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Annual Report

July 1, 1967

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 eighteenth in a series of unclassified Annual Reports, gives an account of the progress of the Laboratory during the period July 1, 1966 - June 30, 1967, 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.

Previous reports in this series are:

BNL 74 (AS-4) July 1, 1950
BNL 131 (AS-5) July 1, 1951
BNL 196 (AS-6) July 1, 1952
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
BNL 994 (AS-20) July 1, 1966

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Printed in the United States of America

Available from

Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151

Price: Printed Copy \$3.00; Microfiche \$0.65

November 1967

2500 copies

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ORGANIZATION CHART
JULY 1, 1967

THE NUMBER OF EMPLOYEES IN EACH ORGANIZATIONAL UNIT ON JULY 1, 1967 IS SHOWN. TOTAL FOR THE LABORATORY, 3341.

The new Chemistry Building. In the background are the reactor stack and the domed containment vessel for the High Flux Beam Research Reactor.

AEC Chairman Glenn T. Seaborg (right), who gave the keynote speech at the dedication on October 14 of the new Chemistry Building, with Dr. Richard W. Dodson (left), Chairman of BNL's Chemistry Department, and Dr. Maurice Goldhaber, Director, Brookhaven National Laboratory.

Introduction

The program and activities of Brookhaven National Laboratory during the fiscal year 1967 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 3-BeV Cosmotron and 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 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 and Puerto Rico and participation in the "Atoms for Peace" traveling AEC nuclear energy exhibits in Europe, Asia, and South America.

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-BeV proton synchrotron (the world's most powerful operating particle accelerator), continues to be one of the major centers for research in high energy physics. The machine, which is operated on a schedule of 21 8-hr shifts per week, was available for a total of 5465 hr during fiscal 1967. Of this time, 66% was used for research. Machine improvements resulted in increased beam intensity; peak intensities of 1.6 to 1.8×10^{12} protons/pulse can now be obtained regularly. As a consequence, weekly average intensities of $> 1.3 \times 10^{12}$ are common. This compares with an average of $> 10^{12}$ for the previous year.

The AGS conversion program was funded by Congress this year in the amount of \$47.8 million, and authorization to commit funds for equipment was received in February. This program is designed to increase the AGS beam intensity to 10^{13} protons/pulse, increase the cycling rate to 1 cycle/sec, reduce radiation damage to components, and provide increased experimental facilities. The additions and modifications to the machine under this program include construction of a 200-MeV proton linac injector, doubling the capacity of the main magnet power supply, installation of a new synchrotron vacuum chamber and pumping system, a new external beam, and an addition to the East Experimental Building.

A complete report on the AGS will be found in the section on High Energy Accelerators.

Cosmotron

In accordance with instructions from the AEC, operation of the Cosmotron was reduced from 21 to 15 shifts per week at the beginning of the fiscal year. At 0700 hr on December 31, operations ceased as directed. During the 6-month operating period there were 3084 potential operating hours. For short periods 3-BeV operation at 10×10^{11} protons/pulse was obtained. An average intensity of about 8×10^{11} was attained toward the end of the calendar year.

Sir Isaiah Berlin on the platform prior to delivering the fourth AUI Distinguished Lecture on April 3. The subject of Sir Isaiah's lecture was "Irrationalism."

Forest dispersion and deposition grid installed by Brookhaven meteorologists in a heavily wooded section of the Laboratory site. In studies to determine the behavior of pollen and other tracer particles in a forested area, particles released from the fenced field in the foreground are detected by particle sampling equipment on the towers. These towers also support meteorological recording instruments.

Staff member observing the gait of a patient receiving treatment for Parkinson's disease at the Medical Department, where scientists are conducting research on the metabolism of trace metals and its relationships to extra-pyramidal diseases.

Mr. Erwin D. Canham, Editor-in-Chief of the *Christian Science Monitor*, delivering the third AUI Distinguished Lecture on January 23. His subject was "The Future of the Printed Word."

The Medical Department's new low-level whole-body counting facility. A nurse simulates a patient in the multi-crystal whole-body counting and gamma-ray scanning spectrometer system. Two banks of 27 sodium iodide crystals, one above and one below the patient, are used.

Installation at the west face of the Brookhaven Graphite Research Reactor of one of the containment vessels for the out-of-pile section of the Chemonuclear In-Pile Research Loop. The chemonuclear program at Brookhaven involves basic and applied research and general development of the use of reactor radiation in the synthesis and production of industrial chemicals.

Control panel of the Chemonuclear In-Pile Research Loop.

Effective January 1, the synchrotron was placed on standby, pending decision on its eventual disposition. The Van de Graaff injector is being converted from pulsed to dc operation for use in a biomedical research program. Additional information on the Cosmotron is given in the section on High Energy Accelerators.

ions, such as carbon and nitrogen, can be accelerated. A flexible target arrangement and beam transport system is also being developed.

Electrostatic Generator

The electrostatic generator accelerates protons, deuterons, and He^3 and He^4 ions with beam cur-

Physicist at the High Flux Beam Research Reactor, studying atomic vibrational spectra in a crystal as a function of temperature by neutron scattering techniques. The furnace (middle left) is designed to reach 2000°C (3600°F) and can be controlled precisely at any temperature in this range. A beam of neutrons from the reactor (background, left) passes through the thin steel window of the furnace and strikes the specimen. The neutron may gain or lose energy in the scattering process. The energy exchange takes place in definite steps which depend upon the normal modes of vibration of the constituent atoms in the crystal lattice. The changes in energy are analyzed by angular measurements made with the large detector in the foreground.

60-in. Cyclotron

In October 1965, the 60-in. cyclotron was shut down for conversion to sector-focusing, variable-energy operation. The necessary modifications are now being effected. When completed, the machine will provide a maximum proton energy of 40 MeV, a deuteron energy of 20 MeV, a He^4 energy of 40 MeV, and a He^3 energy of 60 MeV. The energy will be smoothly and continuously variable down to $\approx 1/10$ of the maximum energy. Heavier

rents up to $75\ \mu\text{A}$ and energies up to 4 MeV. Modifications of the machine currently in progress will permit, in addition, the acceleration of tritium (He^3) ions. Further improvements include a completely new and more versatile beam transport system; this is nearing completion. Construction of a new terminal-beam analyzing system, to provide doubly charged helium ions of substantially improved purity and intensity, is also in progress. With these improvements and recent advances in particle and gamma-ray detection systems and in

data-handling systems, this accelerator is expected to continue as a source of new data on the properties of light- and medium-weight nuclei for a number of years to come. During the past year the machine was operated for research during 609 8-hr shifts. Fast-neutron irradiations for a university group doing collaborative research with the Brook-

This reactor, designed at BNL to meet experimenters' needs for higher neutron fluxes, has a compact core of 28 ETR-type enriched-uranium fuel elements cooled, moderated, and reflected by heavy water. Sixteen experimental facilities are provided; nine of these convey beams of neutrons outside the reactor, and seven allow materials to

Low-level counting facility in the Chemistry Department, used to determine the radioactivity induced in naturally occurring materials from terrestrial and extraterrestrial sources. The facility consists of a 1-ft-thick iron shield containing a particle detection system that can cancel out the major effect of the cosmic-ray activity at the earth's surface and thus produce a background environment sufficiently low to permit the detection and determination of the weak sources of radioactivity induced in naturally occurring materials.

haven Medical Department accounted for 1.2% of the time. The remainder was used for physics research carried out by scientists from Brookhaven and several outside institutions.

High Flux Beam Research Reactor

The High Flux Beam Research Reactor (HFBR), which achieved initial criticality on October 31, 1965, and attained its full design power of 40 MW on February 6, 1966, has now produced 10,320 MWD of energy, 8854 MWD of this total having been produced during fiscal 1967.

be irradiated inside the reactor. Research work has continued to increase at these facilities, particularly at the horizontal beam holes. Additional information on the HFBR may be found in the section on Technical Operations and Services.

Graphite Research Reactor

The Brookhaven Graphite Research Reactor (BGRR), which has been in almost continuous operation since 1950, was operated on a 15-shift per week basis during the year, which reduced the duty cycle of the reactor to 55%. In spite of this re-

duction, dictated by economic factors, the dependability of the facility remained high, with the reactor on line at rated power (20 MW) 98.7% of scheduled operating time. The maximum thermal neutron flux available is $\approx 2 \times 10^{13}$ neutrons/cm²-sec. The reactor loading remained at 615 channels during the year. The annealing procedure to repair radiation damage to the graphite was carried out seven times. This program continues to produce favorable results, as indicated by the periodic measurements of net vertical displacement of the structure and of the width of the central air gap.

The over-all cost of operating the BGRR dropped during the year, as a result of the reduction in duty cycle. A further reduction is scheduled for fiscal 1968. A complete report on the BGRR is given in the section on Technical Operations and Services.

Scene in the Physics Department. A germanium crystal is being distorted to disrupt its structure in a controlled way. The semiconductor germanium, because of its crystal structure, possesses certain advantages as a neutron monochromator. The crystals in their "as received" condition have a structure so perfect that they are useless for many experiments. In the operation shown here, the crystal is heated in a neutral atmosphere to a temperature of about 800°C and is pressed until the desired degree of distortion is reached. Time, temperature, and pressure have all been found to be important parameters.

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. Each salient feature of the reactor was planned in relation to its use for therapy and diagnosis or in the advancement of basic medical science. Operation is on an intermittent basis because of the nature of the research programs. Operating power levels up to 3 MW have been approved for continuous operation, and levels up to 5 MW are permitted for intermittent periods not to exceed 10 minutes. During the year the MRR was operated on 172 occasions. The total integrated energy produced to date is 3,813,403 kWh. Further details on the MRR are included in the section on Technical Operations and Services.

Hot Laboratory

The Hot Laboratory, which is adjacent to the BGRR, contains extensive facilities for the processing, handling, and analysis of highly radioactive materials. It includes three hot cells in which chemical operations can be performed remotely while being observed by periscope, a large hot cell for complete physical examination of radioactive metals and other materials, and several totally sealed systems, some of which are shielded, for working with alpha emitters alone or accompanied by gamma radiation.

Critical Assembly Laboratory

The Critical Assembly Laboratory provides specialized facilities for research in reactor physics and for reactor development studies. These facilities consist of five assembly cells and their associated control areas, a counting room, two uranium storage vaults, an electronics shop, a machine shop, and an analogue computer and two digital computers used for on-line processing as well as for standard data reduction. At present, two cells contain neutron source reactors, and fast reactor critical experiments are being assembled in two others.

High Intensity Radiation Development Laboratory

The primary function of the High Intensity Radiation Development Laboratory (HIRDL) is to obtain engineering data on a variety of radia-

A summer student in the Biology Department preparing a thin-layer chromatogram for separating algal bile pigments.

Beta-ray spectrometer in the Chemistry Department, used for accurately measuring intensities and energies of the monoenergetic groups of electrons emitted by many radioactive nuclei. An adjustment is being made at the electron detector, located at a focal position of the instrument. Across the cylindrical magnet, at a second focal position, the radioactive source is placed, in the form of a very thin deposit. Detailed information about the excited states of nuclei is obtained from these measurements.

A portable, trailer-mounted food irradiator, loaded and tested at BNL's High Intensity Radiation Development Laboratory, being prepared for visits to New England and other areas in a demonstration program. The entire irradiator, which has a 190,000-curie source of Cs^{137} , weighs 40,500 lb. The trailer is 35 ft long and 8 ft wide and is built of aluminum and steel. This irradiator has had many test runs at BNL with grain, mushrooms, and other foods.

Basement of the Biology Department's Controlled Environment Facility for Radiobotany, completed in 1965. Plants are arranged at varying distances from a 12,000-curie source of Cs^{137} , which bombards the plants with gamma rays for 20 hr/day. While personnel are in this shielded room, the source is lowered into a shielded container below the floor. This chamber and five similar ones are equipped with fluorescent lamps that can provide varying light intensities for any desired day length. Humidity and temperature can also be controlled.

Experimental setup in the East Experimental Area at the AGS for measuring high energy meson-proton inelastic scattering. This view, taken looking toward the accelerator, shows the beam transport and analyzing equipment. In the foreground are four of the wire spark chambers and two deflecting magnets.

tion 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. The main design features of HIRDL are two unique cells, one an irradiation cell for the experimental work with radiation sources, and the other a work preparation cell in which various types of sources are prepared. The laboratory is equipped to handle up to two million curies of radiation sources at one time. During the fiscal year almost one million curies of Co^{60} and Cs^{137} were received at HIRDL and made available for research at Brookhaven and elsewhere. In addition, a third shipboard irradiator was loaded with 42,000 curies of Co^{60} for use in the preservation of fishery products in Gulf of Mexico waters. Additional information on the HIRDL is given in the section on Nuclear Engineering.

80-in. Liquid Hydrogen Bubble Chamber

During the year the 80-in. liquid hydrogen bubble chamber, located in the North Experimental Area of the AGS, produced 1.81 million photographs, compared with 1.47 million in the previous year. This bubble chamber, the largest in the world, has an effective volume of 850 liters. It is positioned inside a vacuum chamber; a magnet capable of producing magnetic fields as high as 20,000 gauss with its 280-ton steel yoke completes the assembly, which is constructed in two units that separate to give access to the chamber. The entire 450-ton chamber and magnet assembly rides on an undercarriage and can be translated, rotated, and elevated as required by the experimental program. The flexibility of the chamber as an experimental tool was increased during the year by the use of two liquids other than hydrogen as chamber fillings. One such filling was deuterium, the other was a mixture of 50 atomic % neon and 50 atomic % hydrogen. More information on the 80-in. chamber may be found in the section on Physics.

Central Scientific Computing Facility

By the end of fiscal 1967, the Central Scientific Computing Facility consisted of three major large-scale computers, an IBM 7094 and two CDC 6600's, and two smaller support computers, an IBM 1401 and a CDC 924. The IBM 1401 was

acquired in July, 1966; the second CDC 6600 was accepted and put into operation in May, 1967. A one-million-word extended core storage unit, which is to be shared by the two CDC 6600 computers, is scheduled for delivery in 1968.

The IBM 7094 computer was operated for 21 shifts per week throughout the year and was used to its full capacity. Since a CDC 6600 was available, IBM 7094 usage was confined to existing production programs and on-line processings of bubble-chamber film data. Many production programs were converted to the CDC 6600, which made possible a significant increase in the amount of IBM 7094 time devoted to bubble-chamber data. CDC 6600 operation was scheduled for 15 shifts per week throughout the year, with the second computer taking the workload in June while the first was removed from service for engineering modifications. Further information on the Laboratory's computer program is contained in the section on Applied Mathematics.

MAJOR RESEARCH FACILITIES UNDER DESIGN AND CONSTRUCTION

Tandem Van de Graaff Accelerator

Work on the new Tandem Van de Graaff accelerator facility is proceeding. The High Voltage Engineering Corporation, under a contract awarded by the AEC in March 1965, is progressing satisfactorily in the manufacture of the two model MP Tandem Van de Graaff accelerators. These two accelerators will be used jointly in 3-stage operation or separately as two independent 2-stage accelerators. Singly charged particle energies will range from 2 to 20 MeV for each accelerator in 2-stage operation. Three-stage operation is expected to produce singly charged particles up to 30 MeV with an energy spread $\leq \pm 2$ keV. Multiply charged heavy ions with energies of hundreds of MeV will be available in either mode of operation.

Research programs at this new facility will emphasize the study of nuclear structure over the entire energy range made available through 3-stage operation of the two accelerators. Initially, these programs will be expansions of the existing experimental programs at the cyclotron and the small Van de Graaff accelerators. In preparation for the forthcoming operations of the facility, work is now proceeding on a computerized data acquisi-

First-floor plan of the Tandem Van de Graaff Building, showing the arrangement of the accelerators, target rooms, control room, and other areas.

The Tandem Van de Graaff accelerator facility under construction. The two accelerator tanks are being assembled outside the building. When completed, they will be moved into the building to the positions shown in the plan drawing. The completed walls of target rooms Nos. 4, 3, and 2 are at left center.

Dr. T. Keith Glennan (left), President of AUI, Dr. Maurice Goldhaber (center), Director of BNL, and Mr. Donald Moore, Director of Engineering and Construction, Brookhaven Office of the US AEC, during the ground-breaking ceremony on July 14, 1966, for the Lecture Hall-Cafeteria.

Construction progress on the new Lecture Hall-Cafeteria in mid-1967.

Scientific staff and students.

tion and analysis facility, a high-resolution magnetic spectrometer, scattering chambers, and other experimental apparatus necessary for use in the Tandem Van de Graaff research programs.

Prominent features of the physical layout of the Tandem Van de Graaff facility are the two accelerator rooms, the control room, and the four experimental target rooms. Each target room will contain a multiplicity of separate beam lines. The current state of construction is shown in the accompanying photograph. The two accelerator tanks, the north wall of accelerator rooms Nos. 1 and 2, and parts of target rooms Nos. 3 and 4 can be seen. Construction of the building should be completed in the summer of 1968, followed by installation and testing of the accelerators. Final completion of the facility is expected in 1970.

GENERAL CONSTRUCTION PROGRAM

During the year, construction was completed on the low-level counting facility for clinical research in the Medical Department.

On July 14 ground was broken for the construction of a new Lecture Hall-Cafeteria building. This facility will have a gross area of 51,000 sq ft and will contain a 750-seat cafeteria, a 450-seat lecture hall, and four meeting rooms for small groups. Completion is expected early in 1968.

In the AGS conversion program, now funded by Congress, extensive design work has been initiated, and construction of several new facilities will begin late in 1967. In the meantime, other im-

provements designed to increase the effectiveness of this accelerator as an experimental tool, including external beam equipment and additional shielding, have been completed. An addition to the AGS Service Building is expected to be ready for occupancy early in 1968.

More than 50% of the construction work on new animal laboratories for the Medical Research Center was completed by the end of the fiscal year.

Detailed planning for the laboratories and facilities required to meet Brookhaven's future needs continued. Included are the Applied Science Building (Phase II), 14-ft cryogenic bubble chamber, the Technical Services Building, the electron accelerator, and the Molecular Biology Building. A continuation of this construction program will be requested so that the Laboratory's function as a research center can be efficiently and economically fulfilled.

PERSONNEL

The total number of employees at the Laboratory on June 30, 1967, excluding temporary appointees, Research Collaborators, and guests, was 3333, a net decrease of 10 from the 1966 figure. During the year the regular scientific staff (Ph.D. or equivalent) increased from 442 to 464, Research Associates* increased from 79 to 82, and salaried visitors* decreased from 36 to 27, for a total increase in the salaried staff from 557 to 573. The

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

OPERATING COST DISTRIBUTION BY PROGRAMS

FISCAL YEAR	PHYSICAL SCIENCES	REACTOR DEVELOPMENT	LIFE SCIENCES	ISOTOPE DEVELOPMENT	TRAINING & EDUCATION	OTHER (NET)	TOTAL COST
1967	33,584,030	5,947,334	7,258,843	1,212,747	288,148	1,226,859	49,517,961
1966	32,708,048	6,086,937	7,015,987	1,073,696	311,476	1,019,818	48,215,962
1965	30,233,277	5,718,931	6,593,700	990,596	175,167	1,137,073	44,848,744

MAJOR CATEGORIES OF OPERATING EXPENDITURES

FISCAL YEAR	SALARIES & WAGES	MATERIALS & SUPPLIES SUBCONTRACTS, TRAVEL & SPECIAL PROCUREMENTS	POWER	MISCELLANEOUS (NET)	OPERATING TOTAL
1967	34,748,253	10,902,767	1,838,203	2,028,738	49,517,961
1966	33,738,859	11,409,512	1,756,098	1,311,493	48,215,962
1965	30,796,939	10,999,750	1,627,532	1,424,523	44,848,744

BROOKHAVEN NATIONAL LABORATORY COMPARATIVE BALANCE SHEET

	June 30, 1967	June 30, 1966
Assets		
Cash	\$ 153,560	\$ 130,816
Accounts receivable	173,266	213,932
Advances, deposits, and prepaid expenses	82,154	107,425
Property, plant, and equipment (less reserves of \$80,202,277 at June 30, 1967, and \$69,860,728 at June 30, 1966)	155,853,029	150,273,220
Research materials and supplies	16,924,766	16,523,161
Total assets	\$173,186,775	\$167,248,554
Liabilities		
Accounts payable	\$ 6,964,582	\$ 6,838,073
Accrued vacation	3,031,150	2,774,739
Accrued payroll	249,059	200,544
Atomic Energy Commission	162,941,984	157,435,198
Total liabilities	\$173,186,775	\$167,248,554

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

Table 1
Organizational Expenditures - Fiscal 1965, 1966, 1967
(Includes Operating, Services to Fixed Assets, and Work for Others. Direct Costs of AGS and Other Fixed Assets and Additions to Inventory Are Not Included; See Tables 3 & 4)

		Salaries, Wages, Insurance			Material & Supplies	Sub- contracts & Special Procure- ments	Power	Miscel- laneous (Net)	Total Organi- zational Costs	% of Total	Man-Years		
		Staff	Consultants & Temporary Employees	Travel							Scientific & Professional (Incl. Guests)	Others	Total
Physics & Chemistry Research	1967	12,434,752	339,688	306,478	5,532,594	56,791	1,021,453	(292)	19,691,464	39.8	458.5	692.0	1,150.5
	1966	12,367,282	362,908	254,588	4,985,265	262,374	1,017,826	—	19,250,243	39.9	464.5	715.0	1,179.5
	1965	11,010,475	295,793	242,426	4,683,212	538,199	913,617	—	17,683,722	39.4	451.0	695.5	1,146.5
Biology, Medicine, & Biophysics Research	1967	3,617,806	83,239	87,497	919,378	9,720	—	(8,916)	4,708,724	9.5	178.0	211.5	389.5
	1966	3,506,238	92,791	83,864	948,628	—	—	(8,370)	4,623,151	9.6	167.0	213.0	380.0
	1965	3,265,790	100,745	72,087	817,344	(6)	—	(5,148)	4,250,812	9.5	162.5	226.0	388.5
Nuclear Engineering Research	1967	3,135,171	54,445	106,819	990,785	125,458	—	—	4,412,768	8.9	131.0	114.5	245.5
	1966	3,206,125	64,049	83,464	926,343	314,955	—	—	4,594,936	9.5	147.0	134.5	281.5
	1965	3,142,496	72,366	85,836	981,571	444,813	—	—	4,727,082	10.5	144.0	141.5	285.5
Civilian Applications of Isotopes	1967	453,923	11,388	25,769	262,815	—	—	—	753,895	1.5	21.0	18.5	39.5
	1966	484,288	7,898	12,536	171,876	27,003	—	—	703,601	1.5	21.5	20.5	42.0
	1965	460,158	18,555	12,586	144,310	149	—	—	635,758	1.4	23.0	20.5	43.5
Training & Education	1967	36,496	149,780	13,218	8,631	—	—	—	208,125	0.4	1.0	30.0	31.0
	1966	34,688	121,977	20,089	13,199	24,082	—	—	214,035	0.4	1.0	21.5	22.5
	1965	39,343	58,643	16,342	9,127	1,219	—	—	124,674	0.3	2.0	14.5	16.5
Radiation Protection	1967	729,733	2,791	7,085	88,231	—	—	—	827,840	1.7	15.0	58.0	73.0
	1966	707,546	3,019	6,072	94,270	—	—	—	810,907	1.7	15.0	58.0	73.0
	1965	607,685	1,487	4,054	108,595	—	—	(745)	721,076	1.6	12.5	57.0	69.5
Supporting Scientific & Technical Services	1967	6,404,080	17,768	37,617	903,907	547,356	244,145	(150)	8,154,723	16.5	107.5	484.0	591.5
	1966	5,900,411	6,847	43,013	963,274	676,989	234,858	(4,251)	7,821,141	13.4	92.5	471.5	564.0
	1965	5,249,222	24,748	30,439	1,086,741	487,531	228,284	(126,919)	6,980,046	15.6	84.5	447.5	532.0
Plant Protection & Security	1967	730,228	606	2,453	12,975	—	—	4,160	750,422	1.5	—	78.5	78.5
	1966	682,006	—	2,421	15,850	—	—	3,010	703,287	1.5	—	75.5	75.5
	1965	650,329	—	1,964	15,881	—	—	3,118	671,292	1.5	—	75.0	75.0
Miscellaneous (including Lighting, T & T, Heating Fuels, Special Maintenance, etc.)	1967	—	—	—	60,683	—	572,605	976,508	1,609,796	3.3	—	—	—
	1966	—	—	582	86,357	(469)	503,414	947,754	1,537,638	3.2	—	—	—
	1965	—	—	2,228	123,025	(8,419)	485,631	938,318	1,540,783	3.4	—	—	—
General and Administrative	1967	6,461,875	84,484	83,498	613,910	99,009	—	582,428	7,925,204	16.0	48.0	722.0	770.0
	1966	6,108,462	82,324	206,312	1,041,832	144,743	—	(101,650)	7,482,023	18.3	51.0	692.5	743.5
	1965	5,704,443	66,781	187,913	851,686	—	—	140,899	6,951,722	15.5	49.5	673.0	722.5
Laboratory Total	1967	34,004,064	744,189	670,434	9,393,909	838,424	1,838,203	1,553,738	49,042,961	99.1	960.0	2,409.0	3,369.0
	1966	32,997,046	741,813	712,941	9,246,894	1,449,677	1,756,098	836,493	47,740,962	99.0	959.5	2,402.0	3,361.5
	1965	30,129,941	639,118	655,875	8,821,492	1,463,486	1,627,532	949,523	44,286,967	98.7	929.0	2,350.5	3,279.5
AUI Administration	1967	—	—	—	—	—	—	475,000	475,000	0.9	—	—	—
	1966	—	—	—	—	—	—	475,000	475,000	1.0	—	—	—
	1965	—	—	—	—	—	—	475,000	475,000	1.1	—	—	—
Total AUI and BNL	1967	34,004,064	744,189	670,434	9,393,909	838,424	1,838,203	2,028,738	49,517,961	100.0	960.0	2,409.0	3,369.0
	1966	32,997,046	741,813	712,941	9,246,894	1,449,677	1,756,098	1,311,493	48,215,962	100.0	959.5	2,402.0	3,361.5
	1965	30,129,941	639,118	655,875	8,821,492	1,463,486	1,627,532	1,424,523	44,761,967	99.8	929.0	2,350.5	3,279.5
Work for Others, Direct Costs Only	1967	—	—	—	—	—	—	—	—	—	—	—	—
	1966	—	—	—	—	—	—	—	—	—	—	—	—
	1965	27,868	12	1,706	31,913	25,278	—	—	86,777	0.2	2.0	5.0	7.0
Grand Total	1967	34,004,064	744,189	670,434	9,393,909	838,424	1,838,203	2,028,738	49,517,961*	100.0	960.0	2,409.0	3,369.0
	1966	32,997,046	741,813	712,941	9,246,894	1,449,677	1,756,098	1,311,493	48,215,962**	100.0	959.5	2,402.0	3,361.5
	1965	30,157,809	639,130	657,581	8,853,405	1,488,764	1,627,532	1,424,523	44,848,744†	100.0	931.0	2,355.5	3,286.5

*\$1,213,013 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.

**\$ 857,082 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.

†\$ 771,759 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.

Table 2
Capital Equipment Expenditures
(Including Charges From Organizational Units; See Table 1)

	Fiscal 1967		Fiscal 1966		Fiscal 1965	
	\$	%	\$	%	\$	%
Scientific and hospital	6,287,342	68.0	6,535,677	73.5	7,675,813	90.1
Automotive and heavy mobile	105,771	1.1	209,844	2.4	165,448	1.9
Office machines and furniture	45,615	0.5	86,366	1.0	97,854	1.1
Shop equipment	297,136	3.2	207,793	2.3	200,305	2.4
Computer facility	2,090,674	22.6	1,639,176	18.4	225,045	2.7
Miscellaneous	428,308*	4.6	214,667	2.4	150,647	1.8
Expenditures, Total	9,254,846	100.0	8,893,523	100.0	8,515,112	100.0
Proceeds from sales	(27,201)		(50,024)		(51,058)	
Expenditures, Net	9,227,645		8,843,499		8,464,054	

*Includes cooperative superconductivity studies, \$69.5; technical photography, \$33.2; plant maintenance, \$77.6; HFBR, \$89.7; instrumentation and health physics, \$67.6.

Table 3
Costs Incurred for Fixed Assets*
(Including Charges From Organizational Units; See Table 1)

	Fiscal 1967			Fiscal 1966			Fiscal 1965		
	Man-years			Man-years			Man-years		
	Costs, \$	Sci.	Others	Costs, \$	Sci.	Others	Costs, \$	Sci.	Others
Direct									
Salaries, wages, insurance	1,873,087	60.8	88.7	958,562	36.5	53.9	721,827	21.0	56.5
Materials, construction, etc.	12,862,909			11,314,238			11,214,871		
Subtotal direct	14,735,996			12,272,800			11,936,698		
Charges from organization units	902,183			562,470			629,825		
Total	15,638,179			12,835,270			12,566,523		

*Includes AGS conversion and HFBR.

Table 4
Inventory at Close of Fiscal Year

Type of Inventory	Fiscal year		
	1967	1966	1965
General stores*	\$1,012,180	\$ 907,692	\$ 743,950
Special process spares**	915,546	828,721	613,895
Precious metals and radium	257,576	243,452	209,124
Stable isotopes	41,262	54,071	75,217
Heavy water	613,310	657,969	750,916
Total	\$2,839,874	\$2,691,905	\$2,393,102

*The number of months investment was 3.0 in 1967, 3.0 in 1966, and 2.8 in 1965.

**Category established at direction of AEC to accommodate major components of research machines previously included in initial construction costs.

nonsalaried scientific staff increased from 730 in 1966 to 765 in 1967 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 596, as compared with 598 in 1966, 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 320 visiting scientists and students to work at Brookhaven during the summer of 1967. Of this number, 135 are staff members from various educational and research institutions, and 185 are students.

ADMINISTRATION

The organization of the Laboratory as of July 1, 1967, is given in the Organization Chart at the front of this report. At its annual meeting in October 1966 the AUI Board of Trustees re-elected all the officers of the corporation with the exception of the Treasurer, Mr. James S. Alexander, who, after many years of service, indicated his wish to retire. He has been succeeded by Mr. Joseph F. Lord. At the same meeting it was voted to amend the by-laws of the corporation by eliminating the category of Annual Trustee and increasing the maximum number of Trustees-at-Large to six. Dr. Thomas Gold of Cornell University and Dr. William D. McElroy of the Johns Hopkins University, who had been chosen Annual Trustees in October 1965, were elected Trustees-at-Large for three-year terms ending in October 1969. Mr. Theodore P. Wright, also an Annual Trustee, was elected a Trustee-at-Large for a term ending in October 1967, replacing Dr. Leo Goldberg, who had submitted his resignation.

Several changes in the Laboratory administration took place during the course of the year. Dr.

George H. Vineyard, promoted from Chairman of the Physics Department to Associate Director in August 1966, replaced Dr. Clarke Williams as Deputy Director upon the latter's retirement on July 1, 1967. Dr. Victor P. Bond was promoted to Associate Director for Life Sciences and Chemistry on April 1. Dr. R. Ronald Rau was appointed Chairman of the Physics Department in October, Dr. Eugene P. Cronkite was appointed Chairman of the Medical Department in June, and Mr. Maxwell M. Small was appointed to the newly created post of Manager, Plant Engineering and Planning, on December 1.

FINANCE

AEC-supported research at the Laboratory continued to be financed by the AEC Divisions of Reactor Development and Technology, Research (Physical Sciences), Biology and Medicine (Life Sciences), Training and Education, and Isotope Development. Operating costs for the work in each program and the major categories of operating expenditures are shown in the accompanying figure. Details of the operating expenditures of the Laboratory on a broad operational basis are given in Table 1. Table 2 shows expenditures for capital equipment, Table 3 is a summary of expenditures for fixed assets (plant and equipment), and Table 4 reflects inventories for which the Laboratory is responsible.

CONFERENCES

Three major conferences were held at Brookhaven during fiscal 1967: the Conference on the Properties of Liquid Metals, September 19 to 23; the National Superconductivity Meeting, November 9 to 11; and Biology Symposium No. 20, entitled "Recovery and Repair Mechanisms in Radiobiology," June 5 to 7.

PHYSICAL
SCIENCES
AND
ENGINEERING

Physics

The physics research program consists of experimental and theoretical studies concerned with the structure and fundamental properties of matter. Various features of the complex structure and properties of matter can be most effectively studied by observing the interactions of charged particles, neutral particles, and radiation with matter. Some of these studies deal with the interactions involving individual atoms, atomic nuclei, or nucleons, and others with conglomerates of atoms and molecules in bulk matter. The Alternating Gradient Synchrotron, Cosmotron, 60-in. cyclotron, Van de Graaff accelerator, Graphite Research Reactor, and the High Flux Beam Research Reactor at Brookhaven provide a wide range of energies and diversity of particles and radiation with which to carry out experimental investigations. The researches reported here will be described under the categories of particle physics, nuclear structure, neutron physics, theoretical physics, and solid state physics. The theoretical scientists conduct their investigations in close association with the experimental scientists and provide stimuli for new approaches to the problem.

The work of Brookhaven scientists is augmented by that of a number of visiting and guest scientists on leave from other institutions in this country and abroad. These visitors and guests are attracted to Brookhaven not only by the availability of its facilities but also by the opportunity to collaborate with Brookhaven scientists. The interchange of ideas and experience resulting from the presence of these visiting scientists is very important to an active research program.

PARTICLE PHYSICS

The number of universities and laboratories sharing in the particle physics research at Brookhaven National Laboratory clearly demonstrates its national nature. About two-thirds of the work at the Alternating Gradient Synchrotron (AGS) is done by groups from these organizations. During fiscal 1967 more than 500 guest scientists participated in the program, including representatives of all the AUI institutions:

Columbia University
Cornell University
Harvard University
Johns Hopkins University
Massachusetts Institute of Technology
Princeton University
University of Pennsylvania
University of Rochester
Yale University

The following organizations were also represented:

Brown University
California Institute of Technology
Carnegie Institute of Technology
Case Institute of Technology
City University of New York
Duke University
Florida State University
Indiana University
Institute for Advanced Study
Iowa State University
Naval Research Laboratory
Oak Ridge National Laboratory
Oberlin College
Rockefeller University
Stanford University
State University of New York, Buffalo
State University of New York at Stony Brook
Syracuse University
University of Arizona
University of California at Berkeley
University of California at Irvine
University of California at La Jolla
University of California at Los Angeles
University of California at Riverside
University of Chicago
University of Colorado
University of Illinois
University of Kansas
University of Maryland
University of Massachusetts
University of Michigan
University of Notre Dame
University of Tennessee
University of Washington
University of Wisconsin
Vanderbilt University
Vassar College
Western Reserve University
William Marsh Rice University

Guest scientists also included representatives of the following foreign laboratories: University of Melbourne, Australia; McGill University, Mon-

treil, Canada; University of Manitoba, Canada; London University, England; Oxford University, England; Queen Mary College, England; Rutherford High Energy Laboratory, England; University College, London, England; Woodstock College, England; CEN, Saclay, France; University of Caen, France; Weizmann Institute of Science, Israel; University of Bologna, Italy; University of Milan, Italy; University of Padua, Italy; University of Pisa, Italy; University of Rome, Italy; Nagoya University, Japan; Osaka City University, Japan; Waseda University, Japan; CERN, Geneva, Switzerland; and Max Planck Institute, West Germany.

No attempt has been made to cover all the work accomplished at BNL in particle physics during the past fiscal year. A detailed list of publications in the field is included in Appendix A. The material that follows presents the highlights and a typical cross section of the research activity for this period.

General

Most scientists believe that all phenomena of nature are based on laws that remain valid over time and distance and can eventually be understood. Quantum mechanics, which has been so successful in explaining atomic processes, is an outstanding example of the orderliness of nature. For phenomena involving nucleons no such understanding exists, despite the fact that these particles have been studied intensively for 20 years or more. Although a satisfactory explanation of particle physics still seems quite remote, the field continues to be of great interest because it is a frontier in the understanding of one of the most fundamental aspects of nature.

This section of the annual report describes the work done here by theoretical physicists on this problem and the work of experimental physicists who have used Brookhaven's remarkable resources for exploration of this field. A great many facts are known about the nature and behavior of the many fundamental particles that have been identified, and some simplification of these facts has been achieved through the formulation of conservation laws and invariance principles. Much of the work reported here has been directed toward testing the validity and extent of these concepts, which may become the basis of an understanding of particle physics.

Research at the Cosmotron

During the past year a Brookhaven group, in collaboration with physicists from Los Alamos, the University of Maryland, Rice University, Northeastern University, and Vassar College, used 1-BeV protons from the Brookhaven Cosmotron as a probe to measure the correlation properties of nucleons within the nuclei of helium, carbon, and oxygen. The low energy spread (≈ 1.5 MeV) in the 1-BeV proton beam of the Cosmotron and the use of a magnetic spectrometer constructed of wire-chamber detectors which gave comparable resolution made it possible to resolve the various excited configurations of the nucleons that occur as a result of the interaction. This allowed elastic scattering data to be obtained on helium, carbon, and oxygen. These data showed striking differences compared with similar data obtained with high energy electrons. Since the incident proton interacts much more strongly with the nucleons inside the nucleus than do incident electrons, the incident protons have a good chance of interacting twice before escaping the nucleus, whereas the electrons interact only once. Because of this difference, elastic proton scattering measures the correlations of the nucleons inside the nucleus, while electron scattering essentially measures only the single particle density distribution. These correlations in helium, carbon, and oxygen are now being extracted from the data.

A group from Brown University, MIT, and Padua University has undertaken a study of the decay branching modes of the η meson. The objective is to detect, within one experiment, the charged and neutral decay modes and to determine their various decay ratios. The results of this experiment can be compared with the predictions of theories and models of elementary particles such as the quark model and with the requirements of proposed fundamental symmetries.

The experiment was performed at the Cosmotron with use of a 750-MeV/ c beam of π mesons incident upon a hydrogen target surrounded by an array of thin-foil spark chambers and spark chambers constructed from material of high atomic number. The system was triggered upon disappearance of a π meson from the beam, in coincidence with a pulse from a neutron hodoscope which also detected the time of flight of the neutron in the reaction $\pi^- + p \rightarrow \eta + N$. The data are being analyzed.

Chirality (the quantity $\vec{p} \cdot \vec{\sigma}$) is conserved by weak interactions and by electromagnetic interactions in the relativistic limit, $\beta \rightarrow 1$. The momentum ($\vec{p}$) and spin ($\vec{\sigma}$) directions change together. A Yale-Brookhaven collaborative group investigated the conservation of chirality in the scattering of protons by protons at values of t , the square of the 4-momentum transfer, of about 2 BeV/c by means of a triple scattering experiment.

A polarized beam was produced in a first scattering of an external beam from the Cosmotron on a hydrogen target. The plane of the polarization was then rotated in a magnetic field produced by using the 14-in. BNL bubble chamber coils. The beam was momentum-analyzed and the polarization rotated to be parallel or antiparallel to the momentum by two bending magnets, and a second scattering took place in a liquid hydrogen target. Elastic events were detected and analyzed by a scintillation counter-hodoscope array which was on line to a PDP-8 computer. The events were required to fit 2-body kinematics rather precisely, and thus almost complete discrimination against inelastic processes was possible. The scattered particles next passed into the second stage of the detector, where they were scattered again from carbon plates which served as polarization analyzers. This information was also fed to the PDP-8 on-line computer.

