda
 Masaki Suenaga
 Herbert Susskind
 James W. Sutherland
 Hiroshi Takahashi
 Ignatius Ning-Bang Tang

Silvio J. Tassinari
 Richard S. Thompson*
 Richard J. Tivers
 Walter D. Tucker
 William J. Tunney*
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 Stephen J. Wachtel*
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 Charles H. Waide
 Stanley Weber*
 John R. Weeks
 Eugene V. Weinstock
 Allen J. Weiss
 Jerome Weiss
 George G. Weth*
 Robert G. Wilson
 Virginia H. Wilson
 John K. Wilmshurst
 Henry H. Windsor*
 Edward Wirsing, Jr.
 Richard H. Wiswall, Jr.
 Wen-Shi Yu
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