The analysis of the experimental results is still in process. The final results should give a complete description of the elastic scattering amplitude at 90° in the center of mass, that is, the determination of the singlet and triplet amplitudes and the phase difference between them.

A very extensive series of nuclear chemistry studies and the continuing experimental biology program, both carried out at the Cosmotron, are covered elsewhere in this report.

A special irradiation of meteorites was made for the General Electric Company in an experiment attempting to verify the cosmic-ray sources of particle tracks observed in meteorites.

Research at the Alternating Gradient Synchrotron

In an experiment performed at the AGS a group from Princeton University has compared, to an accuracy of a few tenths of one percent, the decay rates of K^+ and K^- mesons into the τ mode $K^\pm \rightarrow \pi^\pm + \pi^+ + \pi^-$ and the $K_{\mu 2}$ mode ($K \rightarrow \mu + \nu_\mu$). These comparisons constitute tests of two basic in-

variance principles, CP and CPT (charge conservation, parity, time reversal), respectively. Invariance under the CPT operation means that physical laws remain unchanged when particles and antiparticles are interchanged (C), space is inverted as in a mirror (P), and the sequence of events being studied is executed in the opposite order (T). For the strong and electromagnetic interactions C , P , and T invariances seem to be separately valid laws. The weak interactions are known to violate both P and C invariances. The combined CP invariance is also known to be violated in K_2^0 decay (1964 Annual Report). There are, however, very deep theoretical reasons to believe that the combination of all three inversions forms an absolute invariance principle, known as the CPT theorem.

The purpose of this experiment was to learn more about the origin of the CP violation mentioned above and also to test the validity of the CPT theorem in a particular decay channel ($K_{\mu 2}$). The results do not indicate any violation: the τ^+ and τ^- decay rates were found to be equal to within 0.2%, and the $K_{\mu 2}^+$ and $K_{\mu 2}^-$ decay rates to within 4%. As a by-product of this experiment a new value for the absolute decay rate of the τ was found: $(4.496 \pm 0.030) \times 10^6 \text{ sec}^{-1}$.

A Brookhaven counter group this year completed a critical check of the validity of the pion-nucleon forward dispersion relations (FDR) at high energies. In analogy to the dispersion relations for light, these FDR are primarily based on the principle of microscopic causality. This principle states that, even within the very small subnuclear distances within a nucleus that can be reached by a very high-momentum particle probe, signals do not travel faster than light. Previous experimental data had some time ago checked this principle down to distances $\lesssim 1$ fermi (i.e., somewhat less than a proton radius). In the present investigation, 8 to 29-BeV/c π -meson (pion) beams at the Brookhaven AGS were used to critically establish the validity of the pion-proton FDR and check the principle of microscopic causality down to distances $\lesssim 10^{-15}$ cm by direct measurements and probably down to $\lesssim 10^{-16}$ cm, assuming reasonable extrapolation to higher energy of the total cross sections.

A counter-hodoscope system on-line to the PDP-6 computer was used to measure both the real and imaginary parts of the pion-nucleon forward scattering amplitudes to very high precision. Four to

five hundred counter hodoscopes formed a high-resolution magnetic spectrometer system with around 0.4-mrad over-all angular resolution and around 0.4% over-all momentum resolution. This allowed total cross-section measurements of absolute accuracy to $\approx 0.3\%$ and differential cross-section measurements in the small-angle region of absolute accuracy of $\approx 1\%$. Three to six million trigger-selected events per hour for a total of 3 billion events were handled and recorded by the data system, with 10 to 20% of the events analyzed on line by the computer.

The observation of the interference between the known real Coulomb scattering amplitude and the real part of the nuclear amplitude at very small angles (corresponding to impact parameters of about several fermis) was used to measure the real part of the nuclear amplitude. The imaginary part is determined by the total cross section via the optical theorem relation. The ratio of the real to the imaginary parts of the $\pi^\pm$ - p forward scattering amplitude is shown in Figure 1 and compared to the theoretical prediction of the FDR. The agreement is excellent within the systematic errors and has been shown to be very independent of uncertainty in the high energy behavior of the total cross section even for drastic changes. Charge independence at high energies was also verified within the high precision obtained by these experiments and the charge exchange data.

Figure 1. The ratio of the real to the imaginary part of the pion-nucleon forward scattering amplitude as a function of incident momentum. The upper graph is for π^- - p and the lower graph is for π^+ - p forward scattering. The solid line is the prediction of the forward dispersion relations, and the dashed line represents the displacement of the prediction due to systematic scale error. The data points show excellent agreement with the prediction.

As by-products, the inelastic spectrum was obtained and the known low-mass (< 2 BeV) nuclear isobar production characteristics in p - p were observed. For the first time isobar production by $\pi^\pm$ - p was observed, including the isobar-type peak at 1.4 BeV, which considerably increases the probability that it is a *bona fide* nucleon isobar rather than a possible kinematic effect.

In a continuation of previous work, another Brookhaven counter group, using the separated beam, measured the antiproton-proton and antiproton-deuteron total cross sections to high precision in the momentum region 1.0 to 3.3 BeV/ c . Three structures were discovered, one in isospin 0, and two in isospin 1. The total center-of-mass energies were 2380, 2190, and 2345 MeV, respectively. These have been interpreted as being due either to threshold effects for the N^* (1238 MeV) and N^* (1400 MeV) production or to boson resonances. If the latter interpretation is correct, they would be the heaviest bosons observed to date.

This group has also studied the feasibility of measuring the magnetic moment of the Ξ^- hyperon by using a high-intensity, partially separated K^- beam to produce Ξ^- hyperons in liquid hydrogen. The forward-produced hyperons were detected and their polarization ($\hat{p}$) was measured at 1.74, 1.80, and 1.87 BeV/ c . It was shown that $\alpha\hat{p} = 0.19 \pm 0.05$ with no significant momentum variation (α is the longitudinal decay parameter for Ξ^- and is known from other experiments.) It was also shown that solid methane could be used as a target, since the rate of production of Ξ^- hyperons from bound protons in liquid nitrogen is lower by an order of magnitude per target proton. It was concluded that a measurement of the Ξ^- magnetic moment is feasible. A superconducting magnet built for this experiment provided a peak field of 120 kG with which to precess the spin of the Ξ^- before it decays.

A Cornell-Brookhaven group extended their work on elastic pion-proton scattering at large angles. The experiment involved a detailed study of this reaction with much improved accuracy, covering the angular range 25° to 180° in the c.m. system and with incident pion momenta in the range 6 to 17 BeV/ c . The scattered and recoil particles were magnetically analyzed and detected in scintillation counter arrays; an interaction satisfying conditions close to elastic scattering caused spark chambers to be fired. Photographs of the

tracks of the outgoing particles in the spark chambers were analyzed by the Physics Department's flying-spot digitizer, and a separation of elastic from inelastic events was obtained.

In the experiment, much emphasis was placed on the study of scattering at backward angles near 180° , where the group had previously observed a sharp rise in the differential cross section. The analysis of this section of the current experiment is almost complete; the existence of the backward peaks has been confirmed and greater detail obtained. The peak is considerably narrower and higher in the case of π^+p scattering than in π^-p at all energies up to 17 BeV/c. Both cases show a similar variation with incident pion momenta, with the height of the peak becoming less momentum dependent at the higher momenta. A comparison of these results with theoretical predictions is being carried out. The results in the remainder of the angular range are being analyzed. Figure 2 shows the arrangement for the experiment.

A third Brookhaven counter group has investigated very inelastic $p-p$ interactions. In the course of an experiment reported last year, the momentum spectra of secondary protons were observed over a wide range of scattering angles for incident proton energies between 10 and 30 BeV. These proton spectra seem to come from two types of interactions, peripheral ones which resulted in the isobar production, and collisions which were mainly much more inelastic and appeared to be responsible for most of the large-angle proton scattering. This scattering can be accounted for in terms of a nuclear bremsstrahlung process proposed a long time ago. However, additional experiments are required to form a definite conclusion.

In the past few years cosmic-ray evidence has tended to indicate a difference in the cross sections for μ^+ and μ^- mesons (muons) scattered by electrons. Such a result is in essential contradiction to the theory of quantum electrodynamics in its present formulation. If such an asymmetry can be clearly established, one of two results must obtain: either the present theory must be modified, or a new process is at work.

The University of Washington's Cosmic Ray Group has performed an experiment at the Brookhaven AGS to test these alternatives. A beam of high energy muons is caused to pass through a water target. Electrons struck by muons in this target pass through the water to a total absorption

shower counter, where the pulse height gives a measure of the electron energy. By using muon beams of both signs and equal momenta, together with measured electron energy spectra, two important measurements can be made. First, the spectra for the two signs of charge can be compared in order to detect an asymmetry in scattering; second, the electron energy spectra themselves can be used to measure the absolute scattering cross sections. The results of the first measurement indicate equality of the cross sections to an accuracy of $\pm 10\%$. This finding contradicts the previous results of cosmic-ray experiments, which showed large asymmetries in the same region of energy transfer. The results of the absolute cross-section measurement are still in a very preliminary stage of analysis, but, do not so far appear to disagree with theory.

A measurement of the differential cross section for muon-proton elastic scattering has been performed at the AGS by a group of physicists from Columbia University and the University of Rochester. The purpose of this experiment is to test for any difference between the electromagnetic interactions of the muon and the electron by direct comparison with measurements of electron-proton scattering.

Figure 2. Experimental arrangement for measuring the elastic scattering of 6 to 17-BeV/c pions from protons near 180° in the c.m. system. The pion beam hits the liquid hydrogen target T . Pions scattered near 180° are momentum-analyzed by magnet M_1 with use of a number of scintillation counter telescopes, shown as π_1 , π_2 , and π_3 , and the spark chambers SC_1 to SC_5 . Recoil protons are momentum-analyzed by magnets M_2 and M_3 with use of scintillation counter telescopes P_2 and P_3 . The threshold gas Cerenkov counter C in anticoincidence rejects forward-going pions.

The muon has been a much-studied particle in the 35 years since its discovery. In recent years there has been a growing awareness of its resemblance to the electron in its weak and electromagnetic interactions and the absence of strong interactions. The only known differences between these two particles are that the muon is much heavier (≈ 200 times) than the electron, and that each of these particles has its own neutrino. The general belief among particle physicists is that the mass differences among particles arise from some difference in the interactions of the particles. A comparison of muon and electron scattering by protons at large momentum transfers will decide whether or not the identity of electromagnetic structure of these two particles persists down to very small distances.

A similar experiment was performed at the AGS by the Brookhaven-Columbia-Rochester group in 1963. Although this experiment was sensitive to any difference in muon and electron structure at distances as small as 10^{-14} cm, no significant difference was discovered. The current experiment was designed to extend this limit to even smaller distances by improving the statistics and also by studying more detailed characteristics of the muon-proton scattering cross section. The cross section is a function of the momentum transfer as well as the incident beam momentum; however, the dependence on the latter is known to be very weak and was expected to show no effect under the conditions of the previous experiment. In the present experiment this weak dependence was studied by using three different momenta of the incident muon, 6, 11, and 17 BeV/ c . For 6 and 11 BeV/ c both positive and negative muons were used. A comparison of the data for positive and negative muons of the same momentum will give additional information on the nature of muon-proton interactions. For each beam condition $\approx 5 \times 10^9$ muons passed through the hydrogen target. Six large spark chambers were used to detect recoil protons with momenta up to 800 MeV/ c , and four smaller chambers detected the incident and scattered muon. A total of 100,000 spark chamber photographs were taken and are being analyzed. Approximately 4000 elastic events in the momentum transfer region from 350 to 750 MeV/ c are expected for each of the 5 different beam conditions.

In an experiment at the AGS (see Figure 3), a group from the University of Michigan, the Stan-

ford Linear Accelerator Center (SLAC), and Princeton University measured differential cross sections for small-angle n - p elastic scattering. A 1° neutron beam and thick-plate spark chambers were used to detect the scattered neutrons. The energy of the neutrons was determined from the scattering kinematics. The nominal neutron energy range was 8 to 28.5 BeV, and the range of 4-momentum transfer studied was 0.1 to 2.5 (BeV/ c)².

The data from the experiment are being analyzed. These data are the first on n - p elastic scattering in this energy range. The small momentum transfer region studied is of particular interest in Regge pole theory, especially with respect to the shape of the diffraction peak and its behavior with energy.

In conjunction with the above experiment, the same neutron beam was used to measure high energy n - p total cross sections.

There has been a continuing reliance in $SU(3)$, quark, and Regge pole theories on an $I=1$, $S=0$ scalar meson in the mass region below the ρ meson. Several indications of a meson having a mass in the region 550 to 600 MeV and decaying into $\pi^+\pi^0$ (the " ζ ") have been reported, but other experiments have failed to confirm them. In a search for such a meson, MIT physicists studied the reaction $\pi^+ + p \rightarrow \pi^+ + \pi^0 + p$ at an incident pion momentum near 1 BeV/ c . The dipion mass spectrum of almost 7000 events shows no statistically significant bumps, giving an upper limit of ≈ 0.1 mb (99% confidence level) for a meson with a width narrower than the experimental resolution (about ± 10 MeV).

During the past year an MIT group in collaboration with a group from the University of Pisa has finished work on the analysis of data from a charge exchange experiment, $\pi^- + p \rightarrow n + \text{neutrals}$. Results include measurement of the spin of the f^0 , existence of the decay mode $\omega^0 \rightarrow \pi^0 + \gamma$, and an upper limit on the decay mode $\eta \rightarrow \pi^0 + \gamma + \gamma$. Analysis of the data from another charge exchange experiment completed by the MIT group this year is nearly complete. Results so far include observation of K charge exchange at 8 BeV/ c and observation of the dikaon mass spectrum in the reaction $\pi^- + p \rightarrow K_1^0 K_1^0 + \text{neutrals}$.

During fiscal 1967 about 4.5 million pictures were taken at the AGS with the 30-in. and 80-in. cryogenic bubble chambers filled with liquid hy-

drogen, deuterium, or mixtures of hydrogen (or deuterium) with neon. The chambers were exposed to beams of particles of varying masses and momenta. About two-thirds of the photographs taken of interactions in these two chambers are being analyzed at various laboratories and universities by many groups of users.

The BNL Bubble Chamber Group is currently studying several areas of physics with bubble-chamber photographs from the 30-in. and 80-in. chambers. The exposures in the 80-in. chamber included 6-BeV/c $\pi^\pm p$ (part of this work is in collaboration with the City University of New York), 4.6 and 5.0-BeV/c $K^- p$ (in collaboration with Syracuse University and the BNL Nuclear Interaction Group), 1 to 7-BeV/c $K_2^0 p$ (in collaboration with Yale University), and 28.5-BeV/c pp . Those in the 30-in. chamber included 0.6 to 0.8-BeV/c $K^- p$ and stopping K^- and $\bar{p}$ on p with neon. Some of the results are discussed below.

Analysis of an exposure of the 80-in. cryogenic bubble chamber filled with hydrogen to a 6-BeV/c $\pi^\pm$ -meson beam from the AGS has yielded evidence for a 2-pion resonance, the g_1^- meson, at a mass of 1630 MeV and with a width of 100 MeV (see Figure 4). The well-determined quantum numbers are positive G -parity, negative spatial parity, and odd spin. An analysis using the angu-

lar distribution of the pions from the decay of the g_1^- meson favors the assignment of spin 3, the highest spin value yet found for a meson resonance. In the context of the unitary symmetry scheme, it may turn out that the g_1^- and the re-

Figure 3. Layout of the Michigan-SLAC-Princeton n - p elastic scattering experiment. The anticounter rejects events in which a charged particle enters the neutron detector. A_1 and A_2 are anticounters; SC_1 through SC_4 are spark chambers; and P_1 , P_2 , and P_3 are proton telescope counters.

Figure 4. Dipion mass spectra for three final states. The g_1^- meson at 1.63 BeV in the $\pi^-\pi^0$ mass distribution (b) and its neutral $\pi^+\pi^-$ contribution (c) are indicated. The absence of enhancements at 1.63 BeV in the doubly charged $\pi^+\pi^+$ mass spectrum (a) suggests that the isospin assignment of the g_1^- is 1.

cently discovered K^* at a mass of 1800 MeV should be grouped into a meson multiplet of high spin. In the framework of the Regge pole theory, the g_1^- meson could be the recurrence of the ρ meson.

In addition, in this 6-BeV/c $\pi^\pm p$ experiment the K^* (1300 MeV) meson has been observed in the reaction $\pi^- + p \rightarrow \Lambda + K^* (1300)^0 \rightarrow \Lambda + (K\pi\pi)^0$. No enhancement is observed at 1300 MeV in the doubly charged $K\pi\pi$ state from the reaction $\pi^+ + p \rightarrow \Lambda + (K\pi\pi)^{++}$. Previous experiments on the K^* (1300) have come mainly from K^+p interactions, where either a kinematic or a resonance interpretation for the K^* (1300) can be formulated. The $\pi^\pm p$ data support a resonance interpretation for the K^* (1300), which has several properties not usually associated with kinematic effects. These properties are a definite isospin, a narrow width, and decay modes [$K^* (890)$, π^- , and $K\pi\pi$] that do not arise from the usual exchange diagrams. The analysis shows that the K^* (1300) has an isospin of $\frac{1}{2}$, a spin >0 , a mass of 1300 MeV, and a width of 60 MeV.

The exposure to 6-BeV/c $\pi^\pm p$ was also used to investigate the dynamics of associated production

Figure 5. Distribution in $\cos \theta^*$ of K^0 in the over-all c.m. system from the reactions $\pi^- + p \rightarrow K^0 + Y^0$ at 6 BeV/c, where Y^0 is either Λ or Σ^0 . The well-defined background peak is comprised of 10 events in the region of $\cos \theta_{K^0}^* < -0.9$.

of strange mesons and hyperons. The striking angular distribution shown in Figure 5 can be described as peripheral and antiperipheral (very close) collisions only. About 2% of the associated production is antiperipheral. This type of antiperipheral collision, previously observed clearly only in the π^+p elastic scattering, corresponds to a radius of interaction of $<10^{-14}$ cm.

Analysis of 300,000 photographs of 4.6 and 5.0-BeV/c K^-p interactions in the 80-in. chamber was continued in collaboration with Syracuse University and the BNL Nuclear Interaction Group. The K^* (1420 MeV) spin-parity was shown to be 2^+ , as expected, by excluding the 1^- and 3^- possibilities allowed by earlier experiments (see Figure 6). A paper on regular and "inverted" Deck mechanisms in the reaction $K^- + p \rightarrow p + \bar{K}^0 + \pi^0 + \pi^-$ has been submitted for publication. The regular Deck

Figure 6. Decay angular distributions for the K^* (1420). (a) and (b): Decay angles for the normal to the 3-body $K\pi\pi$ decay plane for the $K^*(1420)^0$ selected with a 4-momentum transfer $0 < \Delta^2(n) < 0.2$ BeV. (c) and (d): Decay angles for the $K^*(1420)^- \rightarrow (\bar{K}^0\pi^-)$ selected with $0.2 < \Delta^2(p) < 0.5$ BeV². Before folding, the distributions are symmetrical. The curves are normalized to the solid-line histograms which have background subtracted; the dashed histograms do not have any background subtraction. The spin parity $J^P = 2^+$ is seen to be favored over 1^- and 3^- in (c).

mechanism is the exchange of a pseudoscalar meson between the incident particles with subsequent vector meson formation at one vertex and virtual diffraction elastic scattering of the exchanged particle with the target at the other. This leads to a low mass (pseudoscalar meson–vector meson) system. The “inverted” Deck mechanism interchanges the roles of the pseudoscalar and vector mesons. That is, the exchanged particle is the vector meson. The scattering at the vector meson–target vertex leads again to a low mass enhancement. A large contribution of this “inverted” Deck diagram is required to explain all aspects of the kinematic low mass enhancement observed.

The branching ratios of the f^* (1500 MeV) and the K^* (1420 MeV) resonances were determined. The absence of the “new” Υ_1^* (1680 MeV) in the $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ states and the presence of the “old” Υ_1^* (1660 MeV) in $K^- + p \rightarrow \Sigma^0 + \pi^+ + \pi^-$ states are being studied. The sample of 8 Ω^- hyperons, 800 Ξ^- hyperons, and 40 f^* resonances will be increased 2.5 times with the analysis of additional exposures taken in the 80-in. chamber, which are now being processed.

Strong interactions of $K_2^0 p$ were also studied, with emphasis on those reactions in which the incident K_2^0 interacts peripherally and yields an outgoing K_1^0 . Such interactions occur through the exchange of odd-spin particles like the ρ , ω , and ϕ . A search for a Ξ^* with isospin $\frac{1}{2}$ was made in the reaction $K_2^0 \rightarrow \Xi^0 + K_1^0 + \pi^+$. An upper limit of 10 μb was obtained.

Approximately 100,000 pictures were taken of 28.5-BeV/ c protons incident on hydrogen in the 80-in. chamber (see Figure 7). A final sample of about 15,000 2-prong and 15,000 4-prong events will be obtained from these pictures. Preliminary results from studying about $\frac{1}{5}$ of the total sample of 2- and 4-prong events have shown no double isobar production in the final state $pp\pi^+\pi^-$, although the N^* (1238) is produced in about half the events in the $p\pi^+$ mode. A broad enhancement centered at about 1400 MeV was found in the $n\pi^+$ and $p\pi^0$ systems from the $pn\pi^+$ and $pp\pi^0$ final states. This is similar to what has been seen in counter experiments. The shape of the enhancement found here cannot be explained as a mechanism of the “Deck” type. Further investigation of this enhancement awaits availability of all the data. A thorough study should then allow limits to be placed upon the elasticity of the isobars previously observed in counter experiments.

Several hundred events having six or more prongs were processed, and evidence for strong N^* (1238) production appears in these events as well. An investigation of the high-multiplicity events is of interest for studying central or core interactions: however, further analysis of a larger sample of data is needed.

In the 30-in. chamber additional work on low energy (600 to 800-MeV/ c) K^- scattering on hydrogen revealed a very complicated set of structures near a mass of 1660 MeV. There are probably at least three resonances very near this en-

Figure 7. Typical 28.5-BeV/ c pp interactions. The beam enters from the left. An 8-pronged interaction is seen below a 6-pronged one in the left-hand section of the picture.

ergy. To fully sort out this situation, very accurate sets of angular distributions and polarizations at many energies will be needed. A considerable number of events at 725 MeV/c will be analyzed with use of flying-spot digitizer measurements. This will complement the data expected from other extensive exposures at neighboring energies.

The reactions produced by K^- mesons and antiprotons which are stopped in a mixture of liquid hydrogen and neon are being studied. About 30,000 pictures have been obtained in the 30-in. bubble chamber, including both antiproton and K -meson pictures at each of two concentrations, 1.7 and 4.4 at. % neon.

The ratio of neon to hydrogen capture is determined from scan-table identification of the events and then compared with the prediction of the Fermi-Teller "Z-law." At present weak evidence for an anomalous deviation from this prediction is observed. Additional bubble-chamber pictures at several other low neon concentrations are being requested so that this capture ratio can be investigated in more detail.

The K^- photographs are particularly well suited for identification of neutral hyperfragments. A search for the hyperfragment consisting of a Λ hyperon and two neutrons is being conducted.

The experimental activities of the BNL Nuclear Interaction Group have been concerned with two major areas, namely the weak and the strong in-

teractions of elementary particles. In the former, the main effort in collaboration with the Carnegie Institute of Technology has been the study of the decay and interaction of K^0 mesons produced by 600-MeV/c $K+d$ interactions. To date, $\approx 350,000$ pictures have been taken in the BNL 30-in. deuterium bubble chamber and have been completely scanned and analyzed. The results are discussed under three headings.

1. The question of the existence of $\Delta Q = -\Delta S$ currents. At present the evidence is conflicting. A study of the time distribution of 335 leptonic decays in the present experiment shows no evidence for such currents; if they exist at all, they must be rather small in magnitude. In addition, the rate for leptonic decay of K^0 mesons was measured and found to agree with that predicted by the $\Delta I = \frac{1}{2}$ rule and the already known rate for K^+ decays.

2. The sign and magnitude of the $K_L - K_S$ mass difference. This quantity is measured by studying the frequency with which K^0 mesons interact after they are produced and the length of time required for interaction. The K^0 scattered in 72 of the 161 events obtained, and in 89 it interacted and produced a Λ . The analysis of these events indicates that $M_L > M_S$, i.e., the K_L is heavier than the K_S (see Figure 8) and the mass difference is $(0.72 \pm 0.18)/c^2 \times 10^{10}$. A by-product of the endeavor is an accurate determination of the K_S lifetime: 10,000 events yielded $\tau_S = (0.858 \pm 0.014) 10^{-10}$ sec.

3. A search for CP violation in the decay $K_S^0 \rightarrow \pi^+ + \pi^- + \pi^0$. Since the discovery by the Princeton group (1964 Annual Report) that $K_L^0 \rightarrow \pi^+ + \pi^-$, which demonstrates that CP is violated, work has been done on another interesting question - whether CP is violated in other reactions such as $K_S^0 \rightarrow \pi^+ + \pi^- + \pi^0$. This is a much more difficult experiment to evaluate, since a signal will certainly be observed due to the $K_L^0 \rightarrow \pi^+ + \pi^- + \pi^0$ with a short observed lifetime. The problem is to determine whether there is an excess of such events which can be ascribed to the K_S^0 . Forty-four such events were found, and the conclusion is that they all can essentially be due to the K_L^0 decay into $\pi^+ + \pi^- + \pi^0$.

In the field of strong interactions the work has been centered mainly on the search for particles or resonances whose quantum numbers would place them in higher group representations than the already observed 8 and 10 groups, namely $\overline{10}$ or 27. The analysis of the 100,000 pictures taken

Figure 8. Determination of the sign of the $K_L - K_S$ mass difference. The curves shown for $M(K_L - K_S) = +0.55 \tau_S^{-1}$ and $-0.55 \tau_S^{-1}$ obviously indicate the positive solution, i.e., that K_L is heavier than K_S .

in the 80-in. hydrogen bubble chamber exposed to a 3-BeV/c K^+ beam has continued. The reactions studied were $K^+ + p \rightarrow K^+ + K^+ + \Lambda$; $K^+ + K^+ + \Sigma^0$; $K^0 + p + \pi^+$; and $K^0 + \pi^+ + \pi^+$. Two types of unusual particles were looked for, the first a meson with strangeness +2 and isospin 1 which would decay into a $K^+ K^+$ final state, and the second a baryon with strangeness +1 and isospin 0 or 1 which would decay into the $K^0 p$ or $K^0 \pi^+ n$ final state. The net result of both endeavors was negative. Where previously there was a bump in the $K^+ K^+$ mass distribution from a CERN experiment, this exposure had a dip, the sum giving a distribution consistent with phase space. In the baryon case, an upper limit for the production of an $S = +1$ resonance from either final state is $< 50 \mu\text{b}$.

The rf separated beam built by a Yale-BNL group has opened up the realm of high energy experiments in the range 8 to 30 BeV/c. New techniques will be required to obtain many of the results from these experiments. However, standard bubble-chamber techniques are being applied with good success to highly constrained types of events.

Interesting results have been obtained by university groups in experiments utilizing the 80-in. bubble chamber. The SLAC group has studied πp interactions at 16 BeV/c, and the University of Wisconsin group has studied similar interactions at 25 BeV/c. The SLAC exposure has concentrated on 4-pronged events, which show copious production of N^* , ρ^0 , ω^0 , and f^0 . The Wisconsin experiment has been concerned with high-multiplicity events (6 and 8 prongs) and strange particle production, the cross section for which was found to be about 4 mb. $\bar{Y}^* N$ production accounts for about $12 \mu\text{b}$ of this. An 8-BeV/c $\pi^- p$ exposure for a Notre Dame group has shown the cross section for $p\bar{p}n$ production to be $\approx 70 \mu\text{b}$, and a Rutgers group, in an experiment at 8.4 BeV/c, has observed $22 \pi^+ + p \rightarrow p + p + \bar{p} + \pi^+$ events.

The Lawrence Radiation Laboratory (Alvarez group) is studying a series of $p\bar{p}$ exposures from 13 to 28 BeV/c for cross sections and other general features of these reactions. Iowa State University is studying 4-prong $p\bar{p}$ events, especially $p + p \rightarrow p + p + \pi^+ + \pi^-$ at 22 BeV/c.

Various $K^\pm p$ exposures have also been made in the 80-in. chamber with use of the rf separated beam. Yale University has found production of Ξ and Λ hyperons in their 12.8-BeV/c $K^- p$ exposure.

The University of Rochester has a 12.8-BeV/c $K^+ p$ exposure and has observed $K^+ + p \rightarrow \bar{\Lambda} + p + p$ and $\bar{\Sigma}^0 + p + p$, each with cross sections of about $5 \mu\text{b}$. Larger antibaryon cross sections are obtained at lower energies. The Lawrence Radiation Laboratory (Goldhaber group) has observed antiscascade (Ξ^-) production (about $10 \mu\text{b}$) in their 9.0-BeV/c $K^+ p$ exposure, and UCLA has found a cross section of about $38 \mu\text{b}$ for $\bar{\Lambda}$ production at 7.4 BeV/c. These groups are also studying the $K\pi\pi$ system in vee + 2-prong and in vee + 4-prong events ($K^\pm + p \rightarrow p + K + \pi + \pi$). The situation regarding various kinematic enhancements and the role of the $K^*(1300 \text{ MeV})$ resonance should be clarified by means of these studies in the coming year.

Low energy experiments were performed in the 30-in. chamber by several groups. The University of Maryland and Columbia University are separately analyzing $\Sigma^\pm$ leptonic decays in a one-million-picture exposure of stopping K^- mesons in hydrogen. The Maryland group has examined $2\frac{1}{2}$ million $\Sigma^\pm$ hyperons decaying into $n + e^\pm + \nu$ or $n + \mu^\pm + \nu$. The Columbia group has measured 280,000 Σ^- in order to obtain the branching ratio for $\Sigma^- \rightarrow n + e^- + \nu$. The decay parameters α , β , and γ of polarized Σ^+ decaying into $n + \pi^+$ produced in the reaction $K^- + p \rightarrow \Sigma^+ + \pi^-$ near 365 MeV/c were measured in a Yale-University of Massachusetts collaboration. A 500,000-picture exposure yielded about 4000 $\Sigma^+ \rightarrow n + \pi^+$ events, of which about 1000 had a subsequent $n + p \rightarrow n + p$ elastic recoil. The right-left asymmetry in the scattering measures the neutron polarization. The values $\alpha = 0.047 \pm 0.07$ and $\phi = (180 \pm 30)^\circ$ (where $\beta = \sin\phi$ and $\gamma = \cos\phi$) were found. This result confirms the theoretical predictions that the S -wave amplitude for $\Sigma^+ \rightarrow n + \pi^+$ is zero.

Columbia University and the State University of New York at Stony Brook have continued their collaborative study of the production of η mesons in a 400,000-picture exposure of the 30-in. chamber in the $\pi^+ + d \rightarrow p + p + \eta$ reaction. They are currently measuring the branching ratio of ($\eta \rightarrow$ all neutrals)/($\eta \rightarrow$ three charged π 's). The Duke University group, in its experiment on $K^- + p \rightarrow \Lambda + \eta$ at threshold (near 700 MeV/c), is also studying the all-neutral decay of the η meson.

Syracuse University, in collaboration with the University of Rome, is studying the reaction $\bar{p} + d \rightarrow p_s + \pi^+ + \pi^- + \pi^-$ in an exposure of 300,000

photographs in the 30-in. chamber. The s -state capture leads uniquely to the 0^- state exactly as in η and τ decays. Much structure has been observed in the 3-pion Dalitz plot, which is yet to be completely understood.

Theory

During the past year the Theoretical Group, in addition to providing assistance to experimental groups on theoretical questions, has done work in a number of important areas.

The very topical questions of spin dependence of high energy scattering and superconvergence relations have received much attention. A simple method of obtaining superconvergence relations for arbitrary spins was derived. The general problem of spin dependence of high energy scattering amplitudes was surveyed. In particular, the relation of spin dependence to singularities in the complex angular momentum plane (J -plane) was studied in detail. It was argued that there are fixed poles in J , independent of the energy, at certain integers ("nonsense, wrong signature" values of J) which yield spin-dependent cross sections, even at the highest energies. At other integers ("nonsense, right signature" values of J) it was argued that there can be no fixed poles because of the unitarity bounds on the scattering amplitude. This was shown to be equivalent to superconvergence relations. The high energy behavior of Compton scattering was studied in its relation to the complex J -plane. It was shown how the Pommeranchuk Regge trajectory couples to photons for forward Compton scattering. An approximate value of the coupling was calculated; the resulting cross section falls within the present limits set by experiment at the highest energies. The convergence of the Drell-Hearn and similar sum rules was analyzed.

A gauge-invariant Lagrangian field theory of the vector meson dominance model has been constructed based on the assumption that vector mesons of the nonet transform like non-Abelian gauge fields under gauge transformations of the second kind. With a $\tilde{U}(12)$ type of strong interaction model, the π^0 lifetime and other predictions are calculated and found to be in agreement with experiment. In addition, a field theory model satisfying approximate chiral algebra and PCAC* has

been constructed. A simpler method was found for obtaining recent results on the nonexistence of certain types of isospin multiplets.

On a more phenomenological level, an experiment was proposed to test the suggestion that interesting "regeneration" effects may occur in nuclear production of ω and ϕ mesons, observable as oscillations in the production rate as a function of mass number. A simplification was found in the calculation of certain high energy kinematic effects ("Deck effect"), clarifying the nature of the process and greatly simplifying rough calculations. A subroutine to compute and plot density matrix elements of resonances produced in 2-body reactions has been written. It is based on a simple model which consists in exchanging 0^- mesons and 1^- vector mesons and uses $SU(6)_W$ invariance at each vertex. This is part of a project in the study of production and decay of resonances.

An extensive energy-dependent phase-shift analysis has been performed on $K+p$ scattering data in the momentum region 140 to 1495 MeV/ c , supplementing the available experimental data by requiring that the resulting solutions also are consistent with forward dispersion relations. Several good solutions have been found and suggestions have been made for experiments to clarify the situation. An attempt is in progress to deduce the form of the π - N double spectral functions from scattering data by using the results of several recently performed π - N phase-shift analyses. A conformal mapping technique is used to provide a parametric form to fit the data in the physical region and to extrapolate the resulting absorptive parts to the double spectral regions.

In the field of weak and electromagnetic interaction phenomenology, it was shown how neutrino and photon-nuclear interactions may exhibit features normally associated with strongly interacting particles, and it was suggested that looking for these features provides a test for certain underlying theories of weak and electromagnetic interactions. A phenomenological analysis of the $K \rightarrow \pi\pi$ ($I=2$) amplitudes, in terms of their irreducible isospin amplitudes corresponding to the $\Delta I=3/2$ and $\Delta I=5/2$ transitions, has been made with reference to the observed violation of CP invariance. The unitarity condition for the $K^0\bar{K}^0$ system has been discussed in detail to evaluate the parameters describing the 2π decay modes. The question of the existence of direct weak couplings

*Partially conserved axial vector currents.

between neutral leptonic currents and neutral strangeness-changing currents has been discussed in the light of recent experimental upper limits on the decay rules for the modes $K_2^0 \rightarrow \mu^+ + \mu^-$ and $K_2^0 \rightarrow e^+ + e^-$. The implication of these limits upon $K^+ \rightarrow \pi^+ + l^+ + l^-$ decays is estimated by using current algebra and PCAC.

Some fundamental field theoretic questions were also investigated. An attempt has been made to construct a Lagrangian field theory of multispinor fields. In this model, field representations of rank higher than two consist of particles with different masses and both parities. The energy densities can be made positive definite with respect to states of the same parity but are otherwise indefinite. These difficulties can be avoided by the use of an indefinite metric or by the argument that the states of opposite parity are an approximate representation of higher continuum excitations required for a consistent Lorentz covariant theory. For a single mass and parity state the canonical commutation relations obtained from the action principle assume an extremely simple form. An investigation was made of the restrictions imposed on the form of field operators by requiring that they satisfy the commutation relations of the inhomogeneous Lorentz group. Two specific kinds of interacting theory were considered, the "instant" form, in which the operators representing transformations leaving surfaces $t = \text{constant}$ invariant remain unchanged by the presence of the interaction, and the "point" form, in which the unchanged operators are those leaving invariant the surfaces $K^L = \text{constant}$. In both cases a theory exists provided that a causal Hamiltonian density can be found whose commutator is proportional to a delta function of the relative space coordinate, and, in the instant case, even if derivatives of the delta function are present, provided that the coefficients of the derivative satisfy a certain condition. No explicit examples were found for interacting identical spin $\frac{1}{2}$ fields other than the usual nonderivative local coupling. The possibility of a noncausal relativistic theory in the instant form was examined.

80-In. Bubble Chamber

During the fiscal year, 1.81 million pictures were taken with the 80-in. chamber. This may be compared with 1.47 million pictures taken during the previous year and with 1 million pictures taken during fiscal 1965. These pictures were distributed

over 20 experiments performed by a total of 14 experimental groups.

The flexibility of the chamber as an experimental tool was increased considerably with the addition of two more liquids as possible chamber fillings. Deuterium was used for the first time this year, and 360,000 pictures were taken in two separate runs. In March the chamber was filled with a mixture of 50 at. % neon and 50 at. % hydrogen and 48,000 pictures were taken as a test with use of a beam of 5.5-BeV/c K^- mesons (see Figure 9). The radiation length in this mixture was 37 cm. An admixture of only 10 at. % neon results in a radiation length of 145 cm compared with the 10-m radiation length of pure hydrogen. These tests point strongly to the possibility of using such mixtures in even larger bubble chambers.

Primarily as a safety measure, a separate building has been constructed just outside the bubble chamber area to house the hydrogen refrigerator and purification equipment. Work is proceeding on fabrication of the necessary transfer lines and plumbing, and the refrigerator and purification equipment is scheduled to be removed from its present position on the bubble chamber and installed in the new building during the fall shutdown of the AGS.

Improvements made to the chamber during this period included a system for reduction of the influx of silica gel dirt to the chamber; the replacement of a recurrently leaking large indium seal by a weld; improvement of the visibility and usefulness of the main window fiducial marks by re-sandblasting them and adding a second set of fiducial marks of particular utility to users of SMP (scanning, measuring, projector) measuring machines; the addition of special sampling valves for accurate determination of the concentration of neon in hydrogen-neon mixtures; and the installation of a new cryogenic purifier for the expansion system which will eliminate loss of running time due to long reactivation times.

Design work has been done and most of the parts have been ordered for a hydraulic expansion system to replace the pneumatic expansion system. This will reduce losses of deuterium and neon. It will also provide more precise control over the expansion conditions and should reduce the rate of entry of dirt into the chamber. The hydraulic expansion system is expected to be more reliable than the pneumatic system, with a consequent increase in over-all efficiency. In addition it is an important

factor in eventually obtaining two or more pictures per AGS pulse. Work has continued on the development of a prototype multipulse camera for this purpose. Some delays have been encountered, but a set of cameras should be ready for the 80-in. chamber during the first part of 1968.

30-in. and 31-in. Bubble Chambers

A total of 2.7 million pictures were taken with the 30-in. bubble chamber during this fiscal year for 14 experiments. Liquid neon-liquid hydrogen and liquid neon-liquid deuterium mixtures with neon concentrations ranging up to 11 at. % were used for the first time for research in high energy physics with this chamber. The system to separate

Figure 9. The 80-in. bubble chamber filled with 50 at. % hydrogen - 50 at. % neon. The 5.5-BeV/c K^- mesons of the incident beam enter the chamber at the bottom of the picture. The first event (4-prong) is a hydrogenlike event (produced on hydrogen or a proton of neon) yielding $\pi^+ + \pi^+ + \pi^- + \pi^- + \pi^0 + \Lambda$. The π^0 is recognized by the two photons, one materializing into an e^+e^- pair, the other giving a Compton electron. The Λ gives a $p + \pi^-$. The second event (3-prong) is neutronlike (produced on a neutron of neon or on the neon nucleus as a whole). It yields $K^- + \pi^- + \pi^+ + \pi^0$ and a neutron or neon recoil (invisible). The π^0 is recognized by two e^+e^- pairs. In this event the π^+ decays to $\mu^+ + \nu$ and the μ^+ decays to $e^+ + \nu + \bar{\nu}$.

neon gas from hydrogen or deuterium gas was completed and tested successfully.

Assembly of the 31-in. bubble chamber (converted from the 20-in. chamber) was completed and the bubble chamber was installed in its block-house (see Figure 10). After several test runs, the chamber began in May to take pictures for the high energy physics program. The magnet for this chamber generates a magnetic field intensity of 23 kG (previously 17 kG). The chamber is equipped with a bright-field, retrodirective illumination system which uses Scotchlite. A hydraulically driven expansion system capable of multipulsing, i.e., producing two or more expansions per AGS pulse, is used to expand the chamber. A camera formerly used with the 20-in. bubble chamber was modified for double-pulse operation with the 31-in. chamber and was tested successfully.

Particle Physics Apparatus

The proposal for construction of a 14-ft-diam cryogenic bubble chamber has been resubmitted to the Atomic Energy Commission for Congressional approval for fiscal 1969. A Title I report on this project was completed last fall. The chamber is to have a useful volume of $\approx 47,000$ liters and a magnetic field of 30 kG. It can be operated with pure hydrogen or deuterium or with any desired

admixture of liquid neon. The justification for this chamber is based on the need for meaningful data on neutrino interactions and for improved statistics, accuracy, and completeness of information on individual events occurring in strong as well as weak interactions. Once the AGS conversion is completed, the 14-ft bubble chamber would provide an experimental tool that would make possible an improvement of two orders of magnitude in many phases of bubble-chamber research. The research and development program for the 14-ft chamber is continuing. It includes general development of such items as optical components, superconductors for the magnet, Fibreglas-epoxy components for the expansion system, and instrumentation equipment. The concepts of all such components are to be tested in a 7-ft test facility which will show performance under actual operating conditions and provide data for further development work leading to the final design of the chamber. Data are especially needed on optics through thick layers of liquid hydrogen or neon, performance of the

Figure 10. The body of the new 31-in. chamber. The expansion system connects at the top. A large part of the inside volume can be seen through the window.

Figure 11. Upper half of the superconducting Helmholtz coil suspended over the 24-in.-diam helium Dewar before cryogenic testing.

Figure 12. A downstream view of the "magnetic fingers" for focusing of pions and kaons to provide high-intensity neutrino beams. The first two fingers are seen in the foreground, and the third is at the rear of the assembly. The target is inside the first finger. Each finger is larger than the preceding one.

Scotchlite to be used for retrodirective illumination, performance of the superconducting magnet coils when operated for long periods of time, and performance of the expansion system over long periods.

In the area of superconducting coil development, a cable-stranding machine designed at BNL was used to strand 20,000 feet of stabilized superconducting cable for an 8-in. bore, 60-kG, split-pair magnet to be used in tests of superconducting materials for large bubble-chamber magnets. One section of the magnet was tested at liquid helium temperatures (see Figure 11) and generated a magnetic field intensity of 51 kG at 750 A. Extensive tests were continued on the resistance of various copper samples as a function of magnetic field, purity, and stress in the copper. Tests were also made of the properties of various insulating materials.

Design of the helium Dewar for the 7-ft test facility superconducting magnet is complete, and construction of the Dewar has begun. A detailed analysis was made of the stresses in the stabilized superconducting windings of this magnet. Magnet conductor specifications were then written and bids for scale-model samples of the conductor and the conductor itself were solicited.

An extensive technical evaluation of the submitted conductor samples was made at 4.2° K with use of appropriate test fixtures inside the bore of the 8-in. magnet together with the 4000-A power supply designed for the 7-ft test facility magnet. After an evaluation of the bid proposals and the results of the tests, the conductor for the 7-ft test facility superconducting magnet was ordered.

Design of other components for the magnet coil assembly was completed and fabrication was begun. Assembly of the device to wind the coils for the 7-ft magnet, which uses parts from surplus radar units, was started.

A "magnetic-finger" particle-focusing system (conceived and designed by R.B. Palmer, Nuclear Interaction Group) has been constructed. Electrical testing of the system has started. The finger system (see Figure 12) will be used to improve the intensity of neutrino beams for use in bubble-chamber and spark-chamber experiments at BNL. The need for such a device arises as follows. Neutrino beams are produced by allowing a parent beam of pions and K mesons (kaons) to decay in flight, after which a shield stops all decay products except the neutrinos. The better the parent particles of all momenta are focused, the more intense the resultant neutrino beam. The "magnetic horn" focusing de-

$$\pi^- + p \rightarrow \gamma + K$$

SC (TW) = TRIPLE CROSSED WIRE PLANE SPARK CHAMBER.
TRIPLE CROSSED SCINTILLATION COUNTER HODOSCOPES
CAN BE USED ALTERNATIVELY IN HIGH RATE CASES WHEN
SPACE RESOLUTION AND MASS IN BEAM REQUIREMENTS
ARE NOT TOO SEVERE.

S = SCINTILLATION COUNTER
C = ČERENKOV COUNTER
H = COUNTER HODOSCOPE
SC = SPARK CHAMBER

Figure 13. Schematic diagram (not to scale) of the double vee magnetic spectrometer using counter hodoscopes, digitized spark-chamber hodoscopes, and an on-line computer system, shown in an arrangement suitable for detecting an associated production event.

vice designed at CERN was considerably improved during its use at both CERN and BNL. The horn was not ideal, however, because its focusing power was restricted to a limited momentum region. The magnetic finger system focuses over a wider momentum range; with it, neutrino fluxes are expected to be more intense by a factor of 3 than those possible with magnetic horns.

A Brookhaven group has for the past several years been developing a double vee magnetic spectrometer system which will be used in an experimental program at the AGS next year. This apparatus will allow a detailed study of double vertex events such as

$$\text{I. } \pi^\pm + p \rightarrow \gamma (\text{or } \gamma^*) + K (\text{or } K^*) \\ \rightarrow N (\text{or } N^*) + M (\text{meson}).$$

$$\text{II. } K^- + p \rightarrow M + \gamma (\text{or } \gamma^*), \\ K^+ + p \rightarrow K (\text{or } K^*) + N (\text{or } N^*).$$

$$\text{III. } \bar{p} + p \rightarrow B + \bar{B} \text{ or } M + \bar{M} \text{ or } K + \bar{K}.$$

As shown in Figure 13, a number of spark-chamber hodoscopes and counter hodoscopes on-line to a computer will be used to allow the simul-

taneous detection of both vees and the momentum analysis of the charged decay particles. The high angular resolution (≤ 1 mrad), space resolution (≈ 1 mm), and the $< 1\%$ momentum resolution expected, combined with the high data rates (increase of ≈ 2 orders of magnitude), compared with previous visual technique investigations, are expected to allow much more detailed investigation for many of these reactions than was previously attainable.

Data Analysis

The BNL Bubble Chamber Group's "conventional" measuring system continued to perform satisfactorily during the year.

A new PDP-5 computer program has been prepared for on-line data acquisition from conventional measurement projectors with magnetic tape output. An incremental magnetic-tape output system has been designed and constructed for the PDP-5 computer, which is on line to four measuring machines, and will soon be installed. Other than this, no further developments of the conventional measuring system are planned in view of the

Figure 14. Measurement in progress with an image-plane digitizer ("mangiospago") of the bipolar coordinate type.

greater role now being played by the flying-spot digitizer (FSD). An orderly scheme for contraction of the conventional measuring system to meet the smaller but finite future requirements is being planned.

The system of "road-makers" for FSD guidance has been expanded to 7 Vanguard scanning/road-making machines. Design is well advanced for connection of the road-makers to the Scientific Data Systems (SDS) Sigma-7 computer of the data terminal network (see below). This connection will eliminate the troublesome and rather slow electro-mechanical hardware and the keypunches now used as an output medium. The Sigma-7 will also be connected to the CDC 6600 so that data can be transferred to the latter without intermediate storage in a physical medium.

A data terminal network project was initiated during the year. Its purpose is to facilitate access to the Laboratory's central computer and real-time data acquisition facilities for measuring equipment. Graphical input and output equipment will include cathode-ray-tube displays in addition to teletype equipment at each station. The system is designed to be capable of expansion to some ten graphical input stations and a similar number of measuring stations.

Construction of the first phase of the data terminal network was begun during the year. The SDS Sigma-7 computer, which is the heart of the network, and most of its peripheral equipment have been delivered. Hardware design for the system is almost complete, and the equipment to provide two remote consoles and ten measuring stations will be delivered by the end of the year. Hardware and software for the link to the CDC 6600 are being designed in consultation with the Applied Mathematics Department. The first stage of Sigma-7 software development, the design of the real-time monitor, has been completed and coding has begun. The development of system routines to operate under the monitor is just beginning.

The BNL Nuclear Interaction Group has made much progress in the use of their image-plane digitizing tables. Important innovations have been introduced and made operational in the data analysis system for bubble-chamber pictures. These innovations are described below.

1. Seven image-plane digitizers of the "mangio-spago" (bipolar coordinate system) type now scan and measure at the same time, combining two op-

erations that previously were separate functions using separate machines. The three newer prototypes have a setting error of about 10μ and are easier to operate than the earlier models. The rate at which events are processed is experiment dependent: typical rates are 7 to 8 events/hr, including scanning, measuring, remeasuring, ionization estimates, and recording. An additional five machines will be operational next year. Figure 14 shows one of these tables in operation.

2. All such tables are connected on line to an SDS 920 computer. This allows simple bookkeeping techniques, automatic control of view changing and other mechanical procedures, simple reconstruction of events on line and remeasurement of events immediately, and communication between computer and operator for further information such as ionizing and stopping of tracks.

3. The output of all measurements is now on two Ampex magnetic-tape outputs which can be used individually or in parallel with paper tape. This allows for direct feed of the magnetic tapes to the CDC 6600 computer with no intermediate steps (such as cards). A rapid access disc of ≈ 1 -million-word capacity is now being connected to the system and will permit conversion of all programs from machine language to FORTRAN. In effect this causes an expansion of the memory, in that large, infrequently used programs can be stored on discs and called when needed, which will

Table 1

Measurements by Brookhaven FSD's
During Year Ending May 1967

Number of events	Type of event	Beam
50,000	2-prong	6-BeV/c π^-
30,000	2-prong, 4-prong, strange-particle	3.5-BeV/c π^-
5,000	2-prong + vee	4.6-BeV/c K^-
20,000	2-prong	6-BeV/c π^+
20,000	2-prong, 4-prong	28-BeV/c p
7,000	small-angle scatters	7-BeV/c $\bar{p}$
3,000	strange-particle, 4-prong	7.4-BeV/c K^-

All measurements are for the 80-in. hydrogen chamber except those with the 3.5-BeV/c π^- beam, which are for the 20-in. hydrogen chamber.

The minimum design rate of 5000 events/week for the system has been reached.

Figure 15. A general view of the Brookhaven 70-mm FSD.

Figure 16. Production chart for FSD measurements since their inception in January 1966. Ordinate is events per week and abscissa is week number. The light-colored bars at the right top represent measurements by the 4 to 6 measuring projectors of the conventional measurement shop and are shown only since December 1966. The dark bars refer to measurements by the 70-mm FSD, the light bars at the bottom of the chart to measurements by the 35-mm machine. The minimum design rate of 5000 events/week for the system has been reached. The decrease in number of events per week in the last few weeks is due to the turning on of new experiments, since the three previous experiments were concluded at about the same time.

greatly increase the flexibility and capability of the computer.

Over the 12-month period ending in May 1967, the Brookhaven FSD's measured 135,000 events, distributed among several experiments as shown in Table 1. Figure 15 is a general view of the 70-mm FSD, and Figure 16 is a production chart for FSD measurements since January 1966.

Considerable progress has been made in developing quality controls for FSD measurements by appropriate subroutines in the chain of computer programs. This type of control is regularly being extended.

Broadening the range of application of the system continues to be the main development activity. A steady expansion in processing rate is being sought by the straightforward procedure of transferring personnel from conventional measuring to rough-digitizing for the FSD's as new experiments begin to run under the FSD system. A weekly rate of 8000 events should be reached in a year.

The BNL Bubble Chamber Group has spent considerable effort on the development of programs for the data processing of all their manual and FSD measurements.

Work has begun on programs for utilization of the data terminal network involving the SDS Sigma-7 computer, and some initial consideration has been given to the new problems in geometrical reconstruction presented by the optical systems of the 7-ft test vessel and proposed 14-ft bubble chamber.

However, the main effort has been the preparation and testing of a comprehensive set of programs for use on the CDC 6600. All these programs have been debugged and put into operation. In many cases testing has been extensive and the programs have been put into daily production use. Emphasis has been placed on uniform treatment of manual and FSD data, and systematic procedures for the operations of scanning, measuring, and digital computer processing of bubble-chamber events have been standardized wherever possible. Efficient use of personnel and equipment has been emphasized.

During the past year, the PDP-6 computer system of the Brookhaven on-line data facility for spark-chamber and counter experiments has been operated on a time-sharing basis that allows several groups to use the computer simultaneously. Two on-line experiments as well as several simul-

taneous off-line jobs were processed. Each group is assigned its own teletype, a protected core area, magnetic tape units, and DEC tape units. The processor is shared according to an automatic time-sharing monitor program which allows a change in user to be made in $\frac{1}{10}$ sec or selectable multiples thereof. The printer, for example, is time shared. The system has worked very well. During the past few months, 2 university groups, 2 university-BNL collaborative groups, and 2 BNL groups have been using it on a regular basis.

NUCLEAR STRUCTURE

Experimental work in the area of nuclear structure consists essentially of the determination of (1) the properties of nuclear energy levels – their energy, spin, parity, lifetime, and electromagnetic moments; (2) the characteristics of transitions between states of a nucleus or between neighboring nuclei; and (3) reaction parameters of importance in testing the validity of current theories of nuclear structure or in guiding their further development. The experiments fall into two general classes, those dealing with unstable (radioactive) nuclei produced by charged-particle bombardment at accelerators or the research reactors, and those concerned with the instantaneous products of nuclear reactions produced by charged particles or neutrons. Some outstanding examples of work carried on during the past year are given below.

A sensitive test for time-reversal invariance of the electromagnetic interaction has been devised which employs the Mössbauer effect on the 90-keV, $E2$ - $M1$ mixed transition in Ru^{99} . This transition is especially suitable for two reasons. The multipole mixing ratio is large ($\delta^2 = 2.7$). In addition, a well-resolved magnetic hyperfine recoil-free absorption spectrum can be obtained with an absorber of Ru^{99} dissolved in iron. The fraction of time-reversal odd component present in a mixed nuclear γ -ray transition is equal to the sine of the phase angle ϕ between the $M1$ and $E2$ components of the mixed transition. In this experiment linearly polarized resonant radiation is employed. It is then possible to measure a term in the resonant absorption cross section of an individual $\Delta m = \pm 1$ magnetic hyperfine component which is directly proportional to $\sin\phi$. This term, which is odd with respect to the sign of the change in magnetic quantum number Δm , is proportional to

Figure 17. Schematic of experimental arrangement for testing time-reversal invariance with the Mössbauer effect. The source is a single line source of Ru^{99} in ruthenium metal. The absorbers are both 4.8 at. % Ru^{99} (98.2% enriched) dissolved in iron. Both absorbers are mounted in H-frame magnets (not shown) and are magnetized in the directions indicated by H and H' , respectively.

$$(\mathbf{k} \cdot \mathbf{j} \times \boldsymbol{\epsilon}) (\mathbf{k} \cdot \mathbf{j}) (\boldsymbol{\epsilon} \cdot \mathbf{j}).$$

Here $\mathbf{j}$ is a unit vector in the direction of magnetization of the Ru-Fe absorber; $\mathbf{k}$ and $\boldsymbol{\epsilon}$ denote the direction of propagation and the direction of linear polarization of the incident γ rays, respectively. Linear polarization of the resonant γ rays emitted by a single line source of Rh^{99} in ruthenium metal is achieved by interposing a resonant polarizing filter consisting of another Ru-Fe absorber magnetized in the direction transverse to $\mathbf{k}$. A schematic of the experiment is shown in Figure 17. When $\mathbf{k}$ is directed along the z axis and $\boldsymbol{\epsilon}$ is aligned along the y (or x) axis, the term proportional to $\sin\phi$ becomes maximum when the magnetization H' of the second absorber is along the $(1,1,1)$ direction as indicated in the figure. This $\sin\phi$ term changes sign upon rotation into any adjacent quadrant or upon the reversal of H' . The $\sin\phi$ term originates from a tilting of the

elliptical polarization of the radiation field, corresponding to a $\Delta m = \pm 1$ transition, when the relative phase between the $M1$ and $E2$ components shifts away from zero or π . With currently available sources, this experiment should reach a lower limit in $\sin\phi$ of several tenths of one percent, an improvement by about an order of magnitude over previous limits from β - γ - γ triple coincidence measurements. During this experiment, a relatively large effect corresponding to $\sin\phi \cong 0.02$ was found. This effect had the correct reflection symmetries but was even with respect to the sign of Δm and was accounted for quantitatively as a nuclear Faraday effect. The Faraday effect manifests itself as a rotation of the linear polarization vector and is due to coherence between the incoming resonant radiation and the recoil-free radiation re-emitted by the resonant nuclei in the magnetically oriented absorber. The dependence of the effect on the polar angle of the direction of magnetization of the second absorber agreed with the theory of the Faraday effect. This angle dependence is very different for the Faraday effect than for a true time-reversal effect. In principle, the Faraday effect does not interfere with a test of time-reversal invariance because of the opposite dependence on a change in sign of Δm . The $\sin\phi$ term is extracted simply by taking the difference between the Faraday effects observed for a matched pair of lines with opposite Δm . It is important, however, to take into account possible effects (such as small quadrupole interactions) that may lead to an "asymmetric" Faraday effect and thereby give an apparent $\sin\phi$ term. These effects can be calculated from a carefully measured hyperfine absorption spectrum. Such calculations are in progress in order to achieve as precise a test of time-reversal invariance as the technique will allow.

Most of the nonspherical nuclei found in nature seem to be approximately axially symmetric. The projection of the total nuclear angular momentum along the symmetry axis is then (approximately) a good quantum number; its magnitude is denoted by K . If K were completely conserved, electromagnetic transitions of multipolarity L between states whose K quantum numbers differed by more than L would be forbidden. This K -selection rule was pointed out by Alaga et al. in 1955. The degree to which these K -forbidden transitions are hindered is one of the best measures of the degree to which K is a good quantum number. The half-lives of

about 100 K -forbidden transitions have been reported. A critical evaluation of the data has been undertaken to establish reliable hindrance factors for these transitions. Special attention has been given to the branching ratios of transitions from one initial state to two or more final states belonging to the same rotational band. The way in which the hindrance factors depend on the degree of forbiddenness, $|\Delta K| - L$, on the multipolarity and the electric or magnetic nature of the transition, on the deformation, and on the nature of the states involved is being investigated.

The capture γ rays of several isotopes have been studied in detail. In the $\text{Hg}^{199}(n,\gamma)\text{Hg}^{200}$ reaction, a total of 32 excited states of Hg^{200} were observed and their modes of decay established. γ Ray energies were determined with an accuracy varying from 0.1 keV for intense transitions to 3.0 keV for very weak transitions. The neutron separation en-

ergy of Hg^{200} is 8028.8 ± 0.5 keV. Additional information was also obtained on the levels of Hg^{200} in a study of the decay of Au^{200} produced from the stable isotope Pt^{198} in the High Flux Beam Research Reactor (HFBR) by double neutron capture. The lower-lying levels of Hg^{200} are found to have properties more complicated than those predicted by a simple vibrational model.

The structure of the isotopes of osmium is of considerable interest because these isotopes are situated in a transition region between deformed and spherical nuclei. In a search for new states of Os^{190} , the γ rays from the $\text{Os}^{189}(n,\gamma)\text{Os}^{190}$ reaction have now been investigated. The level scheme established in this work is shown in Figure 18. Seven new energy levels below 2 MeV were found to be populated by primary transitions from the state formed by neutron capture. The most interesting new levels lie at 912 and 1115 keV. The 912-keV

Figure 18. Level scheme of Os^{190} established in the study of neutron capture γ rays of the $\text{Os}^{189}(n,\gamma)\text{Os}^{190}$ reaction.

level is probably a $0+$ state. The ≈ 200 -keV separation of the 1115-keV level from the 912-keV level suggests that it is a $2+$ rotational state built on the latter. Several models predict that a collective $0+$ state of Os^{190} should lie between 900 and 1000 keV. In terms of the characteristic vibrational and rotational energies of the two nuclei, the energies of the 912-keV level of Os^{190} and the 1086-keV $0+$ level of Os^{188} are closely comparable. The relative strengths of the transitions from the 912-keV level to the $2+$ levels at 558 and 187 keV are important both in determining the nature of the 912-keV level and as a test of the predictions of various nuclear models. The experimental ratio of the reduced transition probabilities of the two transitions is

$$\frac{B(E2, 0+ \rightarrow 2+)}{B(E2, 0+ \rightarrow 2+)} = 20 \pm 5.$$

If the 912-keV level is described as a β vibrational state, or, alternatively, as a 2-phonon vibrational state, the predicted values of this ratio are not in accord with the experimental value. On the

Figure 19. Doppler shift measurement in the $\text{F}^{19}(\alpha, n\gamma)\text{Na}^{22}$ reaction. The spectrum is the sum of three obtained $E_\alpha = 4.7, 4.8$, and 5.2 MeV. Background has been subtracted. The dispersion is 0.4535 keV/channel. The solid curve is a theoretical fit to the γ -ray line shape as described in the text. The parameters used in the theoretical curve are given in the figure (FWHM = full width at half maximum). The full-energy-loss peak of the 1.528 -MeV γ ray corresponds to the Na^{22} $1.528 \rightarrow 0$ transition observed at 0° to the beam. The γ ray results from direct feeding of the 1.528 -MeV level in the $\text{F}^{19}(\alpha, n)\text{Na}^{22}$ reaction initiated in a 1.0 -mg/cm 2 CaF_2 target.

other hand, both the model of Davydov, in which the 912-keV level would be considered to be a 1-phonon γ vibrational state, and the calculations of Kumar and Baranger, in which the β and γ vibrational modes are not treated separately, predict ratios of transition probabilities in reasonable agreement with the experimental value.

In the Van de Graaff program the properties of energy levels in light nuclei were investigated by means of high-resolution Ge-Li γ -ray detectors, particle- γ angular correlation methods, and other techniques. An especially interesting case was the study of the γ -ray decay of the $1-$, 7.12 -MeV state of O^{16} . This state, formed in the $\text{F}^{19}(p, \alpha)\text{O}^{16}$ reaction, is known to emit electric-dipole ($E1$) γ radiation to the $0+$ ground state. An intensive search was made for an $E1$ cascade branch to the $0+$ first excited state of O^{16} at 6.06 MeV. The experimental upper limit of 6×10^{-6} on the relative intensity of this branch corresponds to a reduced transition probability that is more than 100 times weaker than the weakest previously known $E1$ transition in the light elements.

The low-lying energy levels of Ne^{21} , Ne^{23} , and Ar^{41} and the γ -ray transitions between them were investigated in collaboration with a group from Yale University. In these studies p - γ correlations were measured via $(d, p\gamma)$ reactions with use of gas targets of enriched Ne^{20} , Ne^{22} , and Ar^{40} .

A thorough investigation was made of the properties of energy levels in Na^{22} up to about 3 MeV as formed in the reactions $\text{F}^{19}(\alpha, n)\text{Na}^{22}$, $\text{Ne}^{20}(\text{He}^3, p)\text{Na}^{22}$, and $\text{Ne}^{20}(\text{He}^3, n)\text{Mg}^{22}(\beta^+)\text{Na}^{22}$. In the last of these reactions the decay of Mg^{22} was studied by means of a Ge-Li detector. A new γ ray of 1279.8 ± 0.2 keV was observed and resolved from the 1274.5 ± 0.1 -keV γ ray emitted in the decay of the Na^{22} daughter activity. This new result on Mg^{22} decay establishes a 4.6% allowed positron branch to the 1.936 -MeV level of Na^{22} and demonstrates that the spin-parity of the 1.936 -MeV state is $1+$. Other detailed work on the first eleven Na^{22} levels included γ - γ coincidences, angular distributions, p - γ angular correlations, decay modes, and γ -ray Doppler shifts.

An example of a Doppler shift measurement made in the $\text{F}^{19}(\alpha, n\gamma)\text{Na}^{22}$ reaction is illustrated in Figure 19. This figure shows the full-absorption peak of the ground-state transition from the Ne^{22} 1.528 -MeV level. The γ -ray line was observed with a Ge-Li detector at 0° to the α -particle

beam. The peculiar shape is due to the Doppler effect coupled with the lifetime of the 1.528-MeV level. The smooth curve is a theoretical fit to the experimental data and is a function of the lifetime of this level, as well as of parameters describing the stopping process of the recoiling Na^{22} nuclei. A mean lifetime of $(3.8 \pm 0.9) \times 10^{-12}$ sec was obtained for the 1.528-MeV level from this comparison.

Spins, parities, lifetimes, and γ -ray decays were determined for energy levels up to 5 MeV in F^{18} formed in the $\text{O}^{16}(\text{He}^3, p)\text{F}^{18}$ reaction. The g -factor of the 1.131-MeV ($5+$) state of F^{18} was determined to be $+0.568$ by using a differential time-delay technique. The target was placed in a magnetic field and the rate of gyromagnetic precession of the nucleus, while in the 1.131-MeV state, was measured by observing oscillations in the p - γ coincidence time-delay spectrum, superposed on the normal exponential delay curve.

The decay of Co^{56} and Mn^{56} to levels in Fe^{56} was investigated with NaI and Ge-Li detectors. The previously unobserved allowed decay from the ground state of Mn^{56} to the $4+$, 2.085-MeV state in Fe^{56} has been seen ($\log ft = 8.7 \pm 0.2$). Precision energy measurements of the high energy transi-

tions in Fe^{56} and Co^{56} decay, especially at 3253.7 ± 0.2 keV, 3273.7 ± 0.3 keV, and 3452.1 ± 0.3 keV, have been useful as laboratory comparison transitions in an energy range in which precise energy measurements are rare. Use was made of these transitions to extend precision energy calibrations to still higher energies by comparison of two escape peaks and full energy peaks in a Ge-Li detector. To confirm measurements obtained in this fashion, corroborating measurements by a sum-cascade method were also performed. Some of the more useful values obtained for transition energies identified by the nucleus from which they originate are, in keV: 4438.91 ± 0.31 (C^{12}), 5270.60 ± 0.47 (N^{15}), 6129.96 ± 0.46 (O^{16}), and 7117.02 ± 0.49 (O^{16}).

Several experiments have been initiated on electromagnetic properties of levels from $f_{7/2}$ shell nuclei. Among these are the γ -ray energies and intensities from the $\text{Ca}^{48}(d, n\gamma)\text{Sc}^{49}$ reaction, done with n - γ coincidences, and a measurement of the lifetime of the first excited state of Sc^{46} , done with p - γ coincidences from the $\text{Sc}^{45}(d, p)\text{Sc}^{46}$ reaction. The time spectrum yielded a half-life of 8.8 ± 0.4 μsec , consistent with a pure $E2$ transition. Assuming the theoretical $E2$ conversion coefficient of 4.4, this result implies a reduced transition probability $B(E2) = 3.1 \times 10^{-51} e^2 \text{cm}^4$.

Coulomb excitation studies using the doubly ionized helium beam from the BNL electrostatic accelerator have been carried out on a number of separated isotope targets. Yields and, in some in-

Figure 20. Selected portion of the γ -ray spectrum observed in Coulomb excitation of Fe^{57} by 6.5-MeV α particles. The spectrum was obtained with a 10-cm³ planar Ge-Li detector. The target was a 1-mil metallic iron foil enriched to 92.7% in Fe^{57} . Except where noted, the γ rays are those from de-excitation of states in Fe^{57} .

stances, angular distributions of de-excitation γ rays have been measured. Because of the complexity of these spectra, the use of high-resolution Ge-Li detectors was essential. Detailed studies have been made for Fe^{57} and Gd^{155} targets. Reduced transition probabilities $B(E2, \uparrow)$ have been determined and accurate branching ratios obtained. A typical γ -ray spectrum observed in such a Coulomb excitation measurement with a Ge-Li detector is shown in Figure 20.

The 60-in. cyclotron has been undergoing modification to a sector-focusing, variable energy form and will provide a maximum proton energy of 40 MeV, a deuteron energy of 20 MeV, a He^4 energy of 40 MeV, and a He^3 energy of 60 MeV. The energy will be smoothly and continuously variable down to $\approx 1/10$ of the maximum energy. Heavier particles can be accelerated. A flexible target arrangement and beam transport system is being developed.

An experiment employing a resonance fluorescence method has been performed to correctly assign previously measured lifetimes to states in Re^{187} . Recoil compensation was achieved by placing sources of W^{187} near the periphery of a specially constructed high-speed rotor. A 25-cc Ge-Li detector was used to observe the resonantly scattered γ rays from a rhenium metal scatterer. The high-resolution detector was needed to determine

unambiguously the states (618 and 625 keV) to which known mean lives of 1.6×10^{-11} and 7.6×10^{-10} sec should be assigned. The high yield of 618-keV resonantly scattered γ rays is shown in Figure 21. The 1.6×10^{-11} -sec lifetime must thus be assigned to the 618-keV state. The 7.6×10^{-10} -sec mean life thus is assigned to the 625-keV state.

The measurement of the g -factor of a short-lived nuclear excited state by magnetically perturbing a γ - γ angular correlation is often complicated by the presence of other hyperfine interactions which may attenuate the correlation and falsify the measurement of the g -factor. Measurements on the time dependence of the 294 keV - 57 keV γ - γ angular correlation in Pr^{143} have shown that this correlation is severely attenuated in liquid phase sources. Such sources were used in magnetically perturbed correlation measurements for determining the g -factor of the 57.4-keV state ($T_{1/2} = 4.22$ nsec). The observed time dependence of the γ - γ correlation function agrees reasonably well with expectations based on recent conversion electron studies of L -subshell ratios made at Chalk River. After applying a correction appropriate for the measured time dependence of the correlation, the g -factor for the 57.4-keV state may now be determined as $g = (+2.6 \pm 0.2)/\beta$. Use of the paramagnetic correction factor β appropriate to the praseodymium ion in its +3 charge state ($\beta = 2.0$) gives a g -value of $+1.3 \pm 0.1$.

Figure 21. Yield of γ rays from a W^{187} source moving at 9.85×10^4 cm/sec which are resonantly scattered from a natural rhenium metal scatterer. The background is the scattered spectrum observed when the source is moved at a low velocity.

NEUTRON PHYSICS

The new high-intensity fast-neutron chopper system has been in operation at the HFBR for the past year. The system was used to study γ rays following neutron capture in the energy range 0.025 to 1000 eV. These transitions connect states in the compound nucleus at an excitation corresponding to the neutron binding energy with the low-lying nuclear states. Thus, information on both kinds of states may be obtained. With this facility evidence has been obtained for the presence of a direct reaction mechanism in the slow-neutron capture process. Such a mechanism had been postulated, but unambiguous evidence for its presence has never been obtained. In this process an incoming S -wave neutron is scattered by the nuclear potential directly into a low-lying P -state, emitting a γ ray. The reaction amplitude for this effect is largely independent of energy, in contrast to the sharply

varying Breit-Wigner resonance amplitudes. The partial capture cross section may be written

$$\sigma_{n\gamma f} = \pi \lambda_0^2 \lambda_g |A_0 + (\Gamma_n^0 \Gamma_{\gamma f})^{1/2} / [(\Delta E)^2 + \frac{1}{2} i \Gamma]|^2.$$

Evidence for the direct term, A_0 , is obtained from interference with the resonance term. The partial cross sections for the production of 10 strong capture γ rays in the reaction $\text{Co}^{59}(n, \gamma)\text{Co}^{60}$ were measured as a function of neutron energy. The energy variation of the ground-state γ ray exhibited

Figure 22. γ Rays following P -wave neutron capture in the 45.75-eV resonance of Sn^{118} viewed at 90° and 135° to the incident beam. The change in relative intensity establishes that the capturing state has a spin and parity of $\frac{3}{2}^-$.

an interference shape which could be explained by a direct capture cross section of 9.2 mb at 1.0 eV. This result constitutes the first measurement of the direct reaction amplitude in the neutron capture process.

γ Rays following P -wave neutron capture generally display a nonisotropic distribution of the form $a + b \sin^2 \theta$. The measured degree of anisotropy can give information on spins and parities of the final and initial states in the reaction. This was exploited in the case of levels in Sn^{119} resulting from neutron capture in Sn^{118} . Figure 22 shows results obtained at 90° and 135° for capture γ rays for the resonance at 45.8 eV leading to the $\frac{1}{2}^+$ ground state and $\frac{3}{2}^+$ first excited state in Sn^{119} . The apparent asymmetry definitely establishes the spin and parity of this resonance as $\frac{3}{2}^-$. The angular distributions for transitions to 8 final states in Sn^{119} were measured. Results are shown in Table 2 with the deduced spin assignments.

Since neutron capture is a single-channel process, there are strong level-level interference terms in the partial capture cross section. The measured ratio of the partial cross section for the emission of ground-state γ rays to the total capture cross section is compared to the calculated ratio as derived from the Breit-Wigner single-level formula. Strong destructive interference between the 1^+ resonance at 4 eV and a 1^+ bound state is evident in the region near thermal neutron energy for the case of $\text{Tm}^{169}(n, \gamma)\text{Tm}^{170}$. Constructive interference is evident in the region between the 14 and 17-eV resonances. These interference analyses are helpful in assigning resonance spins in doubtful cases. Figure 23 shows the γ -ray spectrum obtained for the 3.9-eV resonance in Tm^{169} . The presence of peak 2

Table 2

Angular Distribution of γ Rays From $\text{Sn}^{118}(n, \gamma)\text{Sn}^{119}$

γ -Ray energy, keV	Final state excitation energy, keV	$I(90^\circ)$ $I(135^\circ)$	Spin of final state
6484	0	1.26 ± 0.17	$\frac{1}{2}^+$
6461	24	0.75 ± 0.10	$\frac{3}{2}^+$
5563	921	0.58 ± 0.10	$\frac{3}{2}^+$
5394	1090	0.95 ± 0.15	$\frac{3}{2}^+$
5297	1187	0.57 ± 0.15	$\frac{3}{2}^+$
5232	1252	1.37 ± 0.20	$\frac{1}{2}^+$
4910	1575	0.72 ± 0.09	$\frac{3}{2}^+$
4709	1775	1.30 ± 0.28	$(\frac{1}{2}^+)$

indicates a transition to the Tm^{170} first excited 2^- state at 37 keV, which clearly establishes the spin of the 3.9-eV level as 1^+ . The reliability of using capture γ -ray spectra for resonance spin assignments has been established by comparison of results obtained in recent experiments with those obtained from transmission experiments using polarized targets.

The neutron cross section of He^3 is large and strongly spin dependent, while the He^4 cross section is small and independent of spin. Recent experiments have demonstrated that phase separation in He^3 - He^4 solutions at low temperatures is easily observed with a neutron beam, and the boundary between the He^3 -rich and He^4 -rich phases can be clearly identified. In principle, it should also be possible to determine the He^3 concentration in each phase, but the results obtained to date are systematically shifted from those obtained by specific heat measurements. The reasons for this difference have not yet been determined. Nuclear spin susceptibility measurements were also made on pure liquid He^3 in the temperature range 1.0° to 0.060°K . These measurements, which involve the use of polarized neutrons, provide an interesting comparison with currently available nuclear magnetic resonance (NMR) measurements.

Installation of the new polarization spectrometer facility at the HFBR is nearing completion. Following a test and calibration period, it should go into research operation by the fall of 1967. In an extension of the experiments with polarized neutrons and nuclei formerly carried out at the Brookhaven Graphite Research Reactor, the improved intensity, resolution, and target environment will permit experiments on a greater variety of ma-

terials and will open up some entirely new experimental areas.

A series of studies was completed this year in which the Mössbauer effect was used to study the time dependence of radiation emitted following the decay of a nuclear level. This work was performed in conjunction with the Technische Hochschule in Munich, West Germany. In measurements on the decay of Co^{57} to Fe^{57} , certain unexpected Mössbauer lines were obtained which were interpreted in terms of metastable charge states following electron capture. The reasoning is as follows. Co^{57} decays by capturing a low-lying electron. This leads to the production of Fe^{57} with a hole in a low-lying electronic level. In an Auger process, an electron falls into and fills the empty hole. The end result of a series of such processes can in some circumstances be very highly charged iron. This is of some chemical interest since the effects are related to chemical equilibrium processes.

In the delayed-coincidence Mössbauer effect studies, the decay of Co^{57} was announced by the emission of a γ ray which was used to start a clock. The clock was stopped by the arrival of a 14-keV Mössbauer γ ray. Mössbauer-Doppler shift or velocity spectra could be taken for a series of delay times following the Co^{57} decay. Detailed analyses of the resulting spectra give a clear indication of the effects occurring as the electronic structure approached equilibrium. A number of chemical compounds were studied in which such time-dependent effects had previously been inferred. In no case were any such effects found in the delayed coincidence studies. It was thus possible to conclude unambiguously that the origin of the observed complex Mössbauer spectra must be sought elsewhere.

One of the questions of interest in the theory of magnetism in both insulators and metals is the way in which the ordering interactions change with the separations between magnetic atoms. A new method of determining this spatial dependence was developed which involves measuring

Figure 23. The γ -ray spectrum following neutron capture in the 3.9-eV resonance of Tm^{169} . The presence of peak 2 indicates a transition to the 2^- state at 37 keV in Tm^{170} and establishes the spin and parity of the 3.9-eV resonance as 1^+ .

the distribution of the magnetization per atom in the vicinity of the transition temperature and in materials in which some of the magnetic atoms have been replaced by nonmagnetic atoms. A theory was formulated by which the relative contributions to the ordering process from a large number of neighbors can be calculated. The calculated magnetization distributions are then compared with the distribution of fields at the nuclei of the magnetic atoms, as determined directly by the Mössbauer effect. Detailed comparisons were made on ferromagnetic alloys of iron in palladium and excellent agreement was found for an interaction range of about 5 Å.

Work was continued on the superconducting transition temperatures of thin films. Recent work has established critical temperatures (T_c 's) near 6°K in aluminum films compared with 1.2°K for bulk aluminum. In films of tin and zinc, T_c 's have been raised to 6°K and 1.8°K, respectively. These values are significantly higher than any found by previous workers using low-temperature deposition techniques and are a result of the different physical contact conditions and geometry used in these experiments. Measurements on the critical field of thin aluminum films indicate that the superconducting state in these films has a paramagnetic susceptibility. Theories of this effect based on spin-orbit scattering can qualitatively explain the data. However, it is not clear how a large enough spin-orbit scattering term can be obtained for such a low Z element as aluminum.

SOLID STATE PHYSICS

The research program 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. Some representative research studies are described briefly below.

Theory

The theory of the Mössbauer effect in the presence of time-fluctuating external electric-field gradients and magnetic fields has been generalized and extended. An exact solution has been found for fields changing in direction as well as in sign. The theory shows that there are a number of phenomena that occur only in this more general case. For example, fields that change their direction are

capable of causing transitions between different nuclear energy levels (nuclear relaxation effects).

The Mössbauer spectra of ferric hemin were explained on the basis of the theory of relaxation phenomena. The spectra had been found by more than eight experimental groups but had not been satisfactorily interpreted until now. The spectra show a quadrupole splitting at low temperature. As the temperature is raised, one of the two lines becomes strongly broadened until at room temperature a very much broadened single-line spectrum is found. The usual feature of these results is that the fluctuation rate of the ions appears to slow down as the temperature is raised. The proposed explanation shows that the spin-spin relaxation in hemin is temperature dependent, and, indeed, as a result of changes in the population of different energy levels, the rate decreases as the temperature is increased.

Theoretical work on first-order phase transitions in magnetic systems has been extended in a number of directions. An exact soluble model of the first-order phase transition has been found. This is a spin-one Ising model with infinite-range interactions and includes a single ion anisotropy term. In the infinite particle limit the molecular field solution is exact. In addition, the various thermodynamic quantities (magnetization, energy) for finite particle numbers have been evaluated directly by computer calculations. The finite particle solution rapidly approaches the infinite particle exact solution as the number of particles is increased to a few thousand.

The role of covalent effects on the energy levels and spin densities of rare-earth ions in crystals was investigated. Effects arising out of the supposedly inert closed $5p$ shell were found to be more important than "covalency" directly involving the open $4f$ shells. This presents a real complication in understanding rare-earth behavior. The interrelation of the magnetic behavior of the heavy rare-earth metals with their electronic band structure and Fermi surface, and in turn with other physical observables such as their resistivity, is being investigated, and a consistent qualitative picture involving an increasing number of details has emerged in the past year. The magnetic perturbations of the conduction bands were examined quantitatively and found to be so pronounced that a perturbation approach to understanding details of these metals' magnetic behavior appears impractical.

The collaborative program with Bell Telephone Laboratories and Rutgers University on the anisotropic effects in the interaction of energetic charged particles in single crystals was continued. There is now a good basic understanding of the "channeling" process in terms of a model in which a series of correlated small-angle scattering events is responsible for steering of particles in an average potential of atom rows or planes. Calculations show that the average potentials and, therefore, the angular channeling widths at a given particle energy increase with decreasing temperature. Experimental results confirming this have been obtained elsewhere.

Computer calculations on "blocking" effects in silicon were performed. These effects are related to channeling but take place when a particle is emitted from a lattice site or is scattered by a lattice atom in the direction of atomic rows or planes. In one model, a large number of particle trajectories were followed after isotropic emission from a lattice atom and successive scattering by atoms of a row until deflection became negligible. Temperature effects were introduced by allowing the emitter and scatterer atoms to have random distributions about perfect lattice sites. In another model, the atomic row was replaced by a temperature-dependent average potential. Comparison between the distributions of emergence directions showed that the average potential concept holds well over a wide range of thermal motion amplitudes.

Computer calculations for the study of point defects in metals were continued. Large vacancy clusters have been investigated with body-centered and face-centered cubic models which simulate α -iron and nickel, respectively, and which previously were used to study single vacancies and interstitials. For α -iron, the tetravacancy was the smallest immobile cluster, and the mono, di, and tri-vacancy essentially share a common migration energy, 0.65 to 0.70 eV. The binding energy gain per additional vacancy increased as the cluster size increased from 2 to 6 vacancies and approached a limiting value of about 0.8 eV/vacancy between 6 and 10 vacancies. The most stable form for small clusters was found to be a void of quite tightly packed vacancies. In the nickel calculations, a void was also found to be the most stable form of cluster, and in this case the shape was investigated in detail. The formation energy per vacancy was close for both spherical and octahedral voids, with

the latter becoming more favored as the size increased, while at the limit of large voids a truncated octahedral shape became most stable. Stacking-fault tetrahedra were found to be less stable than voids for all sizes.

Recent experiments, reported over the last two years, show that alkali halide crystals doped with impurities of small size possess many unusual properties. For example, if a small amount of LiCl is introduced into KCl, the resultant material has altered electrical and acoustical properties. Most interestingly, the material exhibits the electrocaloric effect; that is, the crystal cools upon removal of an electric field (analogous to cooling by demagnetization). These experimental results imply that the small ion (Li^+) does not substitute exactly for the larger ion (K^+) but is located on a site somewhat removed from the normal site. The theoretical work at Brookhaven clarified the factors responsible for the off-site position stability and the nature of the distortion of surrounding ions. The theoretical calculations were rather intricate because the attractive and repulsive energy terms as altered by the disturbed lattice must be considered in detail. Since a large number of ions are displaced when the impurity ion is off the lattice site, calculations must be done on a high-speed computer. The stable configuration obtained in these calculations showed clearly that the lithium ion is not located on the lattice site but is displaced about 20% in the direction of the body diagonal. Such a displacement will occur as long as the impurity ion is small and the repulsive energy terms are not unusually large. The theory predicts that at sufficiently high hydrostatic pressures the impurity ion will move back to the lattice site. High-pressure experiments have not yet been done. From the theory it is also possible to predict which ion, in what host crystal, will be off the lattice site. Agreement with experiment is excellent.

The atomic displacements around a carbon interstitial in iron martensite were calculated by applying two equal doublet forces in the $[110]$ directions and a third doublet force in the $[001]$ direction. The crystal was treated as a finite, elastically isotropic medium containing a uniform distribution of such singularities, and the predicted lattice dilatations were matched to experiment to determine the strengths of the singularity. From the strengths the elastic displacement field around one carbon interstitial was calculated. On the basis

of this field, the mean-square displacement normal to the tetragonal axis is found to be small, while that parallel to this axis is large. From measurements of the attenuation of the Bragg reflections, the first-neighbor displacement can be determined. Using these results, Moss has recently found a displacement of 0.535 Å. This suggests that the irregular octahedral site in martensite is distorted by the presence of a carbon atom to a nearly regular octahedron with an iron-carbon distance of about 1.94 Å.

Crystal Imperfections

The study of defects in crystals continued as a major research activity in solid state physics. Basic investigations of charged-particle interactions with crystals and of the formation and subsequent behavior of color centers in inorganic solids are in progress. The program concerned with electron transport properties of organic crystals has become an important part of the over-all research effort.

The importance of planar channeling in determining the minimum energy loss of particles in transmission through a thin crystal of silicon was demonstrated in an experiment with good energy resolution. It was shown that for the same crystal thickness the minimum energy loss for $\langle 110 \rangle$ axial channeling is equal to that for $\{111\}$ planar channeling. The same result holds true for the $\langle 111 \rangle$ axial and the $\{110\}$ planar channels. These results indicate that axially channeled particles wander from one channel to the next, sampling an electron density whose minimum value is essentially equal to that between two atomic planes.

Studies of radiation-induced effects in alkali halides were continued. The first-stage x-ray-induced *F*-center coloring of KCl was carefully studied in crystals of different purities. At room temperature, the first-stage *F*-center vs dose curve is very roughly a saturating exponential, the second state is linear with dose, and the third state increases rapidly with dose. The "impure" KCl crystal contained roughly ten times the total number of impurity atoms present in a "pure" crystal. Upon irradiation at room temperature, the coloring curves of both crystals were found to consist of three exponential components and a linear component. One of the exponential components is too small to study in detail. The other two can be separated, since one component is sensitive to mechanical straining while the other depends on the

dose rate and can be modified by coloring-bleaching-recoloring cycles. The intensity of the exponential components is 5 or 6 times greater in the "impure" crystals than in the "pure" ones. Furthermore, the far-uv absorption in the two materials is considerably different. These observations suggest that the rate-controlling step in *F*-center coloring is the trapping of holes. The crystals must contain efficient traps if the holes are to be prevented from recombining with *F*-centers and destroying them almost as fast as they are formed.

The major activity in the cooperative program with Picatinny Arsenal is the study of transport mechanisms in pseudostable materials and their relation to incipient and radiation-induced defects. A study was completed on the ultraviolet-induced photolysis of powdered NaBrO₃, both unirradiated and subjected to Co⁶⁰ γ -ray irradiation. The rate vs time curves for all samples show an initial acceleratory stage followed by a constant decomposition rate. This final stage deviates from a second-order dependence on light intensity in a manner opposite to that reported in most previous studies. The curvature observed is attributed to the photolytic generation of additional decomposition sites. γ -Irradiation increases the variation from an exact second-order dependence, decreases the initial rate, and decreases the time required to reach the final stage. A phenomenological theory was developed which is consistent with the observed dependence on intensity.

Work was continued on certain types of geological problems. An example is the dating by radiation-effect studies of mineral apatite samples from Durango, Mexico. Prior to irradiation, these samples contain two electron spin resonance (ESR) absorption signals; when exposed to γ -rays, the two signals increase linearly with dose. Signal vs dose curves showed that the geological doses required to produce the two signals were 1.94×10^6 and 1.86×10^6 R. The maximum annual dose was found to be 1.04 R/yr; hence, the age indicated by these measurements is 2 to 4×10^6 yr. These samples have not as yet been independently dated. However, the stratigraphy at Durango indicates a maximum age for the entire region of 5×10^7 yr. Cursory annealing experiments indicate that the traps producing these ESR signals retain charges for periods much longer than 4×10^6 yr.

Investigation was continued of the electrical and optical properties of crystals of condensed aromatic

hydrocarbons. As previously reported, the two molecules consisting of three benzene rings, anthracene and phenanthrene, behave quite differently. For example, phenanthrene is a much poorer conductor and photoconductor and in addition has an anomaly in its heat capacity and in its resistivity at 72°C. Further investigation has been directed toward interpreting such differences in behavior in terms of differences in molecular structure. Phenanthrene has two hydrogen atoms which, if the molecule is planar, could interfere with one another. Since most of the condensed aromatic hydrocarbons consisting of four rings have at least one pair of crowded hydrogen atoms, anomalous behavior might also be expected in these molecules. To date, a heat capacity anomaly of 869 cal/mole has been found in chrysene at 232°C (m.p., 252°C). It was also demonstrated that the anomalous behavior of phenanthrene is peculiar to the solid state, for in solution it exhibits no heat capacity anomaly. An NMR study of hydrogen in phenanthrene was attempted to determine whether the anomalous behavior at 72°C affected the relaxation time. Although passage through the melting point caused it to decrease by a factor of 25, no variation was seen at 72°C, which indicates that the anomaly is not associated with a large vibrational motion of the hydrogens.

Activity at the 3-MeV electron accelerator was concentrated on experimental equipment assemblies and test runs. A general-purpose data acquisition system was put into operation. The scattering chamber for studies of transition radiation from solid films was completed. The entire system of thin-film evaporator, scattering chamber, scanning uv spectrometer, and photomultiplier detector is essentially complete. A computer program written at SLAC is being used in a study of the properties of the accelerator beam optics. These calculations will make it possible to understand the behavior of the electron gun and the degree to which it has been matched to the beam tube, and should suggest ways of improving beam quality. They should also be of great value later during the ion beam conversion.

Structure of Solids

Another major experimental activity is the use of neutron diffraction in studies of the dynamical and structural properties of solids. The High Flux Beam Research Reactor (HFBR) has now been in

regular operation for more than a year and has proved to be an excellent facility with a high neutron flux combined with a low experimental background. The principal emphasis has shifted to inelastic scattering problems and the precise determination of spin density distributions.

Measurements of phonons in crystals of a rare gas provide a direct way of investigating interatomic potentials in a simple solid state system. The first such measurements were carried out at the HFBR on a single crystal of krypton. A crystal nearly 1 cm³ in size was grown from the liquid phase under a pressure of about 2300 atmospheres, annealed at a temperature of 166°K, and then cooled to 79°K. The relationship between frequency and wave number for phonons in this fcc crystal was measured along the principal symmetry directions on a triple-axis neutron spectrometer. The results are of great interest, since precise theoretical calculations of fundamental properties can be made with a minimum of assumptions. A thorough analysis of the data is still under way, but preliminary results indicate that the quasi-harmonic approximation is probably inadequate for the case of solid krypton.

The study of magnon dispersion relations in 3d metals was continued with emphasis on direct energy analysis. Extensive measurements were made on iron at room temperature, along the [110], [001], and [111] directions, up to magnon energies of 70 MeV (q/q_{max} up to 0.4 in the [110] direction). The results clearly deviate from the classical Heisenberg model, reflecting the effect of the itinerant electrons on magnetism in 3d metals. A comprehensive study of the temperature dependence of the spin wave energy in iron was also carried out and showed that spin waves continue to be well-defined excitations in this metal at temperatures up to $T/T_c \cong 0.99$.

Investigations of magnetic structures and spin density distributions in a variety of materials continued to be an important part of the diffraction program. One material studied in the past year is the deuterium analogue of antiferromagnetic $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, which has been the subject of numerous experimental and theoretical studies in the past decade. This is a problem for which a high neutron flux is a *sine qua non*, since polarized beam techniques cannot be used in this particular case, and the magnetic moment of Cu^{+2} is only 1 μ_B . The spin density distribution of the copper ion was

found to have a marked asphericity which can be satisfactorily explained on the basis of a Cu^{+2} ground-state wave function with an admixture of two $d\gamma$ orbitals in the approximate ratio 90% $d_{x^2-y^2}$ and 10% $d_{3z^2-r^2}$. There is no evidence of appreciable spin density between the Cu^{+2} and Cl^- ions, as suggested by Poulis and Hardeman as a possible explanation of their proton resonance results. A second objective of the study was to determine whether the small canting of the basic antiferromagnetic structure predicted theoretically by Moriya could be detected. A small canted component of about $0.1 \mu_B$ was indeed identified and was found to have a different spatial distribution from that of the main component.

A sample of Cu-Ni (43 at. % Ni^{62}), previously used to study the frequency distribution in disordered alloys, has yielded information on short-range order in this alloy. The miniscule Bragg peaks in this alloy correspond to a coherent scattering length of $<0.03 \times 10^{-12}$ cm, and hence the only observable structure in the diffraction pattern is that due to ordering (or segregation). Neutron data were taken at room temperature, 350°C , 750°C , and 1000°C . Characteristic oscillations of the diffraction data indicated a clustering of like atoms on a microscopic scale. The higher temperature data also show oscillations with only a slight reduction in amplitude at 1000°C . This behavior at high temperature suggests that clustering may also occur in the liquid state of this alloy.

The existence of a neutron electric dipole moment is of such fundamental significance for the understanding of the basic properties of elementary particles that several experiments using entirely different methods are currently in progress. Two such experiments were undertaken at the HFBR. One follows a proposal by Shull of MIT and is being carried out with his collaboration. In this experiment a polarized beam of neutrons is Bragg-scattered from a single crystal of cadmium sulfide, chosen because a significant fraction of the scattering comes from the imaginary part of the nuclear scattering amplitude. At the same time there is an absence of any direct magnetic interaction with the neutron spin in this material. The interaction of the internal electric fields of the crystal with the assumed neutron electric moment should yield a polarization dependence in the scattered intensity. Measurements obtained so far are accurate to 12 parts in 10^5 and lead to a value of

$(4 \pm 5) \times 10^{-22}$ electron charge-cm for the electric moment. This value is $\approx 1/100$ of the upper limit set in an earlier experiment by Smith, Purcell, and Ramsey.

A more conventional approach to the measurement of the neutron electric dipole moment is to attempt to observe a change in the Larmor precession frequency upon the application of strong electric fields. An experiment of this type is being carried out at Brookhaven as a joint effort of the Solid State and Nuclear Moments groups and in collaboration with Silsbee of Stony Brook, Lipworth of Brandeis, and Ramsey of Harvard. In this experiment a beam of polarized neutrons is passed through a 2-meter region in a small, constant magnetic field and an alternating electric field. The influence of the electric field is measured by the change in magnetic resonance frequency of the polarized neutron beam. While the sensitivity of this experiment at present is somewhat less than that of the cadmium sulfide experiment, the counting rates are higher by an order of magnitude. Currently this experiment gives an upper limit of $(4 \pm 4) \times 10^{-22}$ electron charge-cm to the electric moment. After further checks for systematic errors, the experiment will be transferred to a beam port where longer wavelength neutrons are available, and thus greater sensitivity is possible.

THEORETICAL PHYSICS

The effective interaction between He^3 atoms in dilute mixtures of He^3 in liquid He^4 was determined with use of experimental data on the spin diffusion coefficient. It was shown that He^4 modifies the bare He^3 potential by adding a long-range repulsion and a shorter-range attraction. The specific heat, susceptibility, and sound attenuation were calculated and agreed with experiment. It was found that mixtures should undergo fermion superfluid phase transitions but not above 10^{-6}°K , although evidence for the transitions should be seen in the transport coefficients in a currently accessible temperature range.

An order parameter theory of second-order transitions was developed on the assumption that at a temperature T just below the critical temperature T_c , the dependence of physical quantities upon $(T_c - T)$ is not necessarily analytic and is determined by order parameter fluctuations. Application of the method to the λ -transition in He^4

leads to relations between critical exponents identical with those proposed by Widom for gas-liquid transitions and Kadanoff for the Ising model.

While stripping and pickup reactions have been valuable tools in studying the properties of light- and medium-weight nuclei, especially since the development of the distorted wave approximation (DWA), the situation in heavy nuclei has been somewhat uncertain. Angular distribution shapes are complicated and do not allow easy identification of transferred orbital angular momentum. Moreover, it is uncertain whether the DWA can accurately predict the magnitude of these processes. To improve this situation, measurements of the stripping and pickup reactions induced by deuterons on lead were taken at 15, 20, and 25 MeV. Lead was chosen because of its "double" magic character so that assessment of the predicted spectroscopic factors could be made. It was found that theory predicts shapes of angular distributions well and predicts spectroscopic factors within 30% of the shell model estimates.

Since the He^3 ion and triton have the same mass, it is possible that the scattering of these projectiles can be explained by similar optical model potentials. Results obtained in scattering from Ni^{64} and Zr^{90} suggest that this is indeed the case provided that the potential, especially the imaginary part, is allowed to depend on the neutron excess of the target. Indeed, these results can be written in terms of an isospin-dependent interaction familiar from the optical potential for nucleons. Support for this was obtained from analyses of the $\text{Ti}^{48}(\text{He}^3, d)\text{V}^{48}$ reaction to the analogue state.

By using Glauber's multiple scattering formalism, a study was made of the elastic scattering of 1-BeV protons from He^4 . Agreement with recent Brookhaven data is very good. Encouraging preliminary results have also been obtained by introducing further correlation effects in the He^4 nucleus and in an extension of the calculation to the more complex nuclei (C^{12} , O^{16}).

The effect of atomic electrons on nuclear γ -decay lifetimes was investigated. In the static limit the correction factor reduces to the static atomic shielding or antishielding factor, which is known to be large for electric quadrupole moments. The calculations were therefore carried out for $E2$ transitions in heavy atoms. The results indicate a decrease of about 8% in the partial rate for the rota-

tional $2 \rightarrow 0+$ transitions in uranium (transition energy, about 50 keV). The magnitude of the correction falls off rapidly with increasing energy, becoming about 2% at 100 keV. The effect of virtual pair creation on the decay rate is estimated to contribute only a few parts in 10^4 , and hence is negligible compared with the atomic correction.

The K -quantum number in rotational nuclei is so good that the sources of K -breaking mechanisms were re-examined. In addition to the usual Coriolis terms, it was shown that velocity-dependent interactions lead to K -breaking. These terms are of the same order as the Coriolis contributions and so do not lead to qualitative changes in understanding of the K -rules but do enter into quantitative considerations.

The reductions of ionization energy loss of charged particles arising from the polarization of the medium, also called the density effect, were evaluated for a H-Ne mixture (used in bubble chambers) and for LiF , $\text{Li}_2\text{B}_4\text{O}_7$, Al_2O_3 , CaF_2 , NaI , and CsI . For the case of NaI , the resulting values of the most probable loss ϵ_{prob} are in good agreement (within $\pm 2\%$) with energy loss measurements of monoenergetic μ mesons in NaI(Tl) obtained recently at the Stanford Linear Accelerator Center.

The atomic quadrupole shielding (or antishielding) factor R was calculated for several atomic excited states: (1) $\text{Pr } 5d$ and $\text{Tm } 5d$, (2) $\text{Li } 2p$ and $3p$, (3) $\text{Be } (2s2p) ^3P$, and (4) $\text{Cu } 3d$ and $4p$ for configurations $3d^9 4s^2$ and $3d^{10} 4p$, respectively. When the correction factor $C = 1/(1 - R)$ is not applied, the values of the quadrupole moment Q (Cu^{65}) differ appreciably, depending upon whether Q is obtained from the $3d^9 4s^2$ state (-0.161 ± 0.003 b), or from $3d^{10} 4p$ (-0.228 ± 0.005 b). The calculated values of R were found to be $R_{3d} = +0.178$ (shielding) and $R_{4p} = -0.175$ (antishielding). Upon applying C , the resulting values of Q are in excellent agreement, namely, -0.196 ± 0.003 b and -0.194 ± 0.005 b. Thus, the comparison of the two uncorrected Q (Cu^{65}) values provides a very good confirmation of the calculation of the atomic shielding and antishielding effects.

Values of the ionic quadrupole antishielding factor γ_∞ were obtained for Y^{+3} , In^{+3} , Bi^{+3} , and Am^{+2} by direct solution of the inhomogeneous Schrödinger equation for the perturbed wave functions. The hexadecapole antishielding factor η_∞ for the In^{+3} ion was also calculated.

High Energy Accelerators

On December 31, 1966, in accordance with instructions from the AEC, the 3-BeV Cosmotron was shut down and put in standby condition.

A brief tabulation of the milestones in the history of this machine follows.

Authorization	April 1948
Start of construction	December 1948
First injected beam	March 1952
First acceleration in BeV range	May 1952
Acceleration to 3 BeV	January 1954
Use of quadrupole lenses in beam transport	May 1955
Associated production	July 1955

The Accelerator Department's major efforts are devoted to the operation, maintenance, and exploitation of the Alternating Gradient Synchrotron (AGS), a conversion program to increase the intensity of the AGS, and continuous investigation of new ideas in accelerator design and use. The present status and program of the Department are summarized in the following sections.

ALTERNATING GRADIENT SYNCHROTRON

The performance of the AGS improved significantly during the past year. Peak intensities of 1.6 to 1.8×10^{12} protons/pulse can now regularly be obtained, and as a consequence weekly average intensities of $\approx 1.3 \times 10^{12}$ protons/pulse are common.

Radiation levels around the AGS ring and radiation damage to components are matters of continuing concern. Nevertheless, the total radiation exposure of all service personnel was reduced significantly during the year.

Progress has been made toward the incorporation of a third external beam system, the slow external beam facility for the East Experimental Area, and all major components have reached the testing stage.

The activities of the AGS Division relating to the operation of the facility, accelerator studies, and AGS development are summarized below.

Operation

The year was marked not so much by the peak intensity performance of the AGS (2.1×10^{12} pro-

tons/pulse, which had previously been obtained) but, more significantly, by the average weekly beam intensity values obtained. This is reflected in Figures 1 and 2. Figure 3 is a breakdown of scheduled operation time.

Total shutdown periods for scheduled and unscheduled maintenance remained at approximately the same level as during the previous year. During December 1966 a flash fire occurred in the magnet structure adjacent to the G-10 target station, the result of a short circuit in a main magnet bus bar caused by water spray from a radiation-damaged cooling-water hose. The damage was repaired quickly and the total shutdown time required was limited to six days. Other unscheduled shutdown periods of relatively short duration were due to the failure of radiation-damaged organic "O" rings of the ring vacuum envelope.

Two major scheduled shutdown periods of ≈ 4 weeks each were used for experimental rearrangements and modification of the accelerator and linac injector.

More precise data are now being used to schedule maintenance and replacement of certain ring components, such as organic "O" rings, magnet coils, target motors, and cooling-water hoses. For this purpose the total number of interacting protons at nearby locations is being used as a criterion. In this connection, the utilization of the internal targets and external beams of the AGS is of interest (see Table 1).

The effort to reduce total radiation exposure of service personnel continues, and significant progress has been made during the past year. Data for the first quarter of each of the past three years are listed in Table 2.

Accelerator Studies

The major effort in this area was devoted to increasing the maximum attainable intensity in the AGS. This involved further study of the orbital magnetic field to facilitate the correction of dipole and gradient errors. The control of the half-integral resonance stopband was better understood, and some results were obtained related to the effects of transitions through coupling resonance stopbands.

Figure 1. AGS performance during 1967, weekly average beam intensity.

Figure 2. Utilization of the AGS for high energy physics and machine studies.

Figure 3. AGS utilization during fiscal 1967. Sum of enclosed areas represents scheduled operation time. Percentages refer to scheduled time, which is 83% of maximum possible running time.

Table 1

Utilization of Internal Targets and External Beams of the AGS, Fiscal 1967

		% of protons on target	Protons on target
Internal targets, external beams			
F-9/F-10*	internal target, slow spill, flat-top	30	25.3×10^{17}
F-20A	internal target, fast spill, RBD**	9.4	7.7×10^{17}
F-20B	internal target, fast spill, RBD	0.1	0.1×10^{17}
G-9/F-10	internal target, slow spill, flat-top	48	39.2×10^{17}
G-20	internal target, radiochemistry	0	0.0
H-10	internal target, special use, mainly radiation studies	0.2	0.2×10^{17}
I-10	internal target, fast spill, RBD	1.3	1.1×10^{17}
I-10	external beam, fast spill	9.7	7.9×10^{17}
B-10	external beam, fast spill	0	0.0
Total protons on target			81.5×10^{17}

*Letters indicate locations of the 12 "superperiods" of the AGS. Numbers indicate location among 20 magnets of a superperiod. Injection is at magnet A-1.

**RBD=rapid beam deflector.

The behavior of the AGS beam in the energy region below 500 MeV was studied. The beam was extracted by using the fast kicker unit and measurements were made of such characteristics as beam emittance and phase-space density distribution and of the variation of these parameters with proton momentum. Intensity-dependent effects were also studied.

Investigations continued of coherent betatron oscillations in the AGS, at both high and low energy. This intensity-dependent oscillatory behavior is being studied under controlled conditions by stimulating the coherence artificially. A prototype feedback damping system has been developed to suppress these oscillations.

In preparation for the installation of the slow external beam system, study time has been devoted to the use of high-field bump coils capable of producing a 1.5-in. orbit deflection. It was found that a simple half-betatron wavelength orbit bump introduced too much gradient error and resulted in a decrease in peak AGS performance. Subse-

Table 2

Exposure of Service Personnel at the AGS

	First quarter		
	1967	1966	1965
Total exposure, Rem	72	110	460
No. of persons exposed	460	460	340
Av exposure/person, mRem	157	240	114
Total protons, $\times 10^{18}$	2.1	2.0	1.1
Av exposure/person/ 10^{18} (mRem/ 10^{18} protons)	75	120	104
No. of persons exposed to >1 Rem	4	35	5
No. of persons exposed to >500 mRem, <1 Rem	35	48	21

quently, more high-field backleg windings were installed and a simple configuration making use of three sequential half-wavelength bumps was tested, with satisfactory results. Preliminary studies were done on the over-all slow external beam extraction process. Results so far have been satisfactory and further studies are planned.

Operation of the fast external beam was further studied in order to reduce particle loss on the septum magnet. The over-all system was operated in combination with a rapid beam deflector in order to decrease the time spent in the stray field of the septum magnet. Improved fast external beam ejection efficiency was obtained. In addition, multiple pulsing for the fast external beam system was started in connection with the possible multiple operation of the 80-in. bubble-chamber compression system during one AGS acceleration cycle.

For the fast external beam system in the North Experimental Area, calculations of ejection trajectories have been performed to compare the present 3-component extraction system with a possible 2-component system that would use only a thin septum ejector magnet and an improved fast kicker. Results indicate that the proposed system could perform as well as the present system.

Similar calculations have been made for the proposed fast external beam system at H-10 for the converted AGS facility. A preliminary layout of this external beam has been completed, based on trajectories from a 2-component fast ejection system.

Fast external beam ejection trajectories have also been computed for the slow external beam

channel. Once the components are installed, single bunch extraction can be readily achieved.

Technical Development

Linear Accelerator. Modification and development of the injector for the AGS have continued. An expanded rf power system for the linac cavity has been designed which should handle effectively the expected increase in beam intensity resulting from improvements in the ion source and the new high-gradient accelerating column. The single linac cavity rf driving port has been supplemented by two more driving ports. After completion of the modifications each port will be powered by a separate amplifier.

The pulsed 25-MW hard-tube modulator has shown increased reliability during operations over the past year, partly because of several modifications. The modulator is now used routinely to drive the linac power amplifiers with open-loop programmed control. Studies are under way of a closed-loop system that will include the linac cavity; such a system should result in a gain in field flatness.

Ion source studies continued, mainly in combination with the high-gradient-column development and test program. Satisfactory performance of the ion source-gradient column system has been obtained with Pierce electrodes and for beam intensities of up to 300 mA. The high-gradient column has been tested up to 750 kV with beam intensities of 100 mA. The beam quality obtained with the high-gradient facility is compared with

that obtained from the operating preinjector in Figure 4.

Capacitors with increased internal resistance have been incorporated in the Cockcroft-Walton capacitor storage system. As a result, sparkover damage has been essentially eliminated and the reliability of the preinjector system greatly improved.

As part of the linac monitoring system, a single-pulse beam emittance detector has been brought into operation and continuous monitoring of the 50-MeV beam emittance is now possible. This detector, together with the 50-MeV momentum analyzer, has proved to be extremely valuable in monitoring the linac performance.

Accelerator Components. A program of improvement of the high-level rf system for the AGS ring was completed during the year. The program included the installation of new heat exchangers and demineralizers at each accelerating station, installation of new gaps and other mechanical changes in the cavities, redesign of the tuning servos, and modifications of the 12 final rf power amplifiers. In addition, the low-level end of the rf driver amplifier was redesigned to provide better AGS performance. The program has resulted in a significant reduction in maintenance requirements and an increase in tube life and has virtually eliminated machine downtime due to failure of the high-level accelerating system.

Six rapid beam deflectors have been constructed to provide multiple deflections in one AGS cycle. Changes in the discharge frequency and polarity can be made quickly by using a high current selector switch mounted externally on the side of the magnet vacuum enclosure.

Interface equipment of the PDP-8 computer has been expanded to include a monitor of accelerator operation. This "status monitor" continuously tests critical machine subsystems and advises the operators of any subsystem failure. In addition, a permanent automatic record of accelerator performance is being obtained. A "time interval meter," which allows the computer to be instantaneously aware of the deviation in time of significant machine control pulses, has been added.

Programs are also being developed for using the PDP-8 computer in conjunction with AGS study programs, such as orbit radius control, ejected beam emittance data analysis, and equilibrium orbit analysis. Further work is being carried on to incorporate a magnetic tape transport and a data

Figure 4. Example of distorted and nondistorted performance of beams that have passed the electrostatic 750-kV accelerating tube. At the left is the distorted image of a 60-mA beam passing a slotted target in the operational preinjector. The picture at the right shows an undistorted image of a similar beam passing an identical target in the high-gradient preinjector.

Figure 5. The 16-in.-diam steel pipe containing bus bars, cables, and water pipes of the slow extracted beam system, being lowered into the AGS. The assembly weighs 5 tons and rolls on ball castors down the chute into a 40-ft-long hole drilled into the shielding over the AGS tunnel. The building below the chute holds the power supplies and other equipment of the slow extracted beam system.

Figure 6. Slow external beam ejector magnet assembly. The first magnet element has a $\frac{1}{4}$ -in.-thick septum (2 turns), and the aperture is $0.800 \times 1\frac{1}{8}$ in. The second and third magnet elements have a $\frac{3}{8}$ -in.-thick septum (3 turns), and the apertures are $0.800 \times 1\frac{1}{8}$ in. Magnet elements are electrically in series, and the maximum current allowable is 6500 A.

disc to facilitate increased data storage capability and allow for a link between the AGS computer and the CDC 6600 computer in the Laboratory's Computer Center.

A new target box with two target airlock systems was installed at G-10. All parts and joints on the box were sealed with metal gaskets. These metal seals have been used successfully with stainless steel, aluminum, glass, and ceramic. To meet the requirements of higher beam intensities an all-metal-seal, radiation-resistant target airlock system has been designed. This airlock incorporates all previously available airlock capabilities, including remote cycling and automatic target transfer. Additional capabilities include remote position adjustment in the vertical as well as the radial coordinate and the possibility of quick replacement of the major functional unit. To simplify the operation of the airlocks an automatic control system has been developed with use of logic modules. A prototype of this system is now undergoing operational tests.

External Beam Systems. Multiple-bunch extraction during one AGS cycle was tested with the fast external beam system. No serious difficulty was encountered, and modification of the equipment was started to provide for multiple extraction in the ejected beam channel at the North Experimental Area.

All major components for the slow extracted beam system have been completed. An enclosure was erected on the inside of the ring at F-10 to hold the power supplies and cooling equipment. A hole was drilled through the shield wall to allow insertion of a prefabricated assembly of cables, pipes, and bus bars (Figure 5). The component parts of the septum and ejector magnets (Figure 6) are on hand. Every attempt has been made in the selection of materials to minimize the use of organic parts. An aluminum oxide coating is used for the coil insulation, and ceramic insulators are used on the cooling-water lines. These magnets are mounted on a drawer assembly which slides into a ring vacuum box and can be readily interchanged with complete spare assemblies.

Assembly of the instrumentation for the slow beam is progressing satisfactorily. Included are observation stations with flags of various sensitivities, a secondary emission chamber for intensity measurement, scanning targets, and quadrant position monitors. In addition, an analysis channel is under

construction for use in studying the ejected beam properties in order to direct a properly aligned and focused beam onto the external target.

Engineering Programs

Power. The AGS electrical power distribution system operated in a very satisfactory manner during the year. There were no service interruptions other than scheduled shutdown periods for annual maintenance.

During the year the main magnet power supply operated very well and $\approx 8 \times 10^6$ magnet current pulses were produced. Total energy consumption of the motor-generator set only was of the order of 22.5×10^6 kWh. During a regular shutdown the generator coverings and ventilating fans were removed and a thorough mechanical inspection of shaft and pole pieces was made. No defects were found.

A 4-unit uninterruptible power supply was placed in service and has proved satisfactory in operation. This unit supplies power to those systems that otherwise could accidentally shut down the operation of the synchrotron in the event of a momentary power failure.

Mechanical Services. The AGS cooling systems have continued to perform well with normal routine maintenance and with few interruptions of accelerator operation during the year. All three wells were again shock-treated with phosphate, and the supply line from the wells was cleaned during the March 1967 shutdown.

Modular cooling systems were fabricated and installed at each of the 12 rf stations of the magnet ring to provide increased pumping capacity, additional cooling capacity, and individual cartridge demineralizers to maintain water quality. These 12 systems are identical; they are mounted on castors and are installed on the outside of the ring girder to allow for easy access and to make the systems truly modular and readily interchangeable.

Air, water, and helium lines were installed for the 31-in. bubble chamber. Magnet cooling is provided by five portable coolers pumping a water-glycol mixture. Procurement is under way of a 6-MW cooling tower and two 1000-gal/min pumps to be assembled as a unit to provide the magnet cooling for the West Experimental Area. An additional 850-gal/min pump is being purchased to supplement the two existing experimental water pumps in the North Experimental Area.

Figure 7. Experimental setup in the West and East Experimental Areas of the AGS, summer 1967.

A 40-hp air-cooled Freon unit has been installed in the F-10 equipment house for the slow extracted beam power supply transistor plate. In addition, a chilled water system and associated components have been installed to provide cooling for additional equipment associated with the slow extracted beam at F-10.

Vacuum. The vacuum systems of the ring and linac continue to improve. Water leaks from magnet cooling coils located inside the vacuum chamber have been eliminated by redesign. Ring vacuum leaks, a result of "O"-ring failures due to radiation damage, have been almost entirely eliminated by the installation of ≈ 50 Inconel X rings, which are designed to fit a normal organic "O"-ring groove and are therefore a direct replacement. The metal rings have a thin plating of lead, covered with a thin plating of indium, and can be used in a 32- μ in. finish flange.

Twenty-two cold cathode sputter-ion pumps are now in service on the AGS and beam line equipment. These vary in size from several 80-liter/sec pumps on the rf separated beam to several 500 and 700-liter/sec pumps on target boxes. The maintenance experience with these pumps has been excellent and is an encouraging portent, since these pumps will be used exclusively in the converted AGS.

A single-channel mass spectrometer for residual gas analysis has been installed. Preliminary analyses show that H_2O , Ar, N_2 , and CH_4 are dominant residual gases.

EXPERIMENTAL PLANNING AND SUPPORT

The research program in high energy physics at the AGS continues to grow in magnitude and complexity. Three bubble chambers are served by four separated beams, while counter and spark-chamber experiments utilize six secondary beams. During the year the chambers accommodated 31 experiments totaling 4.7 million pictures, and 12 counter experiments and several emulsion exposures were completed. The operation of the experimental program was made possible by the plans and efforts of the supporting groups within the Division, who design, construct, and operate much of the equipment used. The highlights of the past year's accomplishments are summarized below.

Experimental Facilities and Program

Five internal targets were used within the AGS for the production of secondary beams. Particle beams for counter experiments were erected at F-10 and G-10. Most of these beams were designed for the specific experiment undertaken, although two of the counter beams are facility beams and consequently are used by one experimental group after another. The most heavily used beam is the electrostatically separated beam erected at G-10 $+ 10^\circ$. This beam, described last year, continues to be used without major modifications. It provides separated K beams up to 2 BeV/ c and anti-proton beams to 3.3 BeV/ c . The beam can now be directed into any one of three locations for use. In this way its efficient utilization has been substantially increased. This beam and the others described in this report are illustrated in Figure 7.

The short branch of the separated beam is being used for a measurement of the magnetic moment of the cascade hyperon by a Brookhaven group. The longer branch was used by a Princeton University group studying the decays of K mesons (kaons). This was followed by a study of kaon and antiproton total cross sections that extended the energy range covered earlier by the same Brookhaven group. A team from Columbia and Syracuse Universities completed a thorough study of antiproton-proton annihilation at rest into neutral particles. The separated beam is currently being used by a Columbia group for a study of the decay spectrum of the η meson.

The incorporation of a "Y" branch in the 4.7° beam from G-10 has allowed the beam to be used by several groups. This beam provides π mesons (pions) from 4 to 16 BeV/ c in the East Experimental Area. One branch of the beam was modified to produce a μ -meson (muon) beam. When the first magnets in the beam array were tuned to 17 BeV/ c , 13-BeV/ c muons emerged from the end of the filter. They were then momentum-analyzed, and about 10^4 muons were produced for 10^{12} protons on the target. A Columbia group is studying muon-proton scattering at small angles and low momentum transfer.

The pion branch of the 4.7° beam was used for a study of pion-proton elastic scatterings covering 0° to 180° in the center-of-mass of the interaction. A group from Cornell University, Case Institute of Technology, and Brookhaven has done the pion scattering experiment from 6 to 17 BeV/ c . This

branch of the beam will now be used for a K -meson regeneration experiment starting with charged K 's. The muon branch of the beam will be used by a Harvard group in their study of inelastic muon interactions.

A neutron beam was erected at the F-10 target for two neutron-proton experiments by physicists from Princeton University, the University of Michigan, and the Stanford Linear Accelerator Center. The neutrons were emitted from the target at 1° and were defined by a series of lead collimators, one of which was 10 ft long. Charged particles were swept out by several dipole magnetic fields. More than 10^5 neutrons of many energies were produced for each pulse of the machine. These neutrons were used for a study of neutron-proton elastic scattering with use of a liquid hydrogen target and a magnetic field to analyze the energy of the recoil proton. Another experiment on neutral cross sections was then done in which a liquid hydrogen and a liquid deuterium target were used.

The three bubble chambers are served by four beams. The 30-in. chamber is at the end of the low energy separated K -meson and antiproton beam. About 2.5 million pictures were completed during the year for experimental groups from Carnegie Institute of Technology, Columbia and Duke Universities, the Universities of Maryland and Massachusetts, Oak Ridge National Laboratory, Princeton, Syracuse, Vanderbilt, Western Reserve, and Yale Universities, Brookhaven, and the University of Melbourne. Chamber fillings of hydrogen and deuterium were used, as well as mixtures of 1% to 10% neon in H_2 or D_2 .

The 80-in. bubble chamber served an active research program this year. Beam No. 4, which incorporates the radio-frequency separators, in its first running period for the fall of 1966 provided about 880,000 pictures at high incident particle energies. Using the unseparated mode, several groups surveyed proton interactions in hydrogen at various incident proton momenta between 13 and 29 BeV/ c ; a total of 268,000 photographs were taken. In addition a π^-p exposure (112,000 pictures) at 13-BeV/ c momentum was run. In the separated mode, the runs included 84,000 pictures of K^-p interactions at 12.8 BeV/ c , 111,000 K^+p pictures at 9.04 BeV/ c , and π^+p exposures at 11.8, 16, and 18.5 BeV/ c (with 33,000, 64,000 and 54,000 pictures, respectively). Furthermore, with deute-

rium in the chamber, 97,000 pictures (some accumulated in the previous year) and 53,000 pictures were taken of K^-d interactions at incident momenta of 12.8 and 7.4 BeV/ c , respectively. A test run separating deuterons for $d-d$ interaction studies at 13.7 BeV/ c indicated that such an experiment may be feasible in beam No. 4. In January 1967, beam No. 3, which incorporates electrostatic separators, resumed its program. Exposures of K^+p interactions at 5.5 BeV/ c (152,000 frames) and K^-p interactions at 4.6 BeV/ c incident momentum (352,000 pictures) were added to already active experiments. New π^-p interaction studies at 4.6 and 7.5 BeV/ c (26,000 and 162,000 pictures, respectively) were started. With a hydrogen-neon mixture in the chamber a 5.5-BeV/ c K^-p exposure (48,000 frames) was successfully completed. A program using beam No. 3 for various exposures in deuterium has been initiated.

The BNL 20-in. hydrogen bubble chamber was rebuilt and enlarged to 31 in. in length by the BNL Bubble Chamber Group. A particle-beam transport and separating system was completed and is being operated in conjunction with the 31-in. chamber.

Two stages of separation are employed to separate π mesons from K mesons up to a momentum of about 3.0 BeV/ c . The lower limit, set by the production cross section and the lifetime of the K^+ meson, is about 1.5 BeV/ c . Protons and antiprotons can be separated from the pions up to the maximum momentum limit of the beam, 4.0 BeV/ c . In the case of antiprotons, the lower momentum limit is about 1.5 BeV/ c and is determined by the rapidly falling production at low momenta. Except for operation at the low momentum limits, adequate fluxes in the bubble chamber are obtained by expending $\leq 1.5 \times 10^{11}$ protons/pulse.

Beginning in May, the 31-in. bubble chamber completed 100,000 pictures of π^- interactions in liquid hydrogen at 1.68 BeV/ c for collaborators from Carnegie Institute of Technology, Vanderbilt University, and Western Reserve University. Antiproton interactions near 2.5 BeV/ c have been obtained by Iowa State University in an exposure of 100,000 pictures. Additional $\bar{p}$, π^- , and K^- runs, in hydrogen and deuterium, are scheduled for 1967.

Experimental Equipment

During the year there were, on the average, eight beams either in operation or under construc-

tion in the East and West Experimental Areas and two beams in the North Experimental Area. These beams occupied some 60,000 sq ft (70%) of the available experimental floor space and another 24,000 sq ft of portable-type outdoor housing. The scheduling and operation in these areas was arranged so that construction of new beams proceeded continuously. During the year ≈ 39 man-years were expended on new beam construction, with the Plant Engineering and Planning Division supplying slightly over half of this total (riggers, carpenters, electricians, etc.) and the Experimental Division's technicians accounting for the remainder.

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

Item	Inventory	Usage, %
Magnets	163 units	91
Power supplies	118 units	96
Beam separators	12 units	83
Shielding	75,000 tons	80
Experimental power	37,000 kVA	86
Experimental cooling water	3,550 gal/min	

The current inventory of experimental gear is steadily being augmented. The inventory of experimental apparatus utilized in beam transport systems has been markedly increased by acquisitions from the Cosmotron. The major part of the Cosmotron apparatus is suitable for use at the AGS as it is, or with minor modifications. Required changes are in progress to restore this equipment to active inventory early in fiscal 1968. In addition, 23 new power supplies have been delivered and orders for twelve 450-kW magnet power supplies have been placed. Six N3Q36 and five N8Q32 quadrupole magnets are on order for use with the slow external proton beam. Five 18Q36 quadrupole magnets, the largest such magnets designed at Brookhaven, were ordered for use in the separated beam to the 80-in. bubble chamber.

In addition to designing magnets, the Mechanical Engineering Group produced numerous vacuum systems, support structures, and collimators for use in the experimental program. One project of interest is a modified transport system for a large spectrometer magnet. The 100-ton magnet is supported by hydrostatic film bearings; a relatively small force will move the large magnet and position it accurately.

Magnetic field studies in the past year have resulted in bringing several basic efforts to full devel-

opment. The conceptual design of quadrupoles has now become routine. A flexible quadrupole design capable of a high field gradient with modest power consumption and producing a lens of high optical purity has been used in a wide variety of magnets.

The design and utilization of routine beam transport dipoles has been augmented by extensive computer calculations of magnet properties. For example, the increased use of wide-angle spectrometers in counter and spark-chamber beams leads to in-the-field modifications to existing window-frame dipoles in which the gap is increased appreciably. Computations then predict the proper spacing of the original coils in this wider gap so that at a desired excitation only minimum aberrations are produced.

A major long-term developmental effort involves special magnets for external beams. For example, C-type iron yokes are needed for separating secondary beams from the primary beam following a target location. Ideally, it is desirable to have a uniform dipole field which discontinuously goes to zero at a certain location, with no iron or copper in the zero field region. Practically speaking, a C-type yoke with a septum current return at the outer edge of the aperture region is the best approximation to this. The lower order symmetry of C-type yokes results in appreciable optical aberrations at lower fields than exist in a window-frame magnet. Calculations of the aberrations as a function of field and also of the septum thickness required for reasonable current density as a function of field are basic factors in the design parameters of such magnets.

The separator group maintains and operates 12 separators in the particle beams for beam purification. The emphasis in the past year has been on the improvement of separator "on-time." This has been accomplished in several ways. Tests have shown that the addition of heat to a separator via a set of all-steel electrodes will increase the amount of time between periods of conditioning. The addition of automatic-current conditioning circuits to beam-separator high-voltage power supplies shortens the conditioning time and allows the operator to concentrate on other duties during the conditioning process. Further improvements have been made in the 600-kV power supplies to increase their reliability. Of the six new 400-kV power supplies delivered this year, four have been

installed in the new beam to the 31-in. chamber and two are being used to power the test separator.

The rf separators have continued to operate successfully. A program to increase their reliability was continued. Spare modules and chassis, easily interchangeable for maintenance purposes, were constructed. Test procedures and testing chassis were devised for checking out the spare components.

The Cryogenic Group's program has centered on the design, fabrication, and operation of liquid hydrogen, liquid deuterium, and liquid helium targets. Ten targets were operated at the AGS and four at the Cosmotron. Most of the targets involve special design requirements tailored specifically to the intended experiment.

A solid-hydrogen target and superconducting magnet experimental system was completed. The system includes a closed-cycle, 4.2° K helium refrigerator with two compressors, a gas holder, freeze-out purification, remote Joule-Thomson (J-T) expansion valve, superconducting magnet Dewar, and a hydrogen fill and purification system. A mobile trailer houses the make-up gas, freeze-out purification, compressors, gas holder, and associated electrical components. From the refrigerator, cold helium gas passes through a remote delivering tube and through a J-T expansion valve. The liquid helium is made directly in the magnet Dewar. The refrigerator, when used as a liquefier, has a capacity of 8.5 liters/hr. As a refrigerator, it will deliver 34 W. The solid hydrogen is made by using the 4.2° K magnet container as a heat sink. In prototype testing the hydrogen appears to be a single crystal. It takes ≈ 6 hr to obtain 86 cc of solid hydrogen.

Liquid hydrogen and liquid helium transfer lines were constructed and maintained for the various experimental setups. The associated equipment for targets, including liquid reservoirs, liquid-level indicator, gaseous vent lines, vacuum electronics, and electrical power control centers, has been maintained by the Cryogenics Group.

The High Energy Equipment Pool provided most of the high-speed logic, pulse counters, printers, etc. for 55 experiments, and 90% of inventory was in use all the time. Equipment is also lent to users outside the high energy research groups on an on-call basis. In this way utilization is increased and instrumentation can be provided for short-term experiments at no additional cost to the Laboratory.

AGS CONVERSION

The AGS conversion program was funded by Congress in fiscal 1967 in the amount of \$47.8 million. Authorization to proceed with detailed design (Title II) was issued early in the year. Authorization to commit funds for equipment was given in February 1967.

The staff of the AGS Conversion Division has expanded steadily during the year. When the Cosmotron was shut down at the end of December, about 50 of its staff members were transferred to the Division. These people, together with a number of new employees, have brought the total strength of the Division to about 140, of whom 57 are scientific and professional personnel and 83 are technical and support personnel.

The primary objectives of the conversion program are (1) to increase the intensity of the accelerated beam to 10^{13} proton/pulse, which will require a 200-MeV, high-intensity proton linac injector; (2) to increase the cycling rate to 1 cycle/sec with no flat-top or 1 cycle/2 sec with a 1-sec flat-top (50% duty), which will require doubling the capacity of the motor-generator-rectifier set and a new, higher power rf system; (3) to reduce radiation damage to the accelerator components, to reduce service and repair time, and to provide adequate safety, which will require a new synchrotron vacuum chamber and pumping system, modularization of the main magnet system, and additional shielding and associated fixtures; and (4) to provide increased experimental facilities, including an addition to the East Experimental Building, a new external beam at H-10 to service the North Experimental Area (large bubble chamber), and increased utilities (particularly electric power). The Conversion Division has three operational groups to carry out this program: the Facilities Group, the Linac Group, and the Synchrotron Ring Modification Group.

The Facilities Group does all the planning and determines the specifications for all the buildings and utilities associated with the conversion program. This group also supervises the efforts of the architect-engineer, Charles T. Main, Inc., of Boston, in carrying out the detailed design and supplying construction supervision for the conventional facilities.

The complex of buildings to house the new 200-MeV linac consists of a preinjector and service

building, the 500-ft-long linac tunnel with its parallel equipment bay, and a 460-ft-long beam transport tunnel from the linac to the synchrotron. Preliminary (Title I) design is complete and detailed design (Title II) has been started. Construction is expected to begin late in the fall of 1967.

Extensive modifications are required over about one-half of the AGS magnet enclosure and the Target Building in order to increase the shielding in areas where the increased intensity will raise the radiation levels. Care is being taken in the design to insure that radiation levels will be low in the remaining portions of the ring. Title II work is progressing rapidly for those portions of the work that will be executed early in the program, and construction work is expected to start late in 1967 or early in 1968. Title I work is being done for the remaining portions.

Two buildings will be constructed inside the AGS ring to house the new motor-generator set with its rectifying equipment and the new synchrotron rf system. Title II design of these buildings is progressing and construction is expected to start late in 1967.

An addition of about 56,000 sq ft will be made to the existing East Experimental Building. Title II design is well advanced and construction is expected to begin in September 1967. Procurement of the 40-ton overhead crane is proceeding. A 25,000-sq-ft addition is planned for the West Target Building. Since its construction will interrupt the operations of the 30-in. and 31-in. bubble chambers, design and construction of this building have been postponed until later in the program.

Theoretical studies of the 200-MeV linac have been actively extended. The effects of space charge on linac beams with peak currents of 100 to 200 mA have been investigated analytically and numerically. Both transverse and longitudinal effects have been examined. Although these studies are not yet complete, they have demonstrated the need for higher fields in the drift-tube quadrupole magnets and for a higher value of the synchronous phase angle in the accelerator. With these modifications the linac should readily accelerate a beam of 100-mA peak current and may well be capable of accelerating 200 mA with some future modifications.

Extensive studies of the multistem drift-tube structure have been carried out. In this structure, the stems play a significant role in modifying

the cavity fields in such a way that the cavity field amplitude and phase distortions due to beam loading are minimized. The multistem concept has been incorporated in the linac design.

The detailed parameters of the linac have been fixed. The final drift-tube table, which employs the results of the MURA computer program for drift-tube cavity field computation, calls for 286 unit cells to accelerate the beam from 0.75 to 200 MeV. These cells are divided into nine independent resonant cavities. Each cell has a pulsed quadrupole magnet (inside the drift tube). Copper-clad steel for the nine cavities has been ordered. Detailed design of the cavities, drift tubes, and quadrupole magnets is proceeding. Fabrication of the cavities is expected to start in the fall of 1967.

There will be two independent preinjectors of the Cockcroft-Walton type, each with a duoplasmatron ion source and a high-gradient accelerating column. Either of these preinjectors can feed the linac through a beam-switching, transport, and bunching section. Procurement of the first Cockcroft-Walton set is proceeding.

The rf power system for the linac, operating at 201.25 Mc/sec, must deliver 40 MW of peak rf power to accelerate 100 mA of beam. Eight of the nine linac cavities will be powered by 5-MW triode amplifiers. The first cavity will be powered by two smaller tetrode units similar to the tetrode stages used to drive the 5-MW triodes. The triode amplifier has been tested above 6.5 MW into a dummy load and is being tested in a resonant load. The amplifier cavity circuit appears to be satisfactory. Procurement and fabrication of the rf system will be initiated during the fall and winter of 1967.

Detailed specifications have been developed for the new motor-generator set and rectifying equipment for the AGS main magnet. This set, as now conceived, will consist of a 12,000-hp motor driving two 50-ton flywheels and two 31-MVA generators. One of the generators will be the one now in use at the AGS. Detailed studies of the torsional vibrations in this set and the expected effects of metal fatigue indicate that the set should be capable of extended reliable service. Negotiations for the procurement of the set are under way.

A prototype amplifier for the ring rf system has been completed and is being tested. Procurement of 14 of these units will be initiated in the fall of

1967. Extensive studies of the rf properties of ferrites are being carried out, and preliminary designs of a 4-gap accelerating cavity have begun.

Final design of the new AGS vacuum chambers has been completed and procurement is proceeding. These chambers incorporate quick-disconnect vacuum seals employing metal gaskets. A high reliability of vacuum sealing has been achieved. There will be one sputter-ion pump for each of the 240 vacuum chamber sections. Procurement of these pumps is under way. A pump power supply has been developed which greatly improves the high-pressure starting and pumping performance of these pumps.

Designs have been completed or are nearing completion for the following equipment associated with the main magnet ring: quick disconnects for magnet bus bar and cooling water, octupole correcting lenses, and a remotely controlled, TV-viewed theodolite for ring magnet survey.

Studies of radiation control and shielding for the AGS have continued. Progress has been made in understanding the details of the shielding properties of the local sand used as one of the primary shielding materials. Detailed measurements have been made in the AGS complex to finalize the shielding and personnel protection designs for the conversion program.

ADVANCED ACCELERATOR DEVELOPMENT

Injection Techniques

For some years the Accelerator Study Group has been investigating possible methods of injection into super-energy synchrotrons. It has been concluded that the method preferred here involves the use of an injector synchrotron of large aperture but small diameter which stores all the necessary charge for a high energy ring in one pulse. This is in contrast to the rapid cycling injector synchrotrons preferred elsewhere, which must be cycled a number of times for each pulse of the high energy ring. To determine whether a synchrotron injector would be preferable to the 200-MeV linear accelerator proposed for the AGS conversion, an intensive 3-month study was undertaken and completed in November 1966. The conclusion was that such a "booster synchrotron" might be preferable for the second phase of the conversion (an increase in injection energy from 200 to 1000 MeV), but

that there were cogent reasons for continuing to prefer the 200-MeV linac for Phase I.

Superconducting Magnets and Lenses

Major progress has been made in the design and fabrication of superconducting dipole, quadrupole, and higher-order multiple magnets. A powerful analytic approach to current distributions in magnets having circular or elliptic apertures, with fields transverse to the axis of the circle or ellipse, has been developed. Computer analysis of practical structures has also been used; in all cases theory and experiment are in good agreement. Fields in solenoids have been extended to 140 kG, and a solenoid with a tapered field is being used to measure magnetic moments of hyperons on the experimental floor of the AGS. A number of quadrupoles have been fabricated and tested, and gradients have been achieved that are three times higher than can be reached in room-temperature, iron-cored quadrupoles. Methods of removing the external stray field characteristics of air-cored magnets have been evolved to permit the use of superconducting components for beam transport in positions close to AGS internal targets.

Super-Energy Accelerators

The synchrotron lattice in which the functions of bending and focusing are separated has been re-explored in the light of recent experience with high-field bending magnets and quadrupoles for beam transport. Pure bending magnets and quadrupoles have symmetry properties that make possible operation at materially higher fields than are attainable in conventional combined-function synchrotron magnets, and their use could result in appreciable savings in construction costs for super-energy synchrotrons.

A year ago there was widespread pessimism about the possibility of using superconductors in synchrotron magnets because intolerable losses were expected when the field of a superconducting magnet was varied at the rapid rate required for use in a synchrotron. Preliminary tests made during the past year on pulsing superconducting magnets have shown the losses to be much lower than those predicted from theory. More refined tests are in progress of losses during pulsing and of the field configurations during rapid changes. If these tests give satisfactory results it may well be possible to design accelerators with magnets in which the

peak fields are four or more times as high as those reached in the AGS magnets. It would thus be possible to reduce the diameter of the machine by the same factor by which the field is increased.

Superconducting rf Separators

Radio-frequency particle separators developed in the Accelerator Department are now in use in one of the beams to the 80-in. bubble chamber. These separators have made possible the analysis of beams of energies up to about 13 BeV instead of 5 BeV, the upper limit with the dc separators. For bubble-chamber work this beam has been extremely useful; since it came into operation in December 1965 it has provided particles for over 800,000 bubble-chamber pictures. For counter work, however, the beam is not satisfactory. The separators require so many megawatts of microwave power that they cannot be pulsed for periods longer than 5 μ sec at a time – too short a period to allow the collection of statistics by using counters. One technique being investigated to alleviate this difficulty is to coat the inside of the separator cavity with a superconductor and cool it to temperatures below the boiling point of liquid helium. The technique of using superconductors in microwave cavities is being developed for use in electron linear accelerators, which also suffer from the shortness of the allowable pulse. The procedure seems equally valid for the rf separator. Preliminary tests have been made at Brookhaven on microwave cavities and it has been shown, as was shown previously at Stanford, that the quality factor Q , which has a room temperature value of about 50,000, can be increased to $>1,000,000,000$ at liquid helium temperatures. When this improved Q factor is achieved in an rf separator, continuous operation should be possible. During the coming year this investigation will be carried on and a plan formulated for eventual construction of a superconducting separator.

Accelerator Theory

Investigations of dense particle beams in synchrotrons and in linear accelerators have shown that there are a number of ways in which these beams can become unstable. In such cases there may be partial or total loss of the beam. Some of these instabilities have been observed, and other unstable processes, not all understood, have appeared during operation of accelerators. Theoretic-

cal work on these processes continues at Brookhaven and elsewhere. The theory has reached a high level of sophistication, and a relatively complete understanding of instabilities should not be far off.

PARTICLE PHYSICS RESEARCH

During the year further measurements were made by the Particle Physics Research Group in an effort to detect fractionally charged particles that might constitute a fundamental representation of $SU(3)$ symmetry. The results of an extension of earlier experiments designed to detect any such particles which might be produced in cosmic rays have now been published. The background was reduced below that observed in earlier measurements through the use of somewhat more stringent criteria, and much lower limits were established for the flux of charge $2e/3$ particles.

A large mass-spectrometer using time-of-flight information and momentum information from the deflection of particles in a magnetic field has been used to establish a limit on the flux of heavy particles with unit charge. The existence of such particles is suggested by certain theories of the strong interactions; they would presumably be members of a fundamental $SU(3)$ triplet. The limits set at this time suggest that stable particles with masses between 5 and 10 BeV/ c^2 are not produced with cross sections that are much larger than 10 μ b in the high energy interactions of primary cosmic-ray protons with nuclei in the atmosphere.

Analyses of data taken on the decays and strong interactions of K_2^0 mesons in liquid hydrogen have been completed. The K_3 pion spectra have been examined with smaller systematic errors than in previous work and show no evidence of the strong enhancement for high energy π^0 mesons suggested in other work. An analysis of the forward production of K_1^0 mesons produced in the bubble chamber together with recent work on CP (charge conjugation, parity) violation and the $K_2 - K_1$ mass difference shows that the previous results of this group, which demonstrated the existence of a large forward peak of K_1^0 mesons, could be understood by considering the effect to be the result of a coherent interference between the CP violating amplitude and the coherent amplitude from the hydrogen in the chamber and the copper wall of the chamber.

Figure 8. The Cosmotron magnet ring, with the shielding removed.

Experimental measurements have been obtained in an extensive program involving the measurements of the polarization and helicity of protons scattered from protons at high momentum transfers, $-t=2$ (BeV/c)². About 20,000,000 events were recorded with use of a complex counter-hodoscope arrangement which fed an on-line computer. Preliminary analyses of the data suggest that the backgrounds are satisfactorily small and that the general experimental design was successful, but final results are not yet available.

In collaboration with research groups at Yale, the University of Massachusetts, and BNL, analyses are being made of 10⁶ pictures taken in the 30-in. Brookhaven hydrogen chamber at the AGS in a K^- -meson beam with a momentum of ≈ 400 MeV/c. This exposure is being used to measure the polarization of the neutron from polarized Σ hyperons in the decays $\Sigma^\pm \rightarrow \eta + \pi^\pm$. The measurement for Σ^+ decays has already been reported, and the conclusion is that Σ^+ decay occurs through the P -wave channel. The data exclude a violation of time-reversal invariance through a large "imaginary" S -wave amplitude and are in striking agreement with several predictions based on the $SU(3)$ nature of the decay interaction.

A determination of the $K_1^0 - K_2^0$ mass difference is also being carried out in a study of the cross sections of the reactions

$$\bar{K}^0 + p \rightarrow K_1^0 + p,$$

$$\bar{K}^0 + p \rightarrow \Lambda + p,$$

$$\bar{K}^0 + p \rightarrow \Sigma^0 + p,$$

as a function of the proper time of the $\bar{K}^0$ before interaction. The first of these reactions provides both the sign and the magnitude, while the others provide only the magnitude of the mass difference. The $\bar{K}^0$'s are created by K^- charge exchange in the chamber.

A systematic study was continued of K^-p interactions between 600 and 840 MeV/c. In particular, the angular distributions in the reaction $K^- + p \rightarrow \Sigma^\pm + \pi^\pm$ in the mass region 1600 to 1700 MeV show considerable structure which cannot be disentangled by the present experiments.

To learn more about the nature of the large peak in the cross section for $K^- + p \rightarrow \Lambda + \eta$ near the threshold energy, an additional exposure was made in the 30-in. hydrogen bubble chamber with a K^- momentum spread of $\Delta p/p = \pm 0.15\%$. As the beam traverses the liquid hydrogen, the energy loss is sufficient to permit analysis of the energy dependence of the cross section very close to threshold, from which it can be inferred whether the peak is due to a resonance or to a scattering length (similar to the large singlet η - p scattering cross section at low energy). The distinction is important because a resonance should be classified in a particle multiplet and the other interpretation as a threshold phenomenon.

Improvements have been undertaken in the track chamber, film scanning, and measuring facilities of the Accelerator Department. The Hermes film plane measuring machine has been fitted with optical shaft position encoders, replacing the original brush-type encoders which were very prone to malfunction due to dirt and corro-

sion. In conjunction with this, a new electronic system was developed to write digital coordinate and control information on paper tape and a typewriter. To increase scanning and measuring capacity, a scanning table with film transport and projectors has been designed and built on which an image-plane digitizer will be installed. The digitizer will utilize the same electronic system (adapted to integrated circuit components) that is in use on the Hermes machine. Three more tables, patterned after the prototype, are under construction. The completed parts will be delivered and assembled shortly.

Other instrumental developments include (1) an interface gate to connect scintillation counter experiments to a digital computer, (2) digital computer programs and hardware for a semiautomatic checker for interface logic wiring, and (3) an IBM written program for transient analysis of complicated circuits, which has been put in operation on the BNL 7094 digital computer.

COSMOTRON

In accordance with instructions from the AEC, operation of the Cosmotron was reduced at the beginning of fiscal 1967 from 21 to 15 shifts/week, and at 0700 on December 31, 1966, operations ceased (see Figure 8). During this 6-month period there were 3084 potential operating hours which were utilized as shown in Figures 9 and 10. The time spent on accelerator studies was devoted to improving the beam intensity to meet the needs of

Figure 9. Cosmotron utilization during fiscal 1967.

the last few experimenters. For short periods in December, 3-BeV operation at 10×10^{11} protons/pulse was attained. However, the average intensity during the early months was $\approx 5 \times 10^{11}$ protons/pulse, rising to nearly 8×10^{11} at the end. The only significant accelerator failure was a cracked insulator on the pulsed liner of the Van de Graaff injector.

Effective January 1, 1967, the synchrotron was put on standby pending determination of its eventual disposition. The Van de Graaff injector was used to conduct several fundamental tests on accelerating columns. It is now being converted from pulsed to dc operation for use in a biomedical research program. The main motor generator was operated several times per month with the main magnet as a load to test ideas and equipment being developed for the AGS conversion project. This program will be continued. A plan to allocate the experimental magnets, power supplies, and similar auxiliary equipment was established. Some of the items have been integrated into existing BNL programs. Equipment has also been promised to other qualified institutions. The buildings continue to serve various divisions of the Accelerator Department as well as the biomedical group.

Research Program

A BNL group, using a double spectrometer in an external beam, continued its investigation of nuclear structure. Taking advantage of the small energy spread (≤ 2.5 MeV) and the long-term energy stability of the Cosmotron, this group has studied reactions of the $(p, 2p)$ and (p, d) type.

Figure 10. Use of the Cosmotron for experiments in high energy physics during fiscal 1967.

By special arrangement, the United States Air Force School of Medicine exposed primates to an external beam of 700-MeV protons.

A group composed of scientists from Yale University and Brookhaven completed the data-taking phase of an experiment to investigate the conservation of chirality in the scattering of protons by protons at values of $-t$ (the square of the 4-momentum transfer) of about $2.0 \text{ (BeV}/c)^2$.

Experimenters from the University of Rochester measured the interference pattern produced by the decay of $K_1^0 \rightarrow \pi^+ + \pi^-$ and the anomalous decay, $K_2^0 \rightarrow \pi^+ + \pi^-$.

Using spark chambers and counters, a group from the Universities of Cambridge and Padua conducted an experiment designed to measure the branching ratios of the η meson among its various decay modes. Both charged and neutral modes were measured.

Considerable time was used by the Chemistry Department, primarily for the study of the production of nuclear fragments.

Short runs were made by the Columbia University Department of Radiology and the BNL Medical Department to measure the linear energy transfer spectra of 2.2-BeV protons.

Instrumentation

The Instrumentation Division develops radiation detection and related instruments of general interest for atomic research and applications. In this class falls the work on germanium radiation detectors, on-line computer systems, and direct-read-out spark chambers, described below. A second category of activity is the design of special circuits, instruments, or techniques to solve particular research problems. This involves improvements in the state of the art or novel applications of known devices or techniques. Some projects of this nature that may be of general interest are described toward the end of this section. In addition, the Division supports a number of services, such as repair and calibration of instruments, vacuum technology, and glass-blowing. This year a computer maintenance group was established to maintain files, stock spare parts, and perform scheduled and emergency maintenance on many of the on-line computer systems now installed at the Laboratory.

GERMANIUM DETECTORS

The charge produced in a semiconductor radiation detector is accurately proportional to the energy dissipated within the sensitive volume. With germanium detectors it is possible to measure the energy of γ rays with great precision. However, the crystals must have a high degree of perfection and the signal amplifiers must be designed with great care.

A number of detectors have been produced for other departments by using the lithium-drifting technique described last year. Efforts have been made to obtain better germanium crystals by working with companies that produce the material and encouraging other potential suppliers. This has involved visits to two companies in Belgium and several companies in the United States, and many discussions with specialists in the field. Samples have been obtained from a number of companies and have been tested, with some encouraging results.

An alternative to lithium compensation is compensation by γ irradiation (first demonstrated by scientists at the Ioffe Institute, Leningrad). γ Rays

compensate impurities by introducing deep traps, but they also cause deleterious effects. Experiments done here show that the technique is feasible. While it may not be possible to produce detectors of as high quality as those produced by lithium-drifting, the γ -ray compensated detectors will be easier to store and ship and cheaper to produce.

Germanium detectors are often used near high-voltage accelerators where they are inevitably exposed to stray neutrons. A study of neutron damage has been instituted by the Physics Department. The performance of lithium-drifted germanium detectors becomes substantially degraded upon exposure to 10^{10} fast neutrons per cm^2 in the 10^6 to 10^7 -eV range. Measurements of pulse shape as well as amplitude distribution have shown that the neutron irradiation produces hole traps.

While semiconductor detectors have excellent intrinsic resolution, the signals are small pulses of charge, comparable to the noise pulses of conventional amplifiers. Low noise amplifiers using field-effect transistors (FET'S) were described in the 1963 Annual Report. New types of FET'S have been studied and used to make amplifiers with a better noise figure. Particular attention has been paid to the problem of operating at high pulse rates. Heretofore pulse-shaping networks designed to enhance the signals relative to amplifier self-noise have produced pulses of long duration which pile up on each other at higher rates. One technique developed to reduce this effect makes use of a modification of the Robinson double-diode base-line restorer which quickly returns the amplifier output to a stable, nonfluctuating base line after each pulse. This circuit can be used to improve the performance of available amplifiers at higher rates.

Another approach is to use time-variant or gated filters which admit the signal plus the inevitable noise for an optimally selected time interval. After the measurement interval the filter is discharged and made ready for the next signal, which substantially reduces the tail pile-up problem at high counting rates. It has been shown both theoretically and experimentally that the filter switching process introduces additional noise for

a time interval related to the filter parameters. Degradation in signal-to-noise ratio can be avoided, however, by allowing the noise to decay to its stationary value before arrival of the signal. Several circuit configurations for accomplishing this are under investigation.

In many radiation detectors the type of incident particle or the position of its interaction can be inferred from the shape of the charge collection pulse. If the pulse is double-differentiated with suitable time constants, its shape can often be adequately characterized by the time between its inception and the zero crossing. A circuit employing three tunnel diode discriminators has been designed for this type of measurement. It produces an output pulse amplitude proportional to the time interval of interest with an uncertainty of about 3 nsec for a 50 to 1 range of pulse amplitude.

A variable frequency precision square-wave generator has been built to replace mercury switch pulsers for calibrating high-resolution pulse spectrometers. Pulses are generated by switching an accurately controlled current into a precision output attenuator. The current can be varied over the range from 0.5 to 10 mA. Rise and fall times are about 10 nsec. A linear ramp generator is included for sweeping the pulse amplitude for system linearity tests.

COMPUTER SYSTEMS

An on-line data-taking system has been assembled for experiments in solid state physics performed at the Dynamitron accelerator. The system consists of a DDP 116 computer with magnetic tape, an analogue-digital converter, and facilities for generating displays. The system will be used for the digital recording of optical spectra which undergo rapid changes due to irradiation of a sample. It may operate simply as a buffer to record data on magnetic tape for subsequent analysis, or it may perform the functions of a 1000-channel analyzer or of a signal averager. The 1000-channel analyzer buffer is connected to a cathode ray tube to provide either map, curve, or isometric display modes.

Work has continued with members of the Physics Department on two SDS Sigma-7 computer systems. Circuits have been designed and built to connect each of these computers to specialized display consoles and to user control stations. A time-sharing executive program has been composed to

augment the SDS monitor program for the Bubble Chamber Group's computer. A supervisory program system is being developed for use with the SDS 920 computer which monitors a number of manual bubble-chamber film scanning stations. The system works in a conversational mode. Coordinates are fed into the computer, a program tests the data, and the operator is notified immediately so that corrections can be made while the picture is on display. The supervisory system includes input/output programs controlling the teletypewriters, digitizers, and film handlers on the scan tables. A time-sharing distributor schedules the individual monitor programs, which are on a disc and are called into core on demand. The monitor programs, which are usually different for each table, may be written in FORTRAN II and inserted into a disc library. A disc-file management program organizes the library of monitor programs and a set of files used to collect output data. After completion of a file, the data are released onto magnetic tape and delivered to the CDC 6600 computer for further analysis.

DIGITAL SPARK PLANES

These devices are finding wide application in the detection and recording of trajectories of high energy charged particles. Fabrication of the wire grid electrodes by printed-circuit techniques and applications with direct readout to a digital computer have been reported previously. This year larger planes have been built and used (see Figure 1), planes have been used to detect several particles at once, the performance of planes at reduced pressure has been explored, and the technique has been applied to a quite different class of experiments.

In the last two years the size has been increased from $\frac{3}{4} \times 1\frac{1}{2}$ ft to 2×6 ft. A set of planes $1\frac{1}{2} \times 3$ ft in area with wires spaced 40 to the inch is currently being used in a π - p scattering experiment at the Alternating Gradient Synchrotron. The spatial resolution is about half the wire spacing. A similar set of planes is being used to measure the back-scattering of K mesons, which requires simultaneous recording of two sparks or tracks. An efficiency of 98% has been achieved for double tracks.

At lower energies (< 1 BeV) scattering of the particles by the material in the chambers or in the air between them becomes a serious problem. Helium-filled bags have been placed between detectors to reduce the air scattering, and planes

Figure 1. Large digitized spark plane with memory core readout.

have been built with thin printed sheets or fine wire electrodes to reduce the amount of material in the beam. To reduce the scattering still further, it becomes necessary to lower the pressure throughout the beam path. The performance of spark planes with fine wire electrodes was studied at reduced pressures. A system was designed and operated with a pressure of $\frac{1}{10}$ atm of helium in the beam pipe and an equal pressure of argon in the spark chamber, separated by $\frac{1}{2}$ -mil Mylar windows.

In all the early work the spark plane wires were passed through magnetic memory cores and the digital readout was similar to that of a digital computer memory. A magnetostrictive delay-line technique has been employed in the *K*-meson experiment. The magnetostrictive pickup lines have a transmitter at one end and a receiver at the other so that the spark-generated signals can be passed from one delay line to another. All position information is thus converted into one sequence of signals in the time domain. Circuits and programs

were developed to digitize the spark positions on the fly and to feed them into a PDP-8 computer with a minimum of electronic components.

A high-precision spark plane for a low energy proton spectrometer (10 to 30 MeV) was developed in collaboration with Los Alamos Scientific Laboratory. In this case a metal mesh cloth of 100 wires/in. was used with electrodes only $\frac{1}{16}$ in. apart. The magnetostrictive delay-line signals were timed with a clock frequency of 100 Mc. Preliminary experiments indicated a position resolution of about 0.1 mm full width at half maximum (FWHM) and a particle resolution of about 0.15 mm FWHM.

WHOLE-BODY COUNTER

A whole-body counter has been designed jointly with the Medical Department and the Harshaw Chemical Company, a highly efficient concern that will provide spectral analysis and spatial data.

After consideration of various factors, the final system consists of a platform to hold the subject, a set of 27 detectors located below the subject, and another set of 27 detectors above, with mechanical adjustment of the vertical distances. Each detector is a 6×2-in. NaI(Tl) crystal with a 6×2-in. NaI light pipe and a 5-in. selected photomultiplier tube. The table and scintillation detectors have been installed. Circuits have been built to amplify the signals from each of the 54 detectors and to convey the position and amplitude information in digital form to a computer-analyzer.

OTHER INSTRUMENTS AND CIRCUITS

A silicon particle detector and sample holder, several integrated circuit amplifiers, and a scaler-timer made with integrated circuit logic elements have been assembled in a double-width AEC module package for use in the routine counting of smears for α contamination. The total count is displayed on a panel meter with full-scale capacities of 10, 100, or 1000 counts.

A mutual inductance bridge for the measurement of paramagnetic susceptibility at cryogenic temperatures has been built. It measures both real and imaginary components of the susceptibility. It has full-scale ranges varying from 100 μ H to 50 mH and, in the most sensitive range, can detect a 2-nH change with an excitation current of 10 mA. The bridge operates at 15 Hz to minimize eddy-current heating in the cryostat. Symmetrical, phase-sensitive detectors are used which are insensitive to even harmonics of the synchronizing signal, so that pickup at power line frequency (60 Hz) and all its harmonics are rejected.

In a chemical reaction rate study it was desired to sample a time-varying signal at intervals of time that were initially short and increased progressively. A digital clock was built with use of integrated circuit binaries and AND circuits which, when triggered, generated four equally spaced pulses followed by four pulses at twice the initial interval, and so forth, for a total of 64 pulses. The clock covers a time interval of about 5 sec approximately logarithmically, with an initial resolution of 50 μ sec.

A current-programming circuit was developed for use with superconducting magnets. The current may be linearly increased or decreased from one level to another in the range 0 to 100 A and at rates from $\frac{1}{2}$ to 20 A/min. The circuit will sense

whether the magnet has ceased to be superconducting and may be set to turn off the current or to activate an alarm.

Further work has been done on electroluminescent dosimetry and on a recording fluorimeter for use in biological studies. A system was built to measure internal friction as a function of radiation damage by measuring the rate of decay of vibration in a small reed of the sample material. A circuit has been designed to turn on and off the beam of the Chemistry Department's Van de Graaff generator in response to external signals, with a switching speed of about 0.1 μ sec.

METEOROLOGY

Wind and Turbulence

Observations of the mean wind and its turbulent components at 75, 150, and 300 ft were used to develop methods for estimating turbulent fluxes and gust loadings on structures and for assessing air pollution from simple sources in uncomplicated terrain.

A simple logarithmic wind-profile model can provide an estimate of the turbulent flux of momentum near the earth's surface, whereas the effects of atmospheric temperature stratification must be incorporated into the profile at greater heights. In the absence of actual diffusion tests at a site, the properties of the mean wind and the vertical and lateral variances or turbulent energy, σ_w^2 and $\sigma_w^2 v$, can be used to assess the air-pollution potential at a site when engineering approximations are required.

The Fourier transform of the turbulent energy, when plotted against frequency, shows the contribution in various frequency bands. The shape of this spectrum is quite important in predicting gust loadings on buildings and other objects. The Brookhaven data, which are among the most extensive in this field, agree well with a theoretical spectrum shape. The spectrum along the direction of the mean wind is not a function of atmospheric stability, while the vertical and crosswind spectra are stability sensitive. The largest total energy appears under very unstable conditions, which indicates the efficiency of the larger-scale eddies in transporting heat, momentum, or any passive pollutant.

The above measurements were all taken during periods when meteorological conditions were not changing. However, for estimating long-term ex-

posures from a source of pollution, or the probability that an adverse dispersion situation will occur for a certain length of time, the statistical quantity known as steadiness of the wind has proved useful. The long-term wind record at Brookhaven indicated that for 24 hr a constant wind from any direction was probable, but for periods >24 hr the steadiness decreased as a result of variations in the large-scale weather patterns. Recently data from other sites have been analyzed (see Figure 2). The free air station at Oak Ridge National Laboratory (ORNL) is quite similar to that at Brookhaven, while the valley station reflects the strong dominance of the diurnal circulation. As would be expected of a monsoonal location, the wind at Tarapur is extremely steady for periods of one month.

Diffusion and Dispersion

The study of particulate penetration into and through a forested region continued. About 15 point-source experiments have been made, including 12 utilizing the simultaneous release of physically identical but color-differentiated particles from 3 points outside the forest. In addition, more than 20 tests were made with use of pollen from an area source of ragweed plants upwind of the forest. General agreement of patterns and magnitudes of concentration was found between these forest tests and similar releases over open terrain. However, several important differences were noted. First, the particles are more widely dispersed both vertically and horizontally by divergence of the wind

Figure 2. Modal values of steadiness of the wind (S) at several diverse locations. The constant slope of the Tarapur curve results from the monsoon climate of India, the change of slope after 24 hr of the BNL and ORNL free air curves reflects changing synoptic conditions, while the change after 12 hr of the ORNL valley curve is caused by the diurnal reversal of the valley wind.

at the forest edge. Second, the dense foliage of the canopy causes most of the particles either to pass above the forest or enter at the lower levels. Finally, decrease of concentration with distance does not follow the same pattern as in the open. Loss is heavy near the forest edge because of impaction, light over the next 40 to 50 meters, and then heavy again because of deposition after about 60 meters of travel. The sampling network is extensive enough to permit calculation of total flux of airborne particles at successive distances into the forest, and for the point source releases reasonable agreement was found between the total flux at the forest edge and the number of particles released. Comparisons between loss in flux and deposition over the same distance could not be made within the forest, since most of the particles were deposited on foliage rather than the ground.

A 6-yr series of field experiments was completed in which dispersion of airborne pollens from 16 circular plots of plants from 5 to 55 m in diameter was studied. Three plant species, ragweed, timothy and corn, which produce pollen 20, 35, and 95 μ in diameter, respectively, were grown as sources, and during the pollination season the plots were surrounded by arrays of sampling devices. Air concentrations were measured at 4 heights and at 4 or 5 distances in all directions from the source, to give a 3-dimensional representation of the dispersion pattern for each test. Deposition to the ground was also measured and related to the loss in airborne pollen. A mathematical model suitable for predicting the dispersion patterns is under development.

Recently the Meteorology Group, in cooperation with the Tennessee Valley Authority and the U.S. Public Health Service, has compared actual plume-rise observations from several TVA power-plant plumes with theoretical and empirical formulas. This extensive set of measurements is almost unique, since it contains all the necessary source and meteorological parameters for proper evaluation. An empirical equation developed for a forthcoming ASME handbook on air pollution, in which the Group has taken an active part, compares favorably with the observed rise.

Instrumentation

Components for a pulsed ruby laser system have been purchased and are being assembled for use in laser-radar (lidar) experiments involving the backscatter of light from airborne particles. The initial

experiments will be conducted with use of oil-fog particles to determine the detailed time-history of the vertical distribution of a dispersing cloud. Such measurements are virtually impossible with the standard sampling techniques used in past studies at this and other sites. Initially data will be recorded by oscillographic techniques, and plans are being formulated to develop an automatic recording unit for the lidar if the initial results are successful.

Obtaining an accurate and representative sample of airborne particulates from the atmosphere is difficult because of the tendency of such particles to deviate from the flow of air actually sampled before that air enters or flows past the sampling device. Therefore the collection efficiency of each type of sampler must be determined for particles of a given size as a function of the conditions of ex-

Figure 3. Filter collection efficiency for a 20- μ particle at a flow rate of 25 liters/min as a function of angle and wind speed. Efficiency decreases at all angles as wind speed increases, but at higher wind speeds the forward-tilting filters are much more efficient, and the backward-tilting filters somewhat more efficient, than those mounted vertically.

posure. Otherwise, experiments involving particulate sampling may yield results ranging from ambiguous to grossly erroneous. During recent years several samplers have been evaluated in the Meteorology Group's wind tunnel, with use of a filter sampling isokinetically as a standard reference. The most extensive series of tests was made on the commercial-type filter holder used in many field dispersion experiments. This holder is designed for 25-mm-diam filters and is normally mounted with the opening upwards, at right angles to the mean horizontal wind. Since the instantaneous wind contains vertical components, the filter intake efficiency is not a simple function of wind speed for a given particle. The effect of changing vertical angle was studied in the wind tunnel by tilting the filter head in successive steps from 30° forward to 30° back from the vertical, and thus vertical components as great as $\pm 30^\circ$ were simulated. Tests were conducted at 4 wind speeds, at 3 flow rates, and with particles of 3 different sizes. All combinations of the variables were tested in triplicate. The data show that the efficiency of filter samplers, and presumably of other samplers drawing air into an intake, varies widely as a function of each of the variables studied. Figure 3 illustrates the variation in efficiency with angle and wind speed for a 20- μ particle at a sampling flow rate of 25 liters/min. Even wider ranges of efficiency are found at lower flow rates for the same particle size. Variation becomes less as particle size decreases, but efficiency approaches a constant and high value only for particles with diameters of less than a few microns.

Atmospheric Diagnostics Program

In addition to the material reported here, the Meteorology Group devoted considerable effort to the initial phases of the Atmospheric Diagnostics Program. This work, which involves cooperation among several groups and divisions, is discussed in the section on Nuclear Engineering.

Chemistry

HIGH ENERGY NUCLEAR REACTIONS

In continuing studies of the reactions of high energy protons with complex nuclei, the major emphasis was on the proton energy range of the Cosmotron, i.e., energies up to 3 BeV, in order to bring this aspect of the study to a certain stage of completion before the closing down of the Cosmotron in December 1966. A substantial part of this work was concerned with the fission of heavy elements, which was studied by a variety of techniques.

Studies Using the Scattering Chamber With Semiconductor Detectors

This apparatus was used to measure kinetic energies and angular correlations of coincident fragments from the fission of uranium and bismuth by 2.9-BeV protons. A secondary-electron emitting foil and an electron lens were added to allow simultaneous measurement of times-of-flight of both fragments, or the properties of a single fragment where only one was observed. The data are accumulated on a multiparameter recording system, stored on magnetic tape, and later processed by a computer. Some results of the study of uranium fission are shown in Figure 1. Those events in which both fragments move collinearly in the laboratory system contain a pronounced contribution of fissions with asymmetric mass splits (Figure 1a). Reductions in mean mass and total kinetic energy with increasing deviation from collinearity can be seen by comparing Figures 1b, c, and d with Figure 1a.

Studies Using Mica Track Detectors

Excitation functions for the binary fission of uranium, bismuth, and gold by protons having energies between 0.6 and 29 BeV were obtained from studies of the tracks produced by fission fragments in mica. Results are compared with those from other laboratories in Figure 2. Ternary fission to the extent of a few tenths of one percent of the binary events was observed for all three targets at energies above 2 BeV. Many single, unpaired

tracks due to high energy spallation recoils and to highly asymmetric fission events were observed. Only fragments of $A \lesssim 40$ give rise to observable tracks in this work.

Studies Using Catcher Foils

Differential range and angular distributions of selected products such as Cu^{64} , Sr^{83} , Pd^{109} , and Ba^{128} from the fission of bismuth by 2.2-BeV protons were measured by radiochemical techniques. Stacks of thin plastic (Mylar) foils were used in this work. To aid in the interpretation of this and a similar study of uranium fission, an improved semiempirical treatment of fission fragment range-energy relations was developed.

Rare-Earth Yields

Work has been started on the hitherto little-studied rare-earth nuclides produced by high energy proton bombardment of heavy elements. Efficient methods for the separation of the rare earths by ion exchange have been developed. Mass separation by means of an electromagnetic isotope separator is achieved with an over-all efficiency of about 0.5% either before or after the chemical separation.

Interactions of Antiprotons and of Protons in Nuclear Emulsions

A study of the interactions of 2.9-BeV antiprotons in nuclear emulsions showed that antiprotons interact with silver and bromine more than twice as frequently as do protons of the same kinetic energy. Antiprotons deposit more energy in the target nuclei and hence produce larger "stars." The cross section for production of light fragments (lithium to carbon) is increased threefold, and that for Li^8 fragments sevenfold, compared to production by proton irradiation. Previous studies of the interaction of 1-, 2-, and 3-BeV protons with nuclear emulsions were improved and placed on a quantitative basis by a series of calibration experiments.

Yields of Stable Isotopes

Yields of the stable isotopes Ne^{20} , Ne^{21} , and Ne^{22} have been measured mass spectrometrically. Results indicate that the isotopes in the mass 20 region arise from a mechanism other than spallation, even from targets as light as copper. Radiochemical studies of the isobaric pair Ne^{24} - Na^{24} have shown that these fragments are produced directly or arise from precursors with only moderate amounts of excitation.

Monte Carlo Calculations

The Monte Carlo intranuclear cascade calculations have been extended to treat incident low energy pions with use of the isobar and one-pion exchange models. To obtain data to test various predictions of the Monte Carlo calculations, scanning of 160,000 pictures of the interactions of 385-MeV protons with copper and tantalum was commenced, and computer programs for the reconstruction of events in the 14-in. bubble chamber were almost completed.

Theoretical Studies of the De-excitation of Highly Excited Nuclei

Calculations previously made on the de-excitation of highly excited nuclei having large angular

Figure 1. Contour maps of total kinetic energy as a function of fragment mass for the binary fission of U^{238} by 2.9-BeV protons. Numbers on contours designate relative intensity. Coincidences were taken with one counter fixed at -90° to the beam direction and other counters at various angles θ and ϕ (the in-plane and out-of-plane angles, respectively).

Figure 2. Excitation functions for the proton-induced fission of U^{238} , Bi, and Au.

momenta were extended in order to examine the evaporative emission of heavy fragments (e.g., Na^{24}) having energies below the classical Coulomb barrier. The calculations show that under conditions such that nucleon emission is strongly suppressed by the centrifugal barrier, such heavy fragment emission becomes predominant over γ -ray emission for angular momenta above a critical value. In fact, these conditions occur with sufficient probability to account for a large part of the fragmentation products observed in the products of intranuclear cascades induced by BeV protons. Another extension of the calculations was to the de-excitation of selected primary products of the thermal neutron fission of U^{235} . The computed amounts of excitation energy removed by neutron and γ -ray emission agreed with experiment, and so resolved a long-standing problem (see Table 1). Average computed energies, multiplicities, and energy spectra were also consistent with observation. A further calculation indicated that isomer ratios resulting from the de-excitation of nuclei often depend strongly on small changes in the positions of low-lying levels other than the isomer levels. This effect, which had been ignored in previous treatments, was found to be large enough to account for the sizable discrepancies (e.g., a factor of three) found between experiment and theory in many cases.

Table 1

Emission of γ rays and neutrons from primary fission products in thermal neutron fission of U^{235} . Comparison of calculated values for the single fission pair Sr^{96} and Xe^{140} (one of the most probable pairs) with experimental data for the average of *all* fission products. The calculations assume that the average excitation energies of Sr^{96} and Xe^{140} are 13.0 and 10.1 MeV, respectively, and that the average angular momentum of each fragment is $\approx 6 \hbar$. These assumed values are based on data independent of the data compared here.

	Calculated			Experimental
	Sr^{96}	Xe^{140}	Total	
Total γ -ray energy, MeV	3.97	3.11	7.08	7.2 ± 0.8
No. of γ rays	4.18	3.99	8.2	7.4 ± 0.8
Av energy per photon, MeV	0.95	0.78	0.87	0.97 ± 0.8
Av no. of neutrons	1.38	1.12	2.50	2.43*
Av kinetic energy of neutrons, MeV	1.13	0.97	1.06	1.20

*Av for all primaries in the mass-split 96-140.

NUCLEAR SPECTROSCOPY

The Effect of Chemical Bonding on the O-Shell Conversion Coefficient in Sn^{119m} Decay

Effects of changes in chemical binding on nuclear transition probabilities have been measured invariably as small changes in the half-lives of nuclei decaying by either electron capture or internally converted isomeric transition. Except for one case in which a 3% effect was found, the half-life change is very small, about 0.1%. On the supposition that much larger changes, observable in some detail, might be demonstrated by measurements made on internal conversion electrons originating from individual levels in the atom, especially from those levels most directly involved in chemical bonding, experiments were undertaken with very thin sources of Sn^{119m} in two different chemical forms. Sources were prepared by imbedding techniques with use of an isotope separator, and identification of the chemical form was verified by Mössbauer measurements made on the

γ rays of the 23.86-keV $M1$ transition. Measurements of the resolved individual internal conversion electron lines of this transition showed that the O -shell line intensity, essentially 5s electrons of the valence shell, is 30% less in SnO_2 than in white tin metal. This demonstrates that the density of 5s electrons at the nucleus of a tin atom bound to oxygen is less than that in a metallic tin atom. It should be noted that it seems to have been impossible from theoretical arguments about bonding to determine even the sign of this effect.

The results of these internal conversion measurements can also be used to compute indirectly the effect of chemical bonding on the $\approx 2 \times 10^{-8}$ -sec half-life of the 24-keV state of Sn^{119} , which has never been measured directly. Such computations show that in the oxide the half-life is about 0.1% greater than in the metal. The change in the 250-day half-life of Sn^{119m} (84-keV state) is presumably of the same order.

The Ratio of the Nuclear Charge Radii of Sn^{119m} and Sn^{119g}

The interpretation of Mössbauer measurements on tin compounds requires knowledge of the relative charge radii of Sn^{119m} and Sn^{119g} . This ratio has been a subject of controversy for several years. The controversy has now been settled in a definitive way at Brookhaven by measurement of the change in the O -shell conversion coefficient of the 23.86-keV transition on going from white tin to SnO_2 (see preceding topic). This measurement, with small screening corrections, combined with Mössbauer data for the isomer shift between white tin and SnO_2 , gives the result: the charge radius ratio $Sn^{119m}(23.86 \text{ keV})/Sn^{119g}(0 \text{ keV})$ is 1.00033 ± 0.0001 .

Internal Conversion Coefficients

The discrepancies between measured and theoretical values for internal conversion coefficients, discussed in last year's report, have been studied further. New experimental data have been obtained on pure transitions of several different multipole orders and energies occurring in a number of different nuclei. These data sometimes differ from the theoretical numbers by amounts larger than the combined uncertainties of experiment and theory, and in some cases even differ in sign. They confirm what seemed not unlikely from examination of the two available sets of theoretical values,

namely, that the theoretical values do not in fact have the 2% accuracy claimed by their authors. In the course of this work, hand and computer methods were developed for simple, accurate interpolation between tabulated theoretical values for the conversion coefficients.

No satisfactory explanation has been found for the discrepancies between theory and experiment in the L -subshell coefficients of $E2$ transitions, described last year. These differences, about 5%, were recently confirmed at Chalk River and at Uppsala. In the course of the past year theoretical results became available for M -subshell conversion ratios for some of these same transitions, and measurements on these cases were made. Preliminary analysis of these results on M conversion shows a trend of the differences similar to that for L conversion, but larger.

CRITICAL STUDY OF THE THEORY OF COLLISION PROCESSES

In a continuing search for the sources of the inadequacy of standard theory to account for the measured probabilities of the electron ejection that accompanies α decay, a critical study is being made of the theories of analogous phenomena in which agreement with experiment seems to be obtained. This study has revealed some curious fortuitous agreements between theory and experiment, a striking one being the following. A paper published from another laboratory reports the results of a theoretical calculation of the ratio of singly charged to doubly charged helium ions produced by bombardment of helium atoms with an electron beam. The basic assumption made in this calculation is that every ejection of one of the atomic electrons by a bombarding electron to produce He^+ constitutes a "sudden" perturbation on the other atomic electron, as a consequence of which the latter may be excited to the continuum. The best available Hartree-Fock wave functions were used in the calculation. The theoretical $\text{He}^+/\text{He}^{++}$ ratio was 1.17 times the reported experimental values, which is quite fair agreement, and the author attributed the 17% discrepancy to the deviation of Hartree-Fock helium wave functions from exact ones. At Brookhaven a calculation was made on the same model, but with simple screened hydrogenic wave functions, the He effective nuclear charge being taken to be $2\frac{1}{6}$ (i.e., the

variational value). In this latter calculation, the theoretical $\text{He}^+/\text{He}^{++}$ ratio was 0.826 times the experimental ratio, i.e., as far below the experimental value as the calculation with Hartree-Fock functions was above. With the assumption that the effective nuclear charge was 2% greater than the variational value, exact agreement with the experimental value was achieved, and when the effective nuclear charge was assumed to be 3% greater than the variational value, the calculation reproduced the result obtained with Hartree-Fock wave functions. The relatively minor difference in results obtained by calculating with very crude and with quite refined wave functions shows that the degree of exactness of wave functions is not a very critical element in the calculation. However, and this is the main point of the present remarks, whatever the wave functions, any agreement between theory and experiment obtained by calculations based on the model described above is fortuitous, because the physics of the model is wrong. The basic assumption of the model, namely, that the knock-out of one electron from a helium atom constitutes a *sudden* perturbation on the other helium electron, requires the ejected electron to depart the atom with a speed large compared with the speed of an electron in the ground state of helium. But even at bombardment energies as high as 1000 eV, only a negligible fraction of knocked-out electrons have momentum sufficiently great to constitute a sudden perturbation; furthermore, few knocked-out electrons have energy great enough even to permit ionization of the second electron. This was shown by calculations of the energy and momentum distributions of electrons knocked out of helium by bombardment with electrons of 12 energies between 50 and 1000 eV. The calculations (the numerical work was done on the CDC 6600 computer with numerical error of $<1\%$) were made in first Born approximation with screened hydrogenic wave functions and with neglect of electron exchange and relativity. If exchange were included in the calculations, presumably the energy spectrum of the knocked-out electrons would have more intensity at higher energies, but not enough to affect significantly the conclusions drawn above. Thus the reported agreement between theory and experiment is fortuitous, as might have been surmised from an analysis of the various physical processes that can lead to the double ionization of helium by electron bombardment.

THE BROOKHAVEN SOLAR NEUTRINO EXPERIMENT

As discussed in the 1966 Annual Report, a neutrino detector has been built in the Homestake Gold Mine at Lead, South Dakota, to observe the neutrino radiation from the sun. Detection is

(see Figure 3). These force the helium gas through the body of liquid in the tank in the form of finely divided bubbles. The argon is ultimately removed from the helium by passing the gas through a charcoal trap held at liquid nitrogen temperatures. The decay of the radioactive Ar^{37} is observed in a miniature low-level proportional counter.

Figure 3. Interior of the solar neutrino detector tank just prior to its being filled with 100,000 gallons of tetrachloroethylene. The two 6-in.-diam horizontal pipes carry the return flow of tetrachloroethylene from circulating pumps located outside the tank. Projecting from the 6-in. pipes are 40 eductor nozzles, each connected to a vertical pipe that projects into the gas space above the liquid level. The high-velocity discharge of liquid through these nozzles into the body of the liquid aspirates gas through the vertical pipes and thus accomplishes very efficient mixing of liquid and gas.

achieved by absorption of neutrinos on the isotope Cl^{37} to form the 35-day radioactive product Ar^{37} . Because of the extremely low value of the neutrino capture cross section, a very large mass of a chlorine-containing compound is essential. Six hundred and ten tons of tetrachloroethylene liquid are used, contained in a tightly sealed tank 48 ft long and 20 ft in diameter. The Ar^{37} is removed from the tank by purging with helium gas. To obtain efficient contact between the helium gas and the liquid, a system of pumps and eductors is used

To avoid the effects of cosmic radiation the detector was built 4850 ft below ground. The tank and associated pumping system were completed in June 1966 and then filled with 100,000 gallons of tetrachloroethylene. Installation of the argon extraction system and instrumentation in January 1967 completed the construction. In view of the relatively high solubility of argon in tetrachloroethylene and the large amount of argon in air, all air, particularly atmospheric argon, had to be removed from the tank. Most of it was removed by

Figure 4. Molecular framework of silyldimethylamine pentamer. The three hydrogen atoms surrounding each silicon atom in the plane perpendicular to the N—Si—N bond are not shown. (This is a stereoscopic pair and may be viewed with a small, hand-held stereoscope or by slightly adjusting the angle between the eyes.)

Figure 5. Molecular structure of methoxytetraphenyl antimony. This is a stereoscopic pair.

purging with cylinder helium and leaving a helium atmosphere. Residual air in the latter was removed by circulation over charcoal. By this means the air argon in the tank was reduced ultimately to $<1 \text{ cm}^3$, and the first exposure to solar neutrinos was started. Initial measurements of the solar neutrino flux will be made during the summer of 1967.

According to the latest theoretical estimate made by a group at the California Institute of Technology, the flux of energetic solar neutrinos at the earth, primarily those from the decay of B^8 in the sun, is 0.6 to $3.6 \times 10^7 \text{ cm}^{-2} \text{ sec}^{-1}$, and the corresponding neutrino capture rate in the 610-ton detector is 3 to 10 per day.

CHEMICAL CRYSTALLOGRAPHY

X-ray and neutron diffraction studies have provided much insight into the structural chemistry of a number of interesting classes of molecules. At Brookhaven the areas of study emphasized have been hydrogen bonding; the chemistry of penta-valent phosphorus, silicon and antimony; the chemistry of transition metal complexes; and the accurate determination of charge density in simple molecules. The rapid development of instrumentation and computer technology has contributed greatly to the collection of data and the interpretation of results. A few examples from the varied program are described here.

Silyldimethylamine, $\text{SiH}_3(\text{CH}_3)_2\text{N}$, has a melting point considerably higher than that of either trimethylamine or disilylmethylamine. Infrared data have suggested a considerable degree of association in the solid state. An x-ray diffraction study has shown that this compound actually exists in the solid as a pentameric molecule consisting of a ten-membered ring of alternating nitrogen and silicon atoms with two carbon atoms bound to each nitrogen and three hydrogen atoms to each silicon (Figure 4). The configuration around the silicon atom is that of a trigonal bipyramid with the nitrogen atoms at the apices and the hydrogen atoms in the equator. This is the first well-established example of a stable compound in which silicon forms five bonds.

Both phosphorus and antimony form many penta-coordinated compounds. Comparative studies of these compounds can be of great use in formulating semiempirical bonding theories. The bond lengths and geometries in these compounds show interesting variations. For example, pentaphenyl phosphorus has been shown to have a trigonal bipyramidal geometry, while pentaphenyl antimony has a square pyramidal configuration. But when a single methoxy group is substituted for a phenyl group in the latter compound, the result is again a trigonal bipyramidal configuration (Figure 5). Accurate molecular dimensions for this compound, as well as for dimethoxytriphenyl antimony (which has the same configuration around the metal atom) have been determined by x-ray diffraction studies.

The rapid collection of accurate neutron diffraction data at the High Flux Beam Research Reactor has made possible high-precision determinations of hydrogen atom positions and thermal vibrational parameters in hydrogen-bonded materials. The potassium acid salt of aspirin is typical of a class of acid salts that have very short (2.44 Å) hydrogen bonds connecting the two anions. A neutron diffraction study of the structure of this crystal, in particular the parameters describing the thermal motions of the hydrogen atom, supports the hypothesis that the hydrogen atom in this bond is located midway between the two oxygen atoms. The estimated frequency for the O—H stretching vibration is $<1000\text{ cm}^{-1}$, a large shift from the normal O—H stretching frequency, but one that is consistent with the infrared spectral data.

The combination of x-ray and neutron diffraction measurements is an elegant way to investigate the effects of chemical bonding on the electron density in molecules. In a study of triazine, $\text{N}_3\text{C}_3\text{H}_3$, the neutron diffraction data have been used to determine accurate positions and thermal parameters of the atoms. These parameters have been used together with free atom scattering factors in a calculation of the x-ray structure factors. A comparison of these calculated structure factors with those observed reveals clearly (Figure 6) the electron density associated with the C—N bond and with the lone pair electrons.

Magnetic Structures Investigated by Neutron Diffraction

A magnetic phase diagram has been constructed for the system $\text{Ca}(\text{Cr}_x\text{Fe}_{1-x})_2\text{O}_4$ for $x \leq 0.5$. The diagram exhibits single-phase regions in which two distinct antiferromagnetic structures are stable. For a broad range of composition and temperature, however, the two magnetic phases coexist at equilibrium. This is the first example of such be-

Figure 6. Difference electron density in triazine. Extra electron density associated with the C—N bond is seen clearly, as is the departure from spherical symmetry of the lone pair electrons.

havior. Transition temperatures and the temperature dependence of magnetic moments and phase concentration have been determined as a function of composition.

The isomorphous compound CaV_2O_4 has also been found to order antiferromagnetically. Three possible collinear models, indistinguishable on the basis of powder diffraction measurements, have been determined by using a method based on magnetic space groups.

MnSn_2 undergoes an abrupt transition at $\approx 73^\circ\text{K}$ from one antiferromagnetic structure to another. A small, modulated spin component makes its appearance about 20° above this temperature and vanishes sharply at the transition. It is suggested that the anomalous susceptibility behavior of MnSn_2 above the transition is produced by a weak coupling between the modulated spin and the main antiferromagnetic spin system.

The spinels HgCr_2S_4 and HgCr_2Se_4 were also studied by neutron diffraction. HgCr_2S_4 is a ferromagnetic spiral which is propagated along the cube edges in domains. The field dependence of the spiral has been analyzed and shown to account for the meta-magnetism of this compound.

Several rare-earth Laves phase systems have been examined, including $\text{Er}(\text{Al}_x\text{Mn}_{1-x})_2$, $\text{Er}(\text{Al}_x\text{Co}_{1-x})_2$, and $\text{Pr}(\text{Al}_x\text{Cu}_{1-x})_2$. In the cobalt system, all the compositions ($x=0.4, 0.5, 0.7, 0.85$, and 1.0) are ferromagnetic, with the cobalt having zero moment. The erbium moment shows large departures from its theoretical value and, in particular, oscillates in magnitude as a function of composition. The manganese system ($x=0.38$ and 0.5) does not order at liquid helium temperatures.

A number of compounds having the tetragonal trirutile structure, an ordered arrangement of three rutile unit cells along the c -axis, have been studied. Two basic types of magnetic structure have been found in which the spins along the cell edge are always antiferromagnetically coupled but the interior ones are either ferromagnetic (A-type) or antiferromagnetic (G-type) with respect to their nearest neighbor along the edge. The particular compounds investigated and their structures are

	Structure	Spin Direction
Cr_2WO_6	A	basal plane
$(\text{CrFe})\text{WO}_6$	G	basal plane
V_2WO_6	A	c -axis
Cr_2TeO_6	G	c -axis
Fe_2TeO_6	G	basal plane

Magnetic Susceptibility Studies

The magnetic susceptibilities of $\text{V}(\text{bipyridine})_3(\text{ClO}_4)_2$, $\text{K}_3\text{Cr}(\text{CN})_6$, and K_2MnCl_6 have been measured as a function of temperature. The ions V^{+2} , Cr^{+3} , and Mn^{+4} , which all have octahedral coordination and are in the 4A_2 state, have a moment of 3.87 Bohr magnetons. This is the value predicted for the 4A_2 state.

The ratio of the exchange integrals for K_2MnCl_6 and Rb_2MnCl_6 has been determined from the paramagnetic susceptibilities. This ratio, 1.35, is in satisfactory agreement with the value 1.30, calculated from the lattice parameters with the assumption that the exchange integrals are due to the singlet-triplet transition in the $\text{Cl}-\text{Cl}$ "molecule" connecting two Mn^{+4} ions.

ISOTOPE EFFECTS

Vapor Pressures of Isotopic Species

Theoretical and experimental studies at Brookhaven over the past decade have shown that new and important information concerning molecular rotation in liquids and solids can be obtained from measurements of isotopic vapor pressures. During the past few years this technique has been applied to the problem of hindered rotation in liquid methane, a problem still unsettled after three decades of investigation during which it was approached by way of heat capacity measurements, molecular spectra (both infrared and Raman), and elastic and inelastic neutron scattering. At Brookhaven the problem was first attacked by making theoretical calculations, based on certain models, of the vapor pressures of isotopic methanes. Comparison of the results of these calculations with the known vapor pressures of the deuteromethanes and C^{13} -methane led to the conclusion that rotation in liquid and in solid methane is hindered.

During the past year the completion of a number of new experiments, together with further calculations, has placed this conclusion on a firm basis. The vapor pressures of CH_3T and C^{14}H_4 have been measured by the column multiplication technique. These molecules have the same molecular weight as the formerly measured CH_2D_2 , but all three molecules have different moments of inertia, a fact related to their all having different

vapor pressures. Calculations based on a free rotor model give the wrong prediction that the small quantum effects (identified by the $1/T^2$ behavior of the vapor pressures) should be in the order $C^{12}H_4 > CH_3T > CH_2D_2 > C^{14}H_4$. The sequence observed experimentally is $C^{12}H_4 > C^{14}H_4 > CH_3T > CH_2D_2$, similar to the order $C^{12}H_4 > C^{13}H_4 > CH_3D$ found formerly. All the vapor pressure data are consistent with the same force-field hindering rotation. These results provide conclusive evidence for hindered rotation in liquid and solid methane. They are confirmed by inelastic and elastic neutron scattering measurements made elsewhere and recently published.

Significant Structure Theory

In the case of monatomic substances, an analysis of isotope effects within the framework of the significant structure theory, which approximates the liquid as a mixture of gaslike and solidlike domains, leads to reasonable agreement with experiment. For polyatomic molecules, however, this theory predicts that the crossover temperature (the point at which two isotopic species have the same vapor pressure) should be the same in the solid and the liquid. Since this is not found experimentally, further refinements will have to be introduced into the significant structure theory as it applies to polyatomic molecules.

Cryostats for Precision Measurements of Vapor Pressures and Molal Volumes of Cryogens

Contemplated work on problems of condensed media has necessitated the design and construction of apparatus to measure vapor pressures, molal volumes, and distribution coefficients with much higher accuracy than is possible with conventional equipment. A new cryostat for vapor pressure measurement, which constitutes the first significant advance over the Giauque-Johnston cryostat, has been designed and constructed. It can be operated from 2° to 350° K, and a temperature stability of at least $\pm 0.001^\circ$ K over the working volume (2 in. in diam by 4 in. high) has been demonstrated between 60° and 250° K. A very useful feature is the incorporation of proportional heat switches operating in the low temperature region. This development avoids the difficulties of parasitic condensation inherent in the use of exchange gas. Operation of the cryostat awaits completion of improved differential pressure sensors.

A simple cryostat has been constructed for the determination of molal volumes of small quantities of cryogens. Preliminary experiments with ethylene show that a precision approaching 1 part in 10^5 is attained with samples as small as 0.5 ml of liquid. With this cryostat it was found that C_2D_4 has a molal volume 1% less than that of C_2H_4 , despite the fact that its vapor pressure is some 3% *greater* than that of C_2H_4 , in accord with theory. The density measurements indicate that the coefficients of expansion of C_2H_4 and C_2D_4 are the same within 0.1%.

Kinetic Isotope Effects and Reaction Mechanisms

If two thermally labile groups, A and B, in a molecule

are separated by a chain of n insulating methylene groups, how small must n become before the bonds to A and B rupture simultaneously when the molecule is excited thermally by collision in solution? To help answer this question, azo compound II was synthesized. The observed secondary α -deuterium isotope

effect in the decomposition of II in ethylbenzene at 113° is $k_{IIa}/k_{IIb} = 1.19$ (4 atoms of deuterium), and the reaction exhibits good first-order kinetics.

Previous work has shown that a symmetrical azo compound such as IV decomposes by simultaneous rupture of both carbon-nitrogen bonds, with a decrease in rate constant of about 12% per deuterium atom. Hence, the observations on compound II

are consistent with a mechanism involving simultaneous carbon-nitrogen bond rupture for one azo linkage, followed by the loss of the second molecule of nitrogen. Thus, the chain of eight methylene groups is an effective insulator. The major product from an

equimolar reaction mixture of IIa and IIb was shown to contain only IIIa and IIIb, with no cross product. It appears then that after the loss of the first nitrogen molecule the ring closes before the second molecule of nitrogen is lost. An alternative explanation is that a very strong cage effect operates.

Participation by neighboring groups in the formation of carbonium ions is well documented. Similar effects, tending to stabilize radicals in a transition state or in an intermediate, are hardly known. Possible phenyl participation in the thermal decomposition of azo compound V was sought.

If a structure such as VII were an important contributor to the stabilization

of the transition state, the secondary α -deuterium isotope effect might be considerably lower than if there were not bonding between the α -carbon and the β -phenyl group. The measured secondary α -

effect in this reaction is $k_{V_a}/k_{V_b} = 1.21$, which indicates that participation, if it occurs, contributes little to the stabilization of the transition state.

The published literature on secondary α -deuterium isotope effects in bimolecular nucleophilic aliphatic substitution has been re-examined. It has been found that the α -deuterium effect is proportional to the difference in the nucleophilicities of the entering and leaving groups. It is also of interest that the zero-point energy contributions to the C^{13} effects in the substitution by water of chloride, bromide, and iodide in methyl halides correlate in the same way with this difference.

Experiments have been completed in which the rates of the following reactions have been determined relative to the rate of CF_3 radical recombination:

Isotopic competition methods were also used to determine $k_{\text{H}_2}/k_{\text{D}_2}$ and $k_{\text{HD}}/k_{\text{DH}}$ directly. The latter ratio is of particular interest since it depends only on properties of the transition state, the reactants being identical in both cases. It is interesting that the ratio $k_{\text{H}_2}/2k_{\text{DH}}$ is almost identical with $2k_{\text{HD}}/k_{\text{D}_2}$, as would be predicted from the rule of the geometric mean. Theoretical estimates of these isotope effects are now being made, based on various empirical and semiempirical models for the potential energy surface.

Photosensitized Reactions Studied With Isotopic Tracers

An intense source of 3261-Å cadmium resonance radiation has been developed, consisting of a small, cadmium-filled quartz bulb inside the tank coil of an rf oscillator. The *cis-trans* isomerization of ethylene- d_2 , catalyzed by 5^3P_1 cadmium atoms excited from the ground state by the above source, has been studied. This has an advantage over the more usual techniques of mercury atom photosensitization, because the excited cadmium atom does not transfer enough energy to break a C—H bond in ethylene. Although this results in very low yields of decomposition products, a substantial amount of *gem*.-ethylene- d_2 is formed during the reaction. The only mechanism seemingly compatible with

this observation involves two electronically excited states of ethylene, one of which is the triplet.

Calculations of Energy Transfer

The exchange of energy between translation and internal degrees of freedom of molecules is the simplest process that occurs in molecular encounters. Exact classical solutions to the energy transfer problem can be obtained by integrating the relevant Hamiltonian equations of motion on a computer. Previously, studies had been made on the exact classical solution to the problem of translational-vibrational energy transfer in the collinear collision between a diatomic molecule and an atom. During fiscal 1967 these calculations have been extended to the semiclassical approximation, and the magnitude of quantum effects was shown to be small. Classical calculations for the atom-diatom molecule system with motion restricted to a plane have also been made, to determine the effect of rotation. The dynamic interaction between molecular vibration and molecular rotation is found to be much larger than anticipated, and further details of this interaction are being investigated.

INORGANIC REACTIONS IN SOLUTION

Studies of oxidation-reduction reactions involving metal ions and their complexes have shown that they are of two main types. These have been called inner-sphere and outer-sphere reactions. In outer-sphere reactions the coordination shells of the metal ions remain intact, while in inner-sphere reactions the metal ions are connected by a common bridging group. Since the immediate products of inner- and outer-sphere reactions are different, the identities of the primary products of a reaction provide valuable information concerning its mechanism.

The immediate products of the oxidation-reduction reaction can be identified by conventional techniques if the substitution reactions

are sufficiently slow, or by flow techniques if the substitution reactions are rapid. By use of the latter techniques, the reactions of Fe^{+2} with a variety of cobalt(III) complexes and the reaction of V^{+2} with CrSCN^{+2} have all been shown to proceed by inner-sphere mechanisms in which an anion is bonded directly to both metal centers.

The reactions of V^{+2} with iron(III) complexes, on the other hand, do not proceed by the above type of mechanism. The electron transfer in the latter reactions is very rapid and is virtually complete in the time required to form a bridged intermediate. As expected for an outer-sphere mechanism, the rates of these reactions are not very dependent on the nature of the ligands attached to the iron(III).

The aquation of FeCl^{+2} proceeds by both acid-dependent and acid-independent paths.

These reactions are catalyzed by Fe^{+2} as follows:

The rate constants for the latter reactions were determined and were shown to be consistent with a mechanism involving the formation of an intermediate in which a hydroxide group is bonded to both the iron(II) and the iron(III).

The rates of formation and aquation of VNCS^{+2} were studied. These rates differ from those of the corresponding FeNCS^{+2} and CrNCS^{+2} reactions in two important respects: (1) The entropies of activation for the VNCS^{+2} reactions are more negative than those for the FeNCS^{+2} and CrNCS^{+2} reactions. (2) The rates of the VNCS^{+2} reactions show no inverse acid dependence. These results can be rationalized by assuming that the vanadium(III) reactions possess more S_{N}^2 character than the corresponding iron(III) and chromium(III) reactions.

HOT-ATOM CHEMISTRY

Oxygen-hydrocarbon studies involving recoil carbon-11 were extended to systems containing up to 95% oxygen. Supplemental to this study was the

collection of highly precise data on oxygen-hydrocarbon systems containing 4.5% oxygen.

A second study involved a detailed investigation of pressure-dependence effects on the mechanism of acetylene and ethylene formation in propane, cyclopropane, and neopentane. Previous work at Brookhaven has shown that excited intermediates probably play an essential role in the reactions of excited carbon atoms. Acetylene, ethylene, and carbon monoxide yields from cyclopropane and propane were studied in the presence of 4.5% O_2 at pressures of 1 to 10,000 torr (Figures 7 and 8). Neopentane was studied between 1 and 1400 torr. The results indicate that the formation of the excited carbene intermediate is product-determining. The initial collision between the carbon atom and the substrate may result in a complex not involving insertion which can either fragment, and thus thermalize the carbon atom, or form the carbene intermediate by subsequent collision. In this model, as the pressure increases the formation of carbene is favored, and the probability of acetylene formation is thereby increased [Eq. (1)].

The carbon monoxide yield [Eq. (2)] goes down as the pressure goes up, since less C^{11} is available for reaction with oxygen.

Figure 7. Cyclopropane pressure vs yields of carbon monoxide and acetylene from the reaction of recoil C^{11} on cyclopropane in the presence of 4.5% O_2 .

An alternative explanation would involve the formation of a very highly excited carbene intermediate in which carbene-to-acetylene formation takes place from the lower levels of excitation and fragmentation takes place from the higher levels of excitation. In this model an increase in pressure would serve to de-excite the intermediate to lower levels and thereby allow the increased formation of acetylene [Eqs. (3) and (4)].

In this scheme the fragments could be thermalized carbon atoms, excited $C^{11}H$, $C^{11}H_2$, $C^{11}H_3$, and other molecular species containing C^{11} .

Both mechanisms are consistent with the observed rise in acetylene yield with increased pressure. A choice between them must await the results of future experiments.

A device for automatic data collection has been developed. It simultaneously records time, counting data, gas-liquid partition chromatography data, and flow rate. A computer program has been developed to evaluate these data. Precision and speed have been improved to the point where it will be possible to study *in detail* the chemical re-

Figure 8. Propane pressure vs yields of carbon monoxide, ethylene, and acetylene from the reaction of recoil C^{11} on propane in the presence of 4.5% O_2 .

actions of isotopes with half-lives of only 1 or 2 min (e.g., O^{15}). As part of this program an absolute flowmeter (flow measurement independent of the mass of the gas) with digital output was developed. A cylindrical window counter with high stability and efficiency of operation was also constructed.

Improved methods of separation of deuterated hydrocarbons were developed in preparation for a continuation of hot-atom double label studies. A separation of toluenes deuterated in the methyl group was accomplished on a 600-ft, 0.010-in. i.d., open-tube stainless steel column coated with squalene and run at 4°C (Figure 9). Experiments with carrier-free recoil labeled toluenes, in which the counting was done with use of a 2-cc internal flow counter attached to the end of the capillary columns, demonstrated that double label experiments with minute quantities were practical.

Reaction Mechanisms

The photolysis of diazo compounds such as cyclopropyldiazomethane produces carbenes analogous in structure to those produced as intermediates in hot-atom studies [Eq. (5)]. These intermediates of known structure provide clues to the existence and nature of precursors that are postulated to precede the final products observed in the hot-atom studies. The cyclopropylcarbinyl carbene formed from photolysis of cyclopropyldiazomethane decomposes to ethylene and acetylene [Eq. (6)] (in addition to other products), which demonstrates that such a carbene can reasonably be postulated as being formed in the final stages of the hot carbon atom cyclopropane reaction [Eq. (5)]. Results are shown in Table 2.

Figure 9. Gas-liquid partition chromatography separation of methyl deuterated toluenes.

Table 2

System	% Yield, major products			
	HC≡CH	H ₂ C=CH ₂	▧	□
C ¹¹ + Δ	49.5	^a	5	0
Δ-CH=N=N $\xrightarrow{h\nu}$	30.1	30.1	25.3	0.81

^aThe ethylene is not labeled and therefore is not detected. The mechanism requires a yield of 49.5%.

The microwave decomposition of carbon suboxide in a flow system has been studied as a possible method for the preparation of thermal carbon atoms. It has been possible to demonstrate a quantitative conversion of the suboxide to carbon atoms and carbon monoxide [Eq. (7)].

By the use of center C^{14} -labeled suboxide it was also possible to demonstrate considerable exchange while the decomposition products were still in the cavity [Eq. (8)].

The amount of exchange observed is about 36% under the conditions of the experiment.

RADIATION CHEMISTRY

Recent studies of the chemical effects of ionizing radiation have been concentrated on more direct observation of the reactive intermediates than was possible in the past. The main tool employed has been pulse radiolysis, in which samples are irradiated with a short, intense burst of high energy electrons and the absorption spectra of the intermediates are followed as a function of time after the irradiation.

Aqueous Systems

In work done at Brookhaven several years ago, the existence of the molecule H_2O_3 , with a lifetime of about 1 sec and formed by irradiation of acidified water containing dissolved oxygen, was inferred from the chemical behavior of irradiated water. This molecule has now been detected optically, following a pulse of electrons, and its absorption spectrum determined. Absorption begins around 2600 Å and increases toward shorter wavelengths. The half-life of the compound in 0.01 *N* HClO_4 , at which acidity it lasts longest, was determined as a function of temperature and was found to vary from 0.10 sec at 59°C to 3.1 sec at 9°C, corresponding to an activation energy of about 13 kcal. The decay of D_2O_3 , formed by irradiation of heavy water, was also studied and found to be about fivefold slower than that of H_2O_3 .

Since the intermediate HO_2 also absorbs light in the same spectral region as H_2O_3 , the experiments give information on the decay of both spe-

cies. The mathematical analysis of the data is complicated, since HO_2 disappears in a second-order reaction, while H_2O_3 decays in a first-order reaction. From the present results, it appears that published data on the spectrum and absorption coefficient of HO_2 (in its various ionic forms) will require considerable revision.

Ionization and Positive Charge Transfer Studied by Optical Methods

Previously, formation of negative radical ions by irradiation of hydrocarbon solutions was studied. At present, formation of highly colored positive ions is also being studied, with use of compounds that readily give up an electron to form a positive ion of known spectrum. Triphenylamine and tetra-*N*-methylphenylenediamine (TMPD), pulse-irradiated in cyclohexane or *n*-hexane, form highly colored positive radical ions by single-electron transfer which disappear in a second-order fashion. With TMPD the rate constant for disappearance was 2.5×10^{11} liter/mole-sec. Such very fast rates are typical of the combination of oppositely charged ions. Triphenylcarbinol, $\phi_3\text{COH}$, gave a small yield of $\phi_3\text{C}^+$ together with a larger yield of neutral radical $\phi_3\text{C}$. Benzyl alcohol gave no absorption corresponding to a positive ion, but gave a yield of benzyl radical $\phi\text{CH}_2\cdot$ which increased linearly with the square root of the concentration of the alcohol. It is thought that with increasing concentration the alcohol molecule intervenes to an increasing extent in the initial or "geminate" recombination of hydrocarbon ions with the electrons to which they gave rise. Alcohols abstract a proton from the hydrocarbon ion, forming R_3CHOH^+ ($\text{R} = \text{H}$ or ϕ), which on neutralization splits out water to form the radical R_3C . The few ions ($G \approx 0.1$) that escape initial recombination are not seen in the case of benzyl alcohol, but those formed from triphenylcarbinol lose water to give the well-known, relatively stable carbenium ion $\phi_3\text{C}^+$.

Pulse Radiolysis of α -Chlorotoluene Solutions

The benzyl radical, known to be produced from α -chlorotoluene in cyclohexane solution, has now been found to be produced almost entirely by dissociative electron capture. This was shown by use of nitrous oxide, an effective reagent for electrons which reacts very slowly with hydrogen atoms and free radicals. Mixtures of α -chlorotoluene and

nitrous oxide in cyclohexane were irradiated with a pulsed electron beam and the yield of benzyl radicals was measured spectrophotometrically. The yield decreased with increasing nitrous oxide concentration, which supports the idea of a competition for electrons, α -chlorotoluene being 1.6 times as reactive as nitrous oxide. In the absence of nitrous oxide the yield of benzyl radicals increased with α -chlorotoluene concentration but was only two-thirds as large as would be inferred from the observed nitrogen yields in nitrous oxide solutions with the assumption that nitrogen is produced exclusively by electron capture by nitrous oxide. Apparently nitrogen can be formed by some process other than electron capture. Hydrogen yields were found to decrease with increasing α -chlorotoluene concentration, most of the decrease being attributable to the electron capture process. Some of the decrease was due to hydrogen atoms reacting with the solute, but the hydrogen atom yield was only 1.3 molecules per 100 eV absorbed, in agreement with a recent estimate in the literature but in disagreement with earlier values in the neighborhood of 3.

Pulse Radiolysis of Polystyrene

Radiation-induced processes that depend on movement of an active species from one point to another should be much slower in polymers than in liquid systems. Polystyrene was chosen for study of this effect because it is easy to prepare either in pure form or with additives and the resulting polymer is transparent to light above 350 $m\mu$. Pure polystyrene showed a weak light absorption following the electron pulse which was nearly independent of wavelength except for a small peak at 405 $m\mu$. The weak absorption had a first half-life of several seconds and was consistent with the general brown color of irradiated polystyrene. The peak at 405 $m\mu$ had a first half-life of 1 msec and was apparently the polystyrene negative ion, since it disappeared when 1-chloro-octane was added to the polymer. The addition of aromatic hydrocarbons (anthracene, diphenyl, perylene, naphthalene, and *para*-terphenyl) produced strong absorptions characteristic of the triplet states of the additives. The anthracene and perylene triplets exhibited first-order decay with half-lives of 18 and 6 msec. The same triplets, when generated by ultraviolet (uv) absorption, are reported to have very similar lifetimes. The diphenyl and naphtha-

lene triplets did not show first-order decay and their first half-lives were only 25 msec, which is much shorter than the lifetimes of the triplets produced by uv absorption (about 1 sec). Some process limits the lifetime of the triplets when produced by radiation. This may be quenching by radicals and other triplet states that are present in the spur, which would imply that in polymers the expansion of a spur is slower by a factor of 10^8 than in liquids, in reasonable agreement with the ratio of diffusion constants. The lifetimes of the naphthalene and diphenyl triplets increase with decreasing temperature and are equal to the photolytic lifetimes (1 sec) at -180°C , which indicates that the short lifetime at room temperature is due to a diffusion process in agreement with the spur mechanism. The triplet states are not formed by ion recombination, since their formation is complete in $<10^{-5}$ sec. Other spectra, believed to be positive and negative ions, are observed which have lifetimes of 1 msec or longer. This work was done in collaboration with a colleague from Aerospace Corporation.

GASEOUS ION CHEMISTRY

During the past years research at Brookhaven in the field of ion-molecule reactions has established the role of orbiting ion-molecule collision processes in ion-molecule reactions. Reactions involving hydrogen molecules or ions with other diatomic species or inert gases have been shown in most cases to proceed at every orbiting collision and to have a velocity dependence predicted by the Langevin model. Similar results have now been obtained on the polyatomic system $\text{CH}_4^+-\text{CH}_4$. The most notable apparent exception to the model proposed for these processes was the case of the He^+-H_2 system, for which no reaction products were observed in very low kinetic energy ion-molecule collisions. This result showed that strongly exothermic processes may be limited in rate by the probability of a quantum transition from the He^+-H_2 energy surface to the H_2^+-He surface of reaction products. Work has been completed in the last year on a series of strongly exothermic reactions between He^+ or Ne^+ and N_2 , NO , O_2 , and CO . Atomic ion products N^+ , O^+ , and C^+ are formed in these reactions with the predicted $1/v$ velocity dependence for Langevin orbiting ion-molecule collisions. $^3\text{He}^+$ and $^4\text{He}^+$ ions

have been used in studies in which the kinetic energy distributions of product atomic ions have been determined. Kinetic energies of O^+ and N^+ formed in He^+-O_2 and He^+-NO reactions were shifted to lower values when $^3He^+$ was substituted for 4He . This shift in product-ion kinetic energy rules out accidentally resonant charge-transfer processes and establishes a mechanism which involves the dissociation of HeN^+ and HeO^+ formed in low-velocity ion-molecule collision processes.

The problem of competition between charge-transfer and rearrangement collision processes has been a puzzle for many years to students of ion-molecule reactions. The fundamental question is the relative importance of resonance interactions that arise from the overlap of electronic wave functions of the colliding ion-molecule system, and the attractive polarization between the ion and the neutral polarizable molecule. Molecular charge transfer cross sections have been calculated

Figure 10. Cross section, Q , for charge transfer in $H_2^+-H_2$ collisions as a function of primary ion kinetic energy. The impact parameter (IP) calculations, based on the model of Gurnee and Magee, are shown, together with the IP curve which has been corrected for the experimentally observed ion molecule (IM) reaction channels. The experimental data of Vance and Bailey and of Cramer are also shown.

for the $H_2^+-H_2$ and $N_2^+-N_2$ systems with use of a simplified impact parameter model and compared with experimental results. These theoretical estimates of charge transfer cross section establish upper limits only, since they do not take into consideration the possibility of competitive channels of reaction in the collision process. In the simplified impact parameter model the ion trajectory is taken to be rectilinear rather than spiral-orbiting. As a result the predicted charge transfer cross sections depend much less sensitively on velocity than do Langevin orbiting ion-molecule collisions. Consequently there are two points of comparison of experiment with theory, the respective magnitudes of theoretical and experimental cross sections and the respective velocity dependences.

The $H_2^+-H_2$ system differs from the $N_2^+-N_2$ system in that with the nitrogen system low kinetic energy ion-molecule reactions with ground state N_2^+ are exothermic and therefore not observed in the mass spectrometric ion source. H_3^+ , on the other hand, is formed in exothermic reactions with Langevin collision cross sections. The theoretical value of the $H_2^+-H_2$ charge transfer cross section is found to be approximately equal to the sum of

Figure 11. Cross section, Q , for charge transfer in $N_2^+-N_2$ collisions as a function of primary ion kinetic energy. The impact parameter (IP) calculation, based on the model of Gurnee and Magee, is shown, together with the IP curve which has been corrected for the experimentally observed ion molecule (IM) reaction channel. The curve labeled STS shows the total charge collection data of Stebbings, Turner, and Smith. The experimental points were obtained in this work.

the H_3^+ formation cross section and the experimentally observed charge transfer cross sections. The theoretical value of the N_2^+-N_2 charge transfer cross section is approximately equal to the value determined experimentally in the Brookhaven tandem isotope-separator-mass spectrometer apparatus. In both the H_2^+-H_2 and N_2^+-N_2 systems evidence for isotopic exchange ($\text{HD}^+ + \text{HD} \rightarrow \text{D}_2^+ + \text{H}_2$) was sought but not obtained. This result eliminates one possible path of charge transfer via a complex formed in ion or atom rearrangement collisions.

The velocity dependences of N_2^+-N_2 and H_2^+-H_2 charge transfer cross sections, determined experimentally, were found to be in good agreement with theory when possible competitive channels of reaction were taken into account (Figures 10 and 11). The model for competition between charge transfer and rearrangement collision processes derived from these studies is the following: charge transfer takes place within a range of impact parameters having a lower limit fixed by the maximum orbiting ion-molecule reaction impact parameter and an upper limit determined by the maximum value of the theoretical impact parameter for rectilinear trajectory ion collisions. The velocity dependence study shows that the impact parameters inferred from the experimental cross sections do not correspond to actual impact parameters and geometries of charge transfer collisions. The concept of the orbiting Langevin collision cross section, providing an upper limit for ion or atomic transfer rearrangement collision processes, is supported in this work.

THEORETICAL ORGANIC CHEMISTRY

Substituent effects in aromatic and aliphatic systems are being investigated by improved Hückel, Pariser-Parr-Pople, and, where possible, Gaussian orbital LCAO*-MO methods. The main purpose of these investigations is to justify if possible, improve, and if necessary replace currently accepted models for propagation of the effects of such substituents through the molecular frameworks to which they are attached.

The following broad division in current interest may be made. Small hydrocarbon molecules such as ethane, propane, and isobutane and the ions

and radicals arising therefrom by abstraction of H atoms and electrons are the model systems chosen for detailed theoretical study of the origin of secondary β -deuterium isotope effects. The improved semiempirical MO methods, reinforced by the results from the essentially rigorous Gaussian SCF method, promise to yield important insights into the energetics and charge distribution changes accompanying formation of the simple radicals and ions from their hydrocarbon precursors. Results already obtained by using more naïve MO methods indicate that hyperconjugation is a major contributing factor in the isotope effects observed for cation and radical-forming reactions and that anharmonicity in $\beta\text{—C—H}$ stretches and HCH bends may contribute substantially to the energy differences accompanying isotope substitution between the reactant and transition states for reaction.

The second general area of interest concerns the effects of varying substituents on aromatic chemical reactivities and on such other observables as the nuclear magnetic resonance (NMR) chemical shift of label atoms in or attached to the aromatic nucleus. A large number of reactivities and fluorine-NMR shift observations have now been internally correlated and fairly satisfactorily cross-related in terms of the dual substituent linear free energy (DSLFE) equation, $\log k/k_0 = \rho_I\sigma_I + \rho_R\sigma_R$. k/k_0 is a ratio of constants for the particularly substituted aromatic versus that for a standard substituted molecule relating to rate constants and equilibrium constants for reactivity or chemical shifts for NMR measurements. It seems fairly certain at this point, as judged by the results obtained, which include positional dependence of the ρ 's and distribution of the total substituent effect between the I ("inductive effect") and R ("resonance effect") categories, that inductive effects are propagated by pole-dipole type interactions between the substituent and reaction (or fluorine-label) center. At the same time, the effect conventionally labeled as resonance appears somewhat more complicated, in that direct (substituent-to-reaction center) polarization of the π -framework may be accompanied by second-order, but by no means negligible, contributions of substituent-to-framework-to-reaction center effects. This second-order effect, it further appears, distributes somewhat differently in the chemical shifts than in reactivity effects, flowing over from R to I when total effects in the latter cases are separated.

*Linear combination of atomic orbitals.

Figure 12. Hellenistic gold girdle containing a coin with the likeness of Ptolemy IV. Neutron activation analysis reveals that the gold of the coin and that of the remainder of the girdle are basically similar in composition, which indicates that such coins probably were melted down (a common practice in those times) to form the girdle. Authenticity of the coin tends to establish the authenticity of the entire girdle. The samples required for analysis weighed only 0.2 mg.

In order to continue and refine the theoretical studies of effects of structure on reactivity, computer programs have been assembled to facilitate improved Hückel MO calculations of the Lipscomb type (explicit kinetic energy inclusion). This method is being applied to examination of various aromatic molecule species for which DSLFE equation correlations are known to apply. The numerical MO studies will be concerned mainly with properties of the aromatic framework; upon extension, it is hoped that consideration of the perturbations exerted by substituents to the framework may be made in mathematically closed (analytic) form.

Various improvements of the methods currently in use are being sought from comparisons with SCF results obtainable from Gaussian orbital calculations. The value of the latter as an aid in parameterization of less rigorous methods should not be overlooked. Programs for the Gaussian orbital computations are at present available. Further, work completed and published during the past year on the parameterization of several semiempirical MO methods will be used in extending the scope of research to include (1) de-

tailed examination of σ bond effects in organic molecule systems and (2) the area of inorganic molecule ligand and crystal field problems.

INVESTIGATIONS OF ARCHAEOLOGICAL AND HISTORICAL MATERIALS

Five groups of specimens of archaeological or historical interest are being investigated by neutron activation analysis: ancient gold objects, Mayan fine orange pottery, First Millennium B.C. South Arabian pottery, Early American colonial pottery, and Eighteenth Century European music manuscript paper. These studies are being carried on in collaboration with archaeologists and historians at Harvard and New York Universities and the Smithsonian Institution. In each instance γ -ray spectra of neutron-irradiated specimens are being measured with lithium-drifted germanium detectors.

Gold objects earlier than the Fifth Century B.C. tended to have the composition of native gold, while Hellenistic and Roman specimens have tended to be of a purer composition which indicates the use of a refined gold in these times (see

Figure 12). Some specimens are found to be related closely in composition. A forgery was revealed by the fact that a "soldered repair" had the same composition as the rest of the object. Apparently a modern casting had been made of an earlier original which had been repaired.

Specimens of Mayan fine orange ware, a special, thin-walled, richly decorated pottery, found at the Central American sites Seibal, Altar de Sacrificios, Kixpek, and Piedras Negras, have all been found to be basically similar in composition. In general, local utilitarian pottery at these sites has had a significantly different composition. This seems to indicate a common source for the fine orange ware.

A type of sand temper pottery occasionally found at First Millennium B.C. sites in South Arabia has the same composition as similar pottery from the Yeha site in Ethiopia. Since this pottery is characteristic of Ethiopia and unusual for South Arabia, its importation from Ethiopia is indicated.

Another pottery study involves a comparison of 17th Century North Devon pottery and similar pottery found at Colonial American excavation sites.

Eighteenth and early Nineteenth Century music manuscript papers from Germany, France, Italy, England, Spain, and Denmark have shown wide variations in trace impurity content, indicative of significant differences in the materials and methods used in their manufacture. It is hoped that these differences can be used for identification and, in some cases, dating.

Three dating studies of ancient materials are being initiated. One is a general study of the feasibility of dating archaeological materials by application of α -particle decay track counting in solids. The other two are C^{14} dating studies of Coptic fabrics and of African wooden figures. These last two programs are to be carried out in collaboration with the Metropolitan Museum and the Museum of Primitive Art.

Nuclear Engineering

The current program of the Nuclear Engineering Department falls into three categories. The first is basic research, which encompasses fundamental studies in reactor physics, chemistry, and metallurgy. Studies are also carried out in the fields of reactor materials at high temperatures, liquid-metal heat transfer and containment, fission product release, hydrogen storage media, and superconductivity in metals.

In the second category is the long-range work of developing components that may bring about significant advances in reactor technology and radiation application. Some of the more important phases of this work are the development of reactor fuels, effects of radiation on structural materials, utilization of fluidized beds for water desalination, radiation engineering methods, ultimate waste disposal, and direct conversion concepts.

The engineering and evaluation studies in the third category are focused on practical application of the work in the preceding categories. Typical studies that continued during the year concerned pulsed fast reactors, chemonuclear reactors, and transuranium elements. Assistance was given to the Division of Reactor Development and Technology of the Atomic Energy Commission in the updating of *Civilian Nuclear Power: A Report to the President - 1962*.

In support of the mainline AEC program on the liquid-metal-cooled fast breeder reactor concept, the emphasis in the Reactor Physics Division has been shifting to work on fast reactor criticals, fast critical experiment analyses, and theoretical work on fast reactor safety and on neutron cross section data. A detailed program of fast reactor experiments has been proposed.

The first goals of the Cross Section Evaluation Working Group, formed at the request of the AEC, have been achieved with the complete evaluation of the neutron cross sections of about 60 isotopes of importance in reactor design. It is hoped to give world-wide distribution to these data shortly by means of the ENDF/B tape format. A proposal to merge the BNL Neutron Cross Section Compilation Center and the Cross Section Evaluation

Center into an enlarged National Neutron Data Center has been approved by the AEC.

Jack Chernick, Associate Head of the Reactor Physics Division, and Dr. Glenn Price, Leader of the Experimental Reactor Physics Group, spent a month at the Bhabha Atomic Research Center in Bombay, India, at the request of the AEC to help initiate a cooperative U.S.-Indian program in the areas of atomic power development and experimental reactor physics, respectively. Dr. Herbert Kouts, Associate Head of the Reactor Physics Division, returned from a year's stay at the Centre d'Études Nucléaires de Saclay, France. Dr. Murrey Goldberg is on detached service with the Experimental Physics Division of the Atomic Energy Research Establishment, Harwell, England.

In the Metallurgy and Materials Science Division, the work of the Liquid-Metal Center (engineering testing, corrosion fundamentals, and sodium solution chemistry) is also directed toward the AEC's fast breeder reactor program.

A program on superconductivity in cooperation with the Cryogenics Group of the Physics Department was continued with studies related to the temperature and magnetic field limitations of superconductivity, the role of surface currents in hysteresis, and the thermodynamic properties of hysteretic superconductors.

Drs. Arthur Paskin and John R. Weeks, together with Dr. Norman Cusack of England, organized an international conference, Properties of Liquid Metals, which was held at BNL in September 1966. This was the first conference of this type to be held in the United States.

At the request of the AEC, a National Superconductivity Information Meeting was organized by Dr. Paskin and held at Brookhaven in November 1966. At this meeting, producers of superconducting materials were informed of the requirements of the users.

A summary of the U.S. work on corrosion by alkali metals was presented at the IAEA Symposium on Alkali Metal Coolants in Vienna, Austria (Nov. 29-Dec. 2, 1966), and a paper on the U.S. work on sodium corrosion was presented

in April 1967 at the Libby-Cockcroft Exchange on Reactor Corrosion, AERE, Harwell, England. Both papers were presented by Dr. Weeks.

Dr. Paskin presented an invited paper on liquid metals in July 1966 at the International Congress of Crystallography in Moscow.

Dr. Joseph S. Bryner presented a paper at the Consultants Symposium on the Nature of Small Defect Clusters at Harwell, England, in July 1966.

An agreement has been concluded between the US AEC and the Japanese Atomic Energy Research Institute to exchange information on the Radiation Polymerization of Ethylene Program and the Chemonuclear Program. Bernard Manowitz will be the program's U.S. coordinator.

Meyer Steinberg was the United States representative to the First IAEA Panel Discussion on Applied Radiation Chemistry held in Vienna, April 1967.

Dr. Donald Metz was a lecturer for three weeks in May 1967 at the US AEC exhibit in Ankara, Turkey.

At the request of the AEC, an atmospheric diagnostic study of potential importance in pollution control has been initiated. This work is being carried out by the Department's Radiation Division and the Meteorology Group of the Instrumentation and Health Physics Department.

The Chemistry and Chemical Engineering Division continued publication of the *High-Temperature Liquid-Metal Technology Review* for a fifth year. Louis G. Stang, Jr., Head of the Hot Laboratory Division, continued as editor of *Nuclear Applications*, a journal of the American Nuclear Society, now in its third year of publication.

The interdisciplinary cooperation begun several years ago between the Hot Laboratory Division and the Medical Department has been strengthened by the gradual termination of the production of special isotopes and the consequent shift in emphasis to the more important field of development of medical applications of isotopes.

EVALUATION AND TECHNICAL ASSISTANCE

Evaluation Studies

Two proposals were evaluated for the AEC. The first, submitted by Atomics International, applied SNAP (systems for nuclear auxiliary power) aerospace safety technology to the safety of central station power plants with pressurized-water or boiling-water reactors. It utilized hydrides to limit

reactivity accidents and to increase the thermal capacity of water-moderated cores. The second, proposed by Burns & Roe, related to single and dual-purpose Co^{60} production reactors. Reports on the evaluations were submitted to the AEC.

The various magnetohydrodynamic (MHD) systems being studied at BNL were evaluated. The technical feasibility and economic potential of systems utilizing nonequilibrium plasmas, produced either directly by ionization with fission fragments or indirectly by ionization with metastable states excited by fission fragments, are being investigated.

A physics review of the Power Burst Facility's pulsed reactor was done for the Phillips Petroleum Company. Some additional calculations were advocated and an evaluation report was submitted to the company.

Transuranium Elements

The studies of Pu^{238} production in epithermal reactors resulted in an economic evaluation of production costs in water reactors. The investigation considered a light-water and a heavy-water system, operating with the equilibrium fuel cycle and utilizing present-day technology. As expected from previous work, the harder spectrum system produced Pu^{238} more economically than the more thermal system. Further, it was found that the estimated annual Pu^{238} requirements could be satisfied by one single-purpose production reactor of reasonable size [1500 MW(th)] and that the production costs would be much lower than those usually quoted if the epithermal system were utilized.

Chemonuclear Reactors

A conceptual design and evaluation of a dual-cycle, nitrogen-fixation, chemonuclear reactor was completed. The fixation takes place in the core by fission fragment energy deposition, forming NO_2 . Waste heat is converted to electricity by conventional means and the power is used to produce hydrogen electrolytically. This hydrogen is combined with the nitrogen catalytically to form ammonia.

The nuclear and chemical plants were evaluated and compared with ammonia production plants utilizing conventional fuels. The chemonuclear production system was shown to be economically competitive with standard nitrogen-fixing plants for selected combinations of fission fragment energy deposition efficiency and plant capacity.

Updating of the 1962 AEC Civilian Nuclear Power Report to the President

BNL personnel are participating in an AEC program to update *Civilian Nuclear Power: A Report to the President - 1962*. This work is being carried out by various task forces set up by the AEC for this purpose. A brief report on the three phases of this program in which Brookhaven is involved is given below.

1. Thorium systems. A technical and economic appraisal of the molten salt breeder reactor concept has been made and submitted to the AEC. A study of the over-all role of thorium in the nuclear power economy is continuing.

2. Advanced converters. The economic potential of such converters as the high-temperature gas-cooled reactor and heavy-water-moderated systems is being evaluated.

3. Systems analysis. A linear programming technique is being used in an attempt to optimize the cost of power in the U.S. over the next few decades. Most of the viable reactor types are being considered in this study.

The major portion of the work on the first phase is being done at BNL, while Oak Ridge National Laboratory has chief responsibility for the second, and Pacific Northwest Laboratory for the third.

REACTOR PHYSICS

Theoretical Reactor Physics

The activities in theoretical reactor physics have been broadened to include support of fast breeder developments. Thus, while work in the field of neutron thermalization has continued, research has been concentrated on the interpretation of pulsed and modulated source experiments. Similarly, work in reactor kinetics has been directed toward the development of general-purpose codes for the study of the space and time dependence of reactor transients and toward fast reactor safety as well as applications to the "flux tilt" xenon oscillation problem, which is important in the design of present-day thermal power reactors.

In the field of neutron thermalization, calculations of the fundamental decay constant of small water systems were performed by using transport theory with proper boundary conditions and including anisotropic scattering. The most sophisticated scattering kernel used was that developed by Young and Koppel which includes anisotropies

in the H_2O molecule. The agreement with experimental results was quite good, provided that the effect of anisotropic scattering was included. The theory of the modulated source experiment was investigated, and it was shown that the relation between the excitation frequency and the complex relaxation length could be derived from the relationship existing between the time decay constant and the buckling obtained in pulsed neutron theory. Hence, it was concluded that both types of experiment yield the same information.

A generalized perturbation approach to nonlinear reactor kinetics was developed which allows the determination of realistic bounds on permissible initial perturbations in situations in which the system is linearly stable and nonlinearly unstable. Application has been made to the "flux tilt" xenon oscillation problem.

Improved iterative techniques involving the determination of optimum trial operators have been derived for the solution of equations of the type occurring in mathematical physics. The method has given significant improvement over equivalent variational calculations for the evaluation of resonance integrals.

Difference approximation techniques have been applied to solve the Navier-Stokes equation for time-dependent flows. Initial applications included the case of the constant acceleration of a body in a viscous fluid. The results showed that the kinetic energy transferred to the fluid is important during initial stages and must be included in the drag forces.

The kinetics of a collection of hard spheres in a spherical cell with reflecting boundary conditions has been studied numerically with use of a digital computer. The equation of state has been obtained up to high densities. A free volume theory was found to fit the data on measured packing densities for hard spheres.

A negative coolant-temperature coefficient would enhance fast reactor safety. Such a coefficient can be produced by introducing high neutron-leakage regions in a fast reactor, as first demonstrated in the case of the settled bed fast reactor concept.

For typical liquid-metal-cooled fast breeder reactor (LMFBR) compositions and sizes, additional sodium regions were introduced into the core to enhance leakage. These regions were indeed found to shift the over-all sodium coefficient toward more negative values without serious impairment of the

breeding ratio. The magnitude of the effect was found to be sensitive to the cross sections used in the calculations, which indicates the importance of accurate cross sections for such LMFBR calculations.

A computer code has been programmed to study both the space and time dependence of reactor transients. The assumption that the spatial power distribution does not change during a transient considerably simplifies the study of reactor transients. The present code has been used to study the accuracy of this assumption under various conditions.

The possibility of measuring transport and inelastic properties of coolant and structural materials by means of transmission experiments has been investigated. The experiments would involve the measurement of the spectrum of transmitted neutrons through large blocks, preferably as a function of position. The improvement of fast neutron spectroscopy for such purposes is currently being undertaken by the Experimental Reactor Physics Group. Application has been to the transmission of neutrons through iron blocks as measured with the Russian IBR pulsed reactor by time-of-flight methods.

Experimental Reactor Physics

The activity in experimental reactor physics during the year has reflected a change in emphasis. In the past, major emphasis was given to the neutronic behavior of thermal reactors, particularly those moderated by light water. As these have become successful commercially, interest has shifted to the problems posed by the fast breeders.

In conformance with these trends, several kinds of experiments using U^{233} fuel have been concluded. Measurements of the material buckling and microscopic neutron flux distributions were made in exponential assemblies consisting of clusters of $U^{233}\text{-O}_2\text{-ThO}_2$ fuel rods with Dowtherm A coolant and heavy-water moderator. The purpose was to provide a few definitive data points to test design calculations for large power reactors operating on the $U^{233}\text{-Th}$ fuel cycle with organic coolant and heavy-water moderator. The assemblies were chosen after consultation with representatives of the Babcock and Wilcox Company, which had expressed particular interest in a reactor of this kind.

The data were compared with calculations performed at BNL with the METHUSELAH reactor code and also with calculations done by the Babcock

and Wilcox Company. Both calculational methods had merit, but neither described all the experiments satisfactorily. However, the range of the experimental data was not sufficiently large to justify improvement or alteration of reactor codes or constants.

Exponential experiments were also conducted with $U^{233}\text{-O}_2\text{-ThO}_2$ ("kilorod") fuel rods in heavy water. Measurements of material buckling, thermal neutron disadvantage factor, fast fission ratio, and resonance-to-thermal capture ratio were made over a wide range of moderator-to-fuel volume ratios. These data have been used by the Reactor Physics Analysis Group to test and improve the cross section library and calculational methods that are incorporated in the HAMMER reactor code.

Experiments with semihomogeneous assemblies of U^{235} and graphite have also been concluded. These have provided six high-precision measurements on the curve of critical mass vs graphite-uranium ratio. Many auxiliary parameters were also measured. The assembly has now been taken apart and deactivated.

A similar assembly was used in measurements of resonance parameters of several important trans-uranium isotopes by oscillator methods. Although final results have been delayed by difficulties in obtaining an analysis of the composition of the samples used, the experiment itself has been considered completed, and the facility has been dismantled.

One other experimental program associated primarily with thermal reactors has been started. It consists of a set of measurements of criticality parameters of $Pu^{239}\text{-Al}$ alloy fuel in highly poisoned heavy water. The performance will depend primarily on the nuclear cross sections of plutonium in the epithermal and intermediate energy regions, and the experiments will thus be a test of knowledge of these cross sections. In particular, it is hoped that they will help to remove uncertainties in the knowledge of the capture-to-fission ratio of Pu^{239} in the intermediate range of energy, this being one of the primary unknowns in the physics of fast neutron breeders.

Comprehensive data on the neutronic properties of 172 lattices composed of slightly enriched uranium fuel elements in a water moderator were compiled and issued as BNL 50035. These data had been accumulated during 15 years of experimentation at BNL. Although previously published in various reports and journals, they are now

available in a single volume with a uniform and consistent format.

These lattices cover a wide range of fuel rod diameters, uranium enrichment, moderator-to-fuel ratio, and thermal neutron absorption. They include both metallic and ceramic fuel. The compilation meets the original intent of the experimental program in that it provides a comprehensive basis for the evaluation and development of reactor codes.

The growth of interest in fast reactors is exemplified by two projects begun during the year. The first uses a small fast critical assembly as a source of neutrons in measurements that are meant to improve understanding of the neutronic performance of fast breeder reactors. The first experiments to be conducted with this assembly will consist of studies of the effects of heterogeneity in fast reactors. The existence of heterogeneity leads to certain difficulties in interpretation of existing experiments and in prediction of performance of fast reactors with realistic construction. The assembly,

called FS-1, has been built and is ready to be operated, but operation has been delayed pending completion and approval of a revised safety analysis report for the Critical Assembly Facility. Figure 1 shows the assembly at a late stage in construction.

The second project is a study of the features affecting resolution and accuracy of proton recoil counters used for fast neutron spectroscopy. Encouraging results have been obtained in the development of methods of achieving consistently theoretical limits on resolution.

A series of experiments has been started to determine whether irradiation of Cf^{252} by neutrons of intermediate energy would lead to more prolific production of Cf^{254} than would irradiation by thermal neutrons. This possibility was suggested by certain features of the systematics of the cross sections of the transuranium isotopes. The experiments consisted of exposures of small samples of Cf^{252} in the intermediate energy flux provided by the central irradiation facilities of the High Flux

Figure 1. FS-1 assembly at a late stage of construction.

Beam Research Reactor (HFBR). Preliminary results indicate that the yield of Cf^{254} by successive capture of intermediate energy neutrons in Cf^{252} is much lower than had been hoped.

Experiments were begun to study the characteristics of potential moderator components for a pulsed fast research reactor. The purpose of a moderator region, when used in conjunction with a pulsed reactor, is to produce a maximum number of low energy neutrons in an exit beam, with a minimum pulse width. The study has been limited to hydrogenous materials (e.g., water, methyl methacrylate, and polythene) because the slowing-down power must be large and thermal neutron diffusion time must be minimized. In general, the neutron yields and pulse widths cannot be adjusted independently, since both usually increase with increasing moderator size. Hence, the problem is to determine empirically the yields and pulse widths in a variety of geometries to arrive at an optimum geometry for any particular requirement.

Data are being collected in steady-state experiments using the Medical Research Reactor and pulsed neutron experiments using the Kaman pulsed neutron source. Relative yields of thermal neutrons are measured in the steady-state experiments as the size, shape, and material of the moderator region are varied. Pulse widths are measured by using the Kaman source, and neutron spectra are measured with use of this source and a 2½-meter flight path. Preliminary data indicate that it is possible to measure all the pertinent neutronic parameters needed to arrive at an optimum design for the neutron moderating region.

Reactor Physics Analysis

The work in reactor physics analysis has been primarily devoted to the application of improved calculational models to recent criticality data, such as those from the U^{235} -graphite critical experiments and the U^{233} - ThO_2 water lattices. In addition, a thorough investigation of the British graphite-moderated BICEP lattices was carried out. The methods developed at BNL for analysis of these and previous studies of heavy and light-water critical experiments have now been tested on most of the data available both at BNL and elsewhere on lattices that do not contain boron or cadmium.

In connection with the latter study it was found that both BICEP graphite lattices and BNL UO_2 - H_2O lattices could be successfully described by

currently accepted cross sections and theoretical methods. It is doubtful whether a meaningful improvement in the analysis of these or similar lattices can be achieved without a thorough re-evaluation of neutron cross sections of the sort now being carried out by the BNL Cross Section Evaluation Center.

Analysis of the BNL U^{235} -graphite experiments was carried out with the aid of the general-purpose code HAMMER and the use of the Monte Carlo code MOCA to determine neutron leakage from these high-leakage cores. The results for the lattice reactivity are satisfactory, and the calculated cadmium and activation ratios are in good agreement with the experimental data.

Analysis of the 3% U^{233} -enriched ThO_2 fueled lattices which were water moderated and reflected has also been completed. Again the HAMMER code was used and satisfactory agreement was obtained. Slight trends in k_{eff} with volume ratio and poison concentration were found to disappear if experimental dysprosium activation disadvantage factors were used instead of the calculated values, which are 2% higher.

Sigma Center

Publication of the massive supplements to BNL 325 has been completed. Volume II ($Z=21$ to 87) contained so many new data that publication in three parts was required. The last of these, Volume IIC ($Z=61$ to 87), is being distributed.

The standard means of storing and transmitting neutron cross section data continues to be the scisrs magnetic tape system, which now contains more than 1,000,000 entries. By international agreement, cross section tapes are exchanged with the Nuclear Data Center at Saclay. Tapes are sent from the Sigma Center to Saclay about every second week. In addition, there has been a considerable flow of published data between the Sigma Center and the Nuclear Data Unit (NDU) of the International Atomic Energy Agency (IAEA) at Vienna. In particular, all data up to 10 keV on major fissionable isotopes were sent to NDU for comparative use at the Paris Conference on Nuclear Data in October 1966. In return, the Sigma Center has received from NDU a considerable amount of recent cross section data obtained at the Dubna, Kurchatov, and Moscow laboratories.

With the completion of BNL 325 publications, the Center is concentrating on checking out the

SCISRS tape and making it as complete as possible. An intercomparison in depth between the Computer Index Neutron Data (CINDA) literature compilation and the Sigma Center reference file has been initiated. A computer-oriented bibliographic system has been perfected for this purpose which provides alpha-numeric sorted listings, e.g., by authors, laboratories, references, or isotopes. The listing by references is nearing completion for distribution as a Sigma Center newsletter. With the aid of the Cross Section Evaluation Center and the BNL Technical Photography and Graphic Arts Division, considerable improvement in rapid Cal-Comp processing of data from tape to graphical plot has been accomplished.

Cross Section Evaluation Center

The Evaluated Nuclear Data File (ENDF) now consists of two parts. ENDF/A is a flexible storage system of fully or partially evaluated data. During the past year additions to the file were made by the Aldermaston-Winfrith Research Establishment through the Nuclear Data Center at Saclay and the General Atomic Division of General Dynamics Corporation.

ENDF/B, a data file containing all the essentials for reactor computations, was assembled by the Cross Section Evaluation Working Group, composed of representatives from several laboratories whose work is coordinated by BNL. Data lists and graphs for 58 materials have been circulated among the group members for checking. In addition, codes linking ENDF/B to major multi-group constant codes have been written by the group. A general distribution of data and codes is planned during 1967.

To calculate the buildup of transuranium isotopes in a high flux beam reactor, an evaluation was made of the thermal fission and capture cross sections and respective resonance integrals of a large number of isotopes from Pu^{242} to Cf^{254} . A systematic treatment of available experimental data on known cross sections of other fissile isotopes, correlated with the binding energy and fission threshold, has yielded empirical results which seem to be consistent with the sparse experimental information on these isotopes.

The total neutron cross section of holmium below 235 eV was fitted by using 48 resonances in a Breit-Wigner multilevel formalism and a calculation of the paramagnetic scattering cross section. The capture and scattering resonance integrals

have been calculated to be 603 and 93 barns, respectively.

An attempt to fit the elastic scattering cross sections of Pb^{206} , Pb^{207} , and Pb^{208} at energies of 0.5, 1.0, and 2.5 MeV is in progress. The results have been evaluated for 1.0-MeV scattering and show good agreement between calculation and experiment.

Further developments in the random matrix theory of nuclear cross section fluctuations include (1) the introduction of time-reversal noninvariant ensembles of unitary collision matrices for calculating small departures from the detailed balance condition in nuclear reactions, and (2) the improvement of the computer programs to permit calculation of sharply peaked eigenvalue distributions.

Pulsed Fast Reactor

A study has been made of advanced research reactor concepts to provide a significant increase in peak neutron flux for pulsed neutron beam experiments. The two systems selected for further concentrated study are the super-prompt-critical pulsed fast reactor and the accelerator-injected, sub-prompt-critical pulsed system. The effort this year has centered on the problems of thermal shock and reactivity pulse width associated with the super-prompt-critical pulsed fast reactor.

A survey was completed of critical volumes and prompt neutron lifetimes for various fuel systems. Results for selected cermetes are presented in Figure 2. The survey included a study of the effects of reflection, coolant volume fractions, and core geometry (spherical or cylindrical, with several height-to-diameter ratios). In addition, for one fuel system (40 vol % UO_2 -SS cermet) the change in reactivity caused by removing the reflection from one face of the cylindrical core was determined. This initial survey helped in the selection of fuel systems for the fuel development and fatigue testing program discussed below.

Complementary studies on the use of poisons (e.g., B^{10} , Li, Ta) in a liner between the core and reflector have indicated that the prompt-neutron lifetime can be reduced without excessive increases in core critical volume (Table 1). Other studies in geometry effects have shown that the reactivity pulse width can be favorably reduced by the use of a core cavity to enhance the neutron leakage from the core face undergoing cyclic reflection. These studies on the effective use of poisons and leakage cavities are continuing.

Figure 2. Comparison of core volumes and lifetimes for U^{233} , Pu^{239} , and U^{235} cermet cores. The calculations assumed spherical geometry, with a 20-cm-thick stainless steel reflector. The core compositions in all cases are 33 vol % sodium, 16.4 vol % stainless steel cladding, and 50.6 vol % fuel cermet.

Table 1

Effect of Various Absorbers Between Core and Reflector on Critical Volume and Neutron Lifetime

(40 vol % UO_2 -SS cermet core; thickness of absorber plus stainless steel reflector is 20 cm)

Absorber	Absorber thickness, cm	SS thickness, cm	Core volume, liters	Lifetime, 10^{-8} sec
B^{10} (0.1300×10^{24} atoms/cm ³)	2	18	55.43	4.178
	4	16	60.48	4.022
	8	12	62.30	3.992
Li (0.042×10^{24} atoms/cm ³)	2	18	47.806	6.0314
	4	16	60.1307	5.1813
	8	12	73.270	4.5880
Ta (0.0555×10^{24} atoms/cm ³)	2	18	33.69	6.0293
	4	16	35.861	5.4996
	8	12	37.67	5.1694

Figure 3. Temperature history at axial peak of hottest fuel rod.

Experiments to determine the characteristics of hydrogenous moderating blocks in pulsed reactors are being done to aid in the design of a moderating block that will give the maximum yield of thermal neutrons commensurate with the natural pulse width of the reactor. Steady-state measurements have been conducted, using neutrons from a U^{235} fission plate. An investigation of neutron pulse shapes has been initiated. In addition, the design of a critical experiment is proceeding and orders have been placed for some components.

A rapid cyclic variation of thermal and inertial stresses in the fuel and cladding is unique to the pulsed fast reactor system. At present, the fuel development program centers on a survey of fuel mechanical properties and fatigue testing of unirradiated fuel specimens being performed by Battelle Memorial Institute. Several fuel systems were selected for specimen fabrication and fatigue testing in fiscal 1967. They include U-10% Mo, U-31% Nb-12% Zr, U-62% Nb-7% Zr, UO_2 -SS cermet, and UO_2 -Mo cermet.

A three-dimensional transient heat transfer code, LION, has been obtained from Knolls Atomic Power Laboratory and adapted at Brookhaven to calculate fuel, cladding, and coolant temperatures during the rapid cyclic variation in heat generation in the pulsed fast reactor. Figure 3 presents the temperature history for one fuel system during a 60-μsec-width pulse repeated at the rate of 22/sec. At the end of the pulse (≈ 45 msec), the temperatures have returned to their initial values. Studies of other fuel systems and geometries are continuing.

Figure 4. Maximum thermal stresses in fuel cermet and cladding of hottest fuel rod. ΔT is the maximum temperature differential during the pulse; σ_z , σ_θ , and σ_r are, respectively, the axial, azimuthal, and radial stresses.

A graphical technique has been developed to analyze the inertial stress-wave pattern in a pin-type fuel slug subjected to a rapid ramp temperature increase. Effort to simplify the analysis is continuing so that it can be easily applied to a multitude of possible fuel systems and geometries. In addition, a digital computer code has been developed to use the output of the LION heat transfer code to calculate the thermal stresses in a clad fuel rod induced by the temperature gradients after the inertial stress-waves have dampened out. Figure 4 shows the thermal stress pattern for the limiting temperature gradient at 192 μ sec, from Figure 3.

METALLURGY AND MATERIALS SCIENCE

Liquid-Metal Center

The major effort of the Liquid-Metal Center is study of the corrosion of materials in flowing sodium at 815°C. These studies are designed to provide information on materials for the liquid-metal fast breeder reactor (LMFBR) program. The work at BNL consists of engineering corrosion tests and studies of liquid-metal corrosion fundamentals and the chemistry of liquid sodium solutions.

Engineering corrosion tests are conducted in natural and forced circulation loops. A typical

Figure 5. Typical natural circulation pump.

natural circulation loop is shown in Figure 5. This design permits corrosion specimens and liquid-metal samples to be inserted in and removed from a loop without exposure to air. By May 3, 1967, four loops had accumulated a total of 4882 hr of operation at a maximum temperature of 760°C. In the longest single run with cold-trapped sodium (2000 hr), type 316 stainless steel, S-1 alloy, and Incoloy 800* are being tested. The weight change measurements indicate a lower corrosion rate for the S-1 alloy than for type 316 SS or Incoloy 800. A variety of iron and cobalt alloys are being tested in the other natural convection loops.

Construction of one forced convection loop has been completed and a second is nearing completion. These loops will be used to test iron, cobalt,

*Type 316 SS: 17% Cr, 12% Ni, 3% Mo, balance Fe; S-1 alloy: 20% Cr, 10% Ni, 7% Mo, balance Co; Incoloy 800: 21% Cr, 32% Ni, 46% Fe.

Figure 6. Flow sheet, forced circulation sodium corrosion loop.

and refractory metal alloys at temperatures up to 815°C in high-velocity sodium at various levels of sodium purity. A schematic of this loop is shown in Figure 6.

In the area of corrosion fundamentals, the thermodynamics and kinetics of the corrosion of materials by liquid sodium are being investigated, as is the role of surface films in the corrosion process. The solubilities of pure Fe, Cr, Ni, Co, and Nb in sodium are being determined, as well as the effects on these solubilities of impurities such as oxygen, carbon, nitrogen, and hydrogen in the sodium. These impurities, especially oxygen, are known to influence the corrosion behavior of steels in sodium. The detailed kinetics of the corrosion of pure metals in sodium will be investigated. Surface films formed on metals in contact with sodium will also be studied.

Preliminary measurements have been made on the solubilities of pure iron and pure nickel in hot-trapped, distilled sodium. Equipment for the other studies is being assembled. A model has been proposed for the corrosion of steels by liquid sodium which accounts for many experimental observations. It assumes that the circulating sodium is

essentially saturated with iron at all times and that the kinetics of precipitation of iron from solution in the lower temperature portions of a loop controls the corrosion rate. Experiments are being planned to establish the validity of this model.

The over-all objective of the sodium chemistry phase of the BNL liquid-metal program is to gain an understanding of the chemistry of sodium coolant systems and of the chemical aspects of corrosion reactions in sodium. The program includes the development of sampling and analytical techniques.

Equipment to measure the thermodynamic properties of sodium solutions by using solid electrolyte galvanic cells is being assembled. Electromigration studies have been initiated to elucidate the nature of oxygen and other impurities dissolved in liquid sodium.

The purpose of the analytical phase of the work is to develop standard sampling techniques and rapid, reliable methods of determining trace impurities in sodium and containment materials. The work includes the development of an isotopic dilution technique as a direct method for determining oxygen in sodium, further development and comparison of amalgamation and vacuum distillation

techniques for oxygen determinations, and development of methods and capabilities for determining carbon, nitrogen, hydrogen, and metallic elements in sodium and containment materials.

Effects of Radiation on Structural Materials

Study of the effects of irradiation temperature and carbon concentration on the low-temperature embrittlement of iron by fast neutrons ($E > 1$ MeV) has indicated that carbon atoms in sufficient concentration at an irradiation temperature at which they have sufficient mobility cause the stabilization of radiation defects that would otherwise be annihilated during the irradiation. The carbon-stabilized defects cause embrittlement upon reaching a critical concentration, apparently by locking dislocation sources.

Electron-transmission studies of fast-neutron-induced precipitation of carbon in iron showed that the density of carbide precipitates increased rapidly with increasing carbon content and with increasing exposure up to 5×10^{14} nvt. Upon additional exposure the densities decreased sharply and then increased gradually, with no evidence of saturation up to 1×10^{17} nvt. The data indicate that different types of sites nucleate carbide precipitation, depending upon carbon concentration and exposure level. After irradiation at 60°C to 2×10^{18} nvt, no carbides were found in iron containing up to 100 ppm C, which indicated that the carbon combined with radiation defects with a binding energy greater than that of carbon in ϵ -carbide.

Dislocation substructures were similar in irradiated and unirradiated iron specimens strained plastically below the embrittlement temperature. After equal tensile strains at ambient temperature, dislocations in unirradiated specimens were more tangled than in irradiated specimens, an indication that the higher initial strain-hardening rate of unirradiated specimens is the result of a higher degree of dislocation tangling.

Field-ion microscopic studies of the annealing of fast-neutron-irradiated platinum disclosed that stage III recovery is due to annihilation of an intrinsic defect identified as a $\langle 100 \rangle$ split interstitial. In tungsten irradiated to 5×10^{19} nvt at 100°C in the HFBR, single vacancies, depleted zones, and single interstitials were observed. Changes in the concentrations of these defects after annealing at 400°C through stage III recovery, combined with the observation that extensive vacancy motion in

tungsten occurs only above 700°C , indicate that stage III recovery in tungsten is due to single interstitials migrating to vacancies and being annihilated.

A program was started to study the effect of irradiation on the mechanical properties of cobalt-base alloys and austenitic stainless steels being considered as fuel-cladding materials for the LMFBR. Methods of altering the structure of the stainless steels to minimize radiation embrittlement at elevated temperatures are being studied. Specimens of stainless steel and cobalt alloys (Haynes alloy No. 25 and Multimet)* are being irradiated in the HFBR in the V-16 in-core thimble, modified for this purpose.

High-Temperature Properties of Materials

Thermodynamic Properties of Refractory Metal Compounds. Free energies, entropies, and enthalpies of formation of the thorium sulfides were determined from measurements on solid electrochemical cells at temperatures from 825° to 925°C . The cells employed were of the following types:

- (I) $\text{Th}, \text{ThF}_4 \mid \text{CaF}_2 \mid \text{ThF}_4, \text{ThS}, \text{Th}_a$
- (II) $\text{Th}, \text{ThF}_4 \mid \text{CaF}_2 \mid \text{ThF}_4, \text{Th}_2\text{S}_3\text{ThS}$
- (III) $\text{Th}, \text{ThF}_4 \mid \text{CaF}_2 \mid \text{ThF}_4, \text{Th}_7\text{S}_{12}, \text{Th}_2\text{S}_3$
- (IV) $\text{Th}, \text{ThF}_4 \mid \text{CaF}_2 \mid \text{ThF}_4, \text{ThS}_2, \text{Th}_7\text{S}_{12}$

Characteristic temperatures for the compounds ThS , ThN , $\text{ThC}_{.91}$, $\text{ThP}_{.95}$, Th_3P_4 , ThO_2 , and ThB_6 were determined from x-ray diffraction peak intensity measurements. The reduction of peak intensity with increasing temperature was measured from room temperature to 1000°C . The entropies of the compounds and the vibrational amplitudes of the atoms in the compounds were calculated.

Electrical Properties of Refractory Metal Compounds. A study was completed of the electrical properties of thorium carbide-thorium nitride solid solutions. Compositions from $\text{ThC}_{.85}\text{N}_{.08}$ to $\text{ThC}_{.20}\text{N}_{.77}$ were investigated from 4°K to about 500°K . The measured properties were similar to those obtained for nonstoichiometric thorium monocarbide. Substituting nitrogen for carbon introduces additional electrons into the band structure of the solid and lowers the Hall coefficient and the electrical resistivity. The resistivity of thorium tetraboride, ThB_4 , was measured from liquid

*Haynes alloy No. 25: 10% Ni, 20% Cr, 15% W, 3% Fe, 0.1% C, 1.0% Si, 1.5% Mn, balance Co; Multimet: 20% Ni, 21% Cr, 3% Mo, 2.5% W, 20% Co, 0.12% C, 0.15% N, 1.0% Nb, 1.0% Si, 1.5% Mn, balance Fe.

nitrogen temperature to 700° K. The resistivity in $\mu\Omega\text{-cm}$ can be represented by the equation $\rho_T = 53.8 + 4.43 \times 10^{-2} (T - 78)$ for the range 78° to 700° K.

Graphite Lamellar Compounds. A gravimetric Knudsen-effusion technique was developed to study the phase equilibria and thermodynamic properties of the potassium-graphite and lithium-graphite compounds. The phase C_{10}K , previously unreported, was shown to exist in this system. This study and previous work on the cesium-graphite and rubidium-graphite systems demonstrate that phase equilibria in these three systems are analogous.

A study of the reactions between cesium and an annealed carbon black revealed the presence of a diffuse two-phase region corresponding to the reaction

In this region composition vs pressure isotherms exhibit reproducible hysteresis which is related to the structure of the carbon black.

Liquid State of Metals

Considerable progress has been made this past year in the understanding of liquid metals and their alloys, as was demonstrated during an international conference entitled Properties of Liquid Metals which was held at Brookhaven in September 1966.

In the area of mass transport, electromigration rates have been measured in a number of liquid alloys. A model has been developed which gives a qualitative description of the behavior of the different atom species in terms of the relative "drag" exerted by the electron current. In the area of electron transport, experiments have been made of the detailed electrical resistivity of the Pb-Sn system. Good agreement is found between experiment and calculations based on the Faber-Ziman substitutional model of resistivity. Thermoelectric powers of dilute liquid Na-In and Na-Cd alloys have been measured accurately in the temperature range 150 to 400° C.

Molecular dynamics techniques have given valuable insight into the atomic motions and correlations in the liquid state. One of the important results of these calculations is the observation that the detailed behavior of the interatomic forces is not relevant in determining the local atomic arrangement in liquids; it is mainly the "hard-sphere" repulsive force that determines the liquid

structure. Further, near the freezing points of all simple liquids their structures are found to obey a law of corresponding state. In order to obtain some insight into the melting and freezing phenomena, molecular dynamics techniques have been applied to derive atomic positions and motions as the solid melts.

Calculations have also been made of the liquid-to-solid transformation. Although various kinds of seeds have been used in attempts to nucleate a crystalline solid, preliminary calculations have not resulted in a crystalline ordered solid at low temperature but rather in an undercooled disorder liquid state.

Superconductivity

Hysteresis. The purpose of these studies is to determine the detailed mechanisms of hysteresis in superconductors and to test experimentally existing models of hysteresis. In particular the "critical state" concept, common to all models for hysteresis, was tested extensively. Various new experiments were performed which can be used to distinguish between hysteresis due to flux pinning and hysteresis resulting from surface currents. The measurements include (1) comparison of the temperature dependence of the critical current with that of remnant magnetization, (2) changes in remnant magnetization with applied transport currents, (3) comparison of the temperature dependence of remnant magnetization from minor and major hysteresis cycles, (4) variation of remnant magnetization as a function of the maximum external field to which the sample was subjected, and (5) the partial Meissner effect in types I and II superconductors observed after cooling in static fields. In addition, a number of experiments examining the similarity between hysteresis in solid and in hollow superconductors were performed.

All the tests show that hysteresis in type II superconductors with low values of the Ginzburg-Landau parameter κ is due solely or predominantly to surface currents and not to pinning effects.

Superconducting Thin Films. Work has continued on the superconducting transition temperatures of thin films. Recent work has established critical temperatures near 6° K in aluminum films compared with 1.2° K for bulk aluminum. Low-temperature films of tin and zinc have had their critical temperatures raised to 6° K and 1.8° K respectively. All these values are significantly higher

than those found by previous workers using low-temperature deposition techniques and are a result of the different physical contact conditions and the geometry used in these experiments. Work is under way to establish the explanation for these effects and also to obtain higher temperatures.

Measurements on the critical field of thin aluminum films indicate that the superconducting state in these films has a paramagnetic susceptibility. Theories of this effect based on spin-orbit scattering can qualitatively explain the data. However, it is not clear how a large enough spin-orbit scattering term can be obtained for such a low Z element as aluminum.

Theoretical work has indicated that long-range superconducting ordering should not occur in one and two dimensions because of fluctuations. To investigate this problem ultrathin films are being made in vacuum approaching 10^{-8} torr.

Development of Superconducting Magnets. Work has continued on the development of superconducting magnets. In particular, the performance of Nb_3Sn magnets was found to be considerably improved by operation below 2.18°K , the superfluid transition temperature of liquid helium. This effect is most pronounced for severely degraded solenoids.

CHEMISTRY AND CHEMICAL ENGINEERING

Reactor Chemistry

Metal Hydrides. The reaction of hydrogen with a large number of alloys has been investigated in a program suggested by the promising characteristics of solid hydrides as hydrogen storage media. Hydrogen has many advantages as a fuel for small power sources: it can be made cheaply either from fossil fuels or by decomposing water with electricity of nuclear origin, it is usable both in fuel cells and in combustion engines, and the reaction product is harmless. A very wide application in the automotive industry of the future is conceivable. However, it has one obvious disadvantage: heavy, high-pressure cylinders or cryogenic apparatus must be used for containment. To these containment methods, metal hydrides offer an alternative worth exploring. Many metals combine spontaneously with gaseous hydrogen to form a solid from which the hydrogen can be recovered by lowering the pressure or raising the temperature. None of the systems described in the litera-

ture, however, fully satisfies all the requirements for stability, cheapness, ease of handling, etc., which an ideal hydrogen-storage medium should meet. Most of the binary systems, i.e., those consisting of hydrogen and a single metallic element, have been quite completely described, but there is a very large number of ternary systems remaining to be explored from which interesting results can be expected. Two intermetallic compounds studied recently at BNL provide illustrations of the variety of reactions that can occur in such systems. The phase Mg_2Ni takes up hydrogen to form a new ternary hydride, according to the equation

where the product is a nonstoichiometric compound in which the value of x depends on the hydrogen pressure; at 304° and 57 psi, it is about 4.2. The compound has a characteristic crystal lattice, different from that of Mg_2Ni . The intermetallic phase Mg_2Cu , on the other hand, reacts in a different way:

As it happens, both systems have relatively high hydrogen dissociation pressures at moderate temperatures and hence have possibilities as storage media. Until now, however, the main goal of the research at BNL has been to find some order in the thermodynamic properties of alloy hydrides in general. Many systems besides the two mentioned have been examined, and data on their pressure-temperature-composition relationships have been obtained. These will be published elsewhere in the near future.

Fluorocarbon Chemistry. Analysis of the radiolysis products of fluorocarbons has revealed some interesting features which have no counterpart in hydrocarbon radiation chemistry. The two principal products from the irradiation of perfluoronaphthalene (C_{10}F_8), which both have the composition $\text{C}_{10}\text{F}_{10}$, have been identified as perfluoro-1,2-divinylbenzene and perfluorobutadienylbenzene. They are new compounds, previously unreported in the literature. Each consists of the starting material plus two fluorine atoms, and the same pattern is observed in the radiolysis of hexafluorobenzene, where C_6F_8 is one of the products. The so-called Dewar valence isomer has also been shown, in recent work here, to be a product of the latter radiolysis; and it may be

Table 2
Chlorine in Fused Salts

Salt	T , °C	Solubility, moles Cl_2 /ml	Diffusion coefficient, cm^2/sec
PbCl_2	535	0.7×10^{-7}	0.72
AgCl_2	518	2.31×10^{-7}	0.12
LiCl-AgCl (eut.)	450	1.54×10^{-7}	0.70

that it acts as an intermediate in the formation of C_6F_8 . Dewar isomers were also produced in the radiolysis of perfluorotoluene. Here, two different ones were expected, depending on the position of the $-\text{CF}_3$ group, and two were found.

Another new compound resulting from this program is perfluoro-1,1-dimethyl cyclopentane. It is produced, by an unknown mechanism, from the radiolysis of perfluorobicyclohexyl.

Fused-Salt Chemistry. Exploitation of high-temperature emf measurements has continued along the lines described in previous reports of this series. In addition, the use of cathodic chronopotentiometry has been extended to solutions of halogen gases in fused halides. Here, the measured quantity, $i_0\tau^{1/2}$, is a function of the concentration of the reducible species and of its diffusion coefficient. By combining the electrical measurements with conventional solubility determinations, both quantities can be obtained. Table 2 gives some recent results for chlorine in fused chlorides. The high values of the diffusion coefficient are noteworthy.

Mechanism of Graphite Formation. The reaction of graphite and hydrogen has been studied to 3000°K with use of resistively heated graphite filaments and has been shown to be a surface reaction which depends on the concentration of atomic hydrogen in the gas phase. In extending the investigation above 3000°K , it has been necessary to use larger filaments whose temperature could be measured by a photoelectric pyrometer and followed with an oscilloscope. Since the reaction of graphite and hydrogen at low pressure and above 3000°K involves the vaporization of graphite and reaction in the gas phase, the vapor species are being investigated spectroscopically as well as by physical measurements. Spectroscopic determinations indicate that the concentration of C_2 is greater than that of C_3 in the presence of either hydrogen or helium. The heat of vaporization of

graphite as determined by the energy balance or the change of evaporation rate with temperature is consistent with the formation of C_2 as a major constituent in the free evaporation of graphite. This differs from the results obtained by mass spectrometry with use of a Knudsen cell at temperatures below 3000°K . The evaporation rate results also indicate a lower vapor pressure for graphite above 3000°K than the calculated values.

Chemical Technology

Fission Product Release Studies. The chemical states and the extent of vaporization of fission products released from sodium were investigated as part of the fast reactor safety studies currently in progress. Experimental results showed that at concentrations expected in reactors, iodine vaporizes from sodium as NaI , while cesium is transported as the element. The excess free energy of mixing of NaI in sodium was measured to provide the necessary data for predicting the extent of its vaporization from sodium. The experimental excess free energy of mixing (cal/mole) is given by the equation $\Delta F_{\text{NaI}}^E = 15,900 - 6.8T$, where T is in $^\circ\text{K}$. The excess free energies of mixing of other species were deduced from phase diagrams with use of a modified Bjerrum relationship. The equilibrium vaporization of cesium and NaI from sodium solutions was measured and found to be in good agreement with theoretical predictions. The extents of Sr , Ba , Rb , and Te vaporization from sodium were predicted by using a similar method.

Transport studies were undertaken to ascertain the factors controlling the rate of fission product release from molten fuels. A general analytical expression was derived which relates fission product release to the individual rate processes in the gas and liquid phases as well as those at the gas-liquid interface. Numerical calculations indicate that the release of iodine from molten uranium is controlled by diffusion in the liquid phase. This fact was verified by experiments that showed the dependence of the release rate on sample liquid depth but not on the molecular weight of the cover gas.

A study of the formation and agglomeration of aerosols produced upon the high-temperature vaporization of UO_2 and PuO_2 was also initiated during the year. The initial particle-size distribution was found to be independent of the UO_2 mass concentration within the range 2.8 mg/m^3 to

2.24 g/m³. Electron micrographs of PuO₂ aerosol deposits showed twisting chains ranging up to 1 μ in length 10 min after initial formation. The individual PuO₂ particles were in the range 100 to 300 Å and were indistinguishable in physical appearance from the UO₂ agglomerates.

Ultimate Waste Disposal. During the past year, principal emphasis has been on obtaining process information applicable to operation of the Pacific Northwest Laboratory's waste solidification prototype. This support work mainly involved pilot-plant production of phosphate glass at Brookhaven from a number of different types of reactor waste and the determination of operating parameters such as viscosities, densities, and volume reductions.

Sulfuric acid in Purex-2 wastes presents a decontamination problem in disposing of the melter off-gas condensates. The results of bench-scale experiments indicate that these condensates can be largely separated into HNO₃ and H₂SO₄ fractions by vacuum distillation, with essentially all the Ru remaining in the still-pot residue for recycling. It is estimated that the small amounts of radioactive contaminants entrained in the volatilized H₂SO₄ can be removed by vapor-phase filtration to effect an over-all decontamination and make the H₂SO₄ suitable for release to the environment; the HNO₃ would be recycled to the fuel reprocessing plant. An investigation into migration of waste elements into platinum was completed with the aid of an ion microprobe mass spectrometer. The results showed small penetration of Pd, Rh, and Ru into the platinum. The significance of this migration will be determined on completion of the high-temperature creep measurements being made on related test specimens similarly exposed.

During the year experimental work at Brookhaven has continued on the development of a process for the disposal of fluid-bed volatility solid wastes. The method under investigation is dispersal of the granular aluminum oxide wastes in glass matrices to give a chemically and mechanically stable product of increased thermal conductivity. Particular emphasis has been placed upon obtaining information pertinent to the design of a waste-processing facility for the fluid-bed volatility demonstration pilot plant at Oak Ridge National Laboratory. In this connection, several pieces of small-scale equipment are now being tested for use in further evaluating the laboratory information and to point up problems that may be encountered in pilot-plant operation.

Figure 7. Experimental heat transfer results for 45°-cross-flow of NaK through a staggered rod bank with only the test rod heated. Lines represent heat transfer characteristics for different rod locations in the bank.

Chemical Engineering

Heat Transfer Research. Research was confined almost entirely to liquid-metal heat transfer, dealing with both liquid-phase and two-phase vapor-liquid problems. The main objective of the program was to gather design information and basic knowledge to aid in the thermal design of liquid-metal-cooled reactors. A small portion of the program was directed toward heat transfer problems in direct-conversion devices, e.g., MHD generators. Some results from 3 of the 12 active projects are briefly summarized here.

In shell-and-tube heat exchangers, the liquid on the shell side flows at various angles across the tubes. In the past, both analytical and experimental studies have been carried out for the two limiting cases of parallel and perpendicular flow. This year the studies were extended to the in-between case of 45° crossflow. Typical experimental results are shown in Figure 7. On the basis of these results and the results of previous analytical studies at Brookhaven, the following semiempirical equation is recommended for estimating oblique-flow heat transfer coefficients for a tube in the interior of a

Figure 8. Experimental measurements of boiling-inception superheats for forced-convection flow of potassium. The experiments were performed in a Haynes alloy No. 25 pumped loop. (Boiler, 3 in. i.d. $\times$ 12 in. long; mass velocity, 3.7×10^5 lb hr $^{-1}$ ft $^{-2}$; inlet subcooling, 12° to 23°F.) Inception points were obtained at preset flow rates, pressures, and inlet subcoolings by incremental increases in heat flux in the test section.

bank when circumferential wall temperature variation approximates that of a simple cosine and when β (see Figure 7) varies between 30° and 90°.

$$\text{Nu} = (\phi_1/D)^{1/2} \left(\frac{P-D}{D} \right)^{1/2} \left[\frac{\sin \beta + \sin^2 \beta}{1 + \sin^2 \beta} \right]^{1/2} \times [5.44 + 0.228 \text{Pe}^{0.614}]$$

For the case of uniform heat flux, the second bracketed term is changed to $[4.60 + 0.193 \text{Pe}^{0.614}]$. The definitions of the terms in the above equation are: ϕ_1 = unit velocity potential at the rear stagnation point of a tube; P = distance between rod centers, on an equilateral triangular grid; D = o.d. of rods; Nu = Nusselt number = hD/k ; k = thermal conductivity of fluid; $h = \bar{q}/(t - t_b)$; $\bar{q}$ = av heat flux at heating surface of rod; t = av temperature of heating surface of rod; t_b = local bulk temperature of flowing stream; Pe = Peclet number = $(Dv_{\max}\rho C_p)/k$; $v_{\max}$ = av linear velocity between rods; ρ = density of fluid; and C_p = specific heat of fluid.

In another experimental project, boiling-inception superheats were measured for potassium in forced-convection flow. This information is required to define conditions for inadvertent boiling in LMFBR-type reactors and to design boilers for

Figure 9. Computed effect of a step increase in Hartmann number on the time variation of mixed mean temperature in MHD duct flow. N_H = Hartmann number, N_{Re} = Reynolds number, N_{Pr} = Prandtl number, and N_{Rm} = magnetic Reynolds number.

Rankine-cycle systems of the SNAP type. In the first series of experiments, boiling inceptions were obtained over a mass velocity range of 2.3×10^5 to 3.7×10^5 lb hr $^{-1}$ ft $^{-2}$, a pressure range of 6 to 20 psia, and a saturation-temperature range of 670° to 816°C. Results showed that superheats substantially in excess of saturation were required to initiate boiling. Measured superheats at initial inception ranged from 17° to 90°C. There was a noticeable time (or history) effect: the inception superheat increased with time in a series of sequential runs under the same conditions. The pressure dependence of the results was found to be in general agreement with theoretical predictions, the superheats increasing with decreasing pressure, as illustrated in Figure 8.

In the field of heat transfer associated with direct-conversion devices, two analytical studies dealing with MHD flows were completed. In the first, the objective was to investigate the transient behavior of an electrically conducting fluid in laminar flow between parallel plates following a step change in flow rate or in magnetic field strength. The results, as shown in Figure 9, indicate that the transient fluid temperature following an increase in magnetic field strength can reach values that are orders of magnitude greater than either the initial or the steady-state values. In the second study, an analytical solution was sought to the entrance-region heat transfer problem for MHD flow with viscous dis-

sipation, with allowance for Joule heating and axial conduction. Sample results were calculated for entrance-region temperature profiles and local Nusselt numbers.

RADIATION RESEARCH AND DEVELOPMENT

Basic Research

Radiation-Induced Solid-State Reactions. X-ray diffraction studies of solid solutions of methacrylamide in isobutyramide reveal that extensive annealing and recrystallization occur during polymerizations. These effects probably play a large role in determining the rate and extent of the reaction and the molecular weight of the product.

The diffusion of several simple gases into 15 previously irradiated amides of different crystal structure and their reaction with the trapped radicals have been studied. With a relatively slowly reacting crystal, such as isobutyramide, oxidation chain lengths of as high as 150 have been observed, the principal product being a hydroperoxide. In certain classes of amides, not only oxygen but other gases such as nitric oxide and sulfur dioxide can also react. The reactions are true volume reactions, and their occurrence and speed can be correlated with known crystal structure. Where the latter is not known, density of the solid appears to be a useful index.

Radiation Chemistry of Aromatic Compounds.

In all 16 aromatics investigated, the *ortho* isomer of an electron-attracting substituent and the *meta* isomer of an electron-repelling substituent are least stable. The data that have been collected are being compiled, and molecular orbital calculations will be started shortly in an attempt to relate the observed effects with a more quantitative structural parameter.

Mechanism of Liquid-State Vinyl Polymerization.

The polymerization rate of ultrapure styrene is a complex function of temperature and dose rate. The temperature coefficient of the process has been observed to vary between -6 and $+2$ kcal/mole, depending on dose rate and temperature interval, between 0° and 50°C . This behavior may be attributed to changing contributions from several propagation reactions and/or several termination reactions. This admixture of competing processes is further reflected in the 0.68-power dependence of polymerization rate on dose rate (between 10^3 and 10^6 rads/hr at 0°C).

Table 3
Transients Observed in Pulse Radiolysis of Styrene

Species	λ_{max} , m μ	$\tau_{1/2}$, μsec	Remarks
Anion	370	4	Completely removed by traces of water; decay slowed by oxygen. First-order decay observed in both cases.
Radical	320	≈ 200	Insensitive to water and oxygen. First-order decay.
?	310 and 320		Formation insensitive to water and oxygen. Readily photolyzed; thermally unstable.

Alpha methylstyrene, which shows a square-root dependence of polymerization rate on dose rate at 0°C , exhibits a much less complex temperature dependence. The data do not yield normal Arrhenius plots, however.

The results of the pulse radiolysis investigation of styrene are summarized in Table 3.

Radiolytic Mechanisms in Inorganic Systems.

The Co^{60} gamma radiolysis of CO_2 adsorbed on silica gel and molecular sieves has been studied as a function of absorbed dose concentration of CO_2 , degassing procedure, and water content of the sorbent. The major product found was CO, along with quantities of O_2 and H_2 . To account for the high CO yields in the silica gel system it is necessary to postulate energy transfer from sorbent to sorbate.

Radiation Chemical Processing

Ethylene Homopolymerization. The experimental program for studying the kinetics and product characteristics of the gamma-radiation-induced polymerization of ethylene was extended by the operation of a small flow experiment.

Data obtained at a temperature of 163°C by using the 89-cc volume reactor indicated the dependence of pressure on rate to be 2.4 ± 0.6 for the pressure range 565 to 890 atm. A half-power dependence of the radiation intensity on rate was also observed. These results are in fair agreement with those obtained in earlier capsule experiments. About 500 g of polymer was formed. However, difficulties were encountered in operating the unit in a steady-state mode of operation.

Figure 10. CIRL installations at the west face of the Brookhaven Graphite Research Reactor.

Table 4

Design Characteristics of BNL In-Pile Research Loop

Gases to be handled	N_2O , N_2 , O_2 , NO_2 , He, CO_2 , CH_4 , NH_3
Gas pressure range	0 to 1000 psig (1 to 69.1 atm)
Temperature range	$-30^\circ F$ to $+1000^\circ F$ ($-34.4^\circ C$ to $+538^\circ C$)
Gas velocity	3 to 30 ft/sec (91.5 to 915 cm/sec)
Maximum volumetric flow rate	170 at 1 atm and $60^\circ F$ SCFM (air) (4550 liters/min at 1 atm and $0^\circ C$)
Fuel zone dimensions	$1\frac{1}{2}$ in. i.d. $\times$ 5 ft long (3.8 cm i.d. $\times$ 1.53 m long)
Maximum flux	2×10^{12} neutrons/cm ² -sec
Maximum fission power level	5000 W

Plastic-Impregnated Concrete. A cooperative program has been established with the Bureau of Reclamation, U.S. Department of the Interior, to study the formation of concrete-polymer combinations by the gamma-radiation-initiated polymerization of monomers impregnated in concrete. The purpose of the program is to attempt to improve the resistance of concrete to sulfate and hot brine solutions, distilled water, freezing and thawing, and cavitation.

Survey-type experiments have been conducted with a variety of monomers in the liquid and gaseous states. Liquid monomers tested were methyl methacrylate, styrene, vinyl acetate, and ethylene gas dissolved in sulfur dioxide. Systems studied in the gas phase were ethylene and mixtures of ethylene and sulfur dioxide. Practically complete penetration and impregnation of the concrete was accomplished with all the systems tested. Samples of these materials were forwarded to the Bureau of Reclamation for evaluation. The compressive strength of the polymethyl methacrylate and poly-

styrene-concrete pieces was increased by 2 to 2.4 times. Hardness increased 1.4 to 1.9 times. The absorption was decreased by as much as 80 to 98%. As a result of these experiments and a projected cost estimate for impregnating concrete drain pipe on a commercial scale which indicated economic feasibility, a basic program to develop other monomer systems and impregnation techniques was initiated.

Chemonuclear In-Pile Research Loop. The installation of this radiation processing loop, the CIRL, at the Brookhaven Graphite Research Reactor (BGRR) is in the final stages. The containments that hold the out-of-pile components are in place, and the tubing and cable interconnections have been made. The control panel has been installed and is being checked out and calibrated. Laminated lead and masonite shielding panels are being put in place. The instruments for the in-line analytical loop have been adapted for operation by remote control and are being mounted in their individual containments. These include a process gas chromatograph, mass spectrometer, process photometer, and gamma scintillation crystal with pulse-height analyzer. Among the last pieces of equipment to be received and installed were the main gas circulators. These are gas-bearing compressors of advanced design that were built to Brookhaven specifications. The 40-ft-long in-pile section has been tested and will soon be inserted in the experimental hole prepared for it in the west face of the BGRR. After the final connections have been made and leak-tested, the CIRL will be ready for test operation. The honeycomb, platinum-clad, enriched uranium-palladium alloy fuel elements are nearing completion and will be ready for use in the CIRL. These elements are being fabricated from 1000 ft of 0.0001-in.-thick foil made at Brookhaven by a rolling process developed here. A summary of design features of the loop is given in Table 4. Figure 10 is a bird's-eye view of the southwest corner of the reactor, showing two of the major containments. Lead shielding is being applied to the higher of the two tanks.

Fission Fragment and Radiation Chemistry

Fixation of Nitrogen. The series of in-pile capsule experiments performed to date on irradiation of a homogeneous gaseous mixture of N_2 and O_2 with fission fragments showed no G -values of nitrogen fixed that were >2 . Experiments were performed as a function of pressure (to 68 atm), com-

Figure 11. Initial (low dose) G -value for $(NO_2)_T$ and N_2O vs gas composition in N_2 - O_2 filling gas.

position, and varying types of radiation, as illustrated in Figure 11. Two-phase experiments with liquid N_2O_4 and with oxide solid substrate catalysts in contact with N_2 - O_2 gas gave no indication of improved yields. However, finely dispersed N_2 - O_2 gas bubbles in water, when irradiated, indicated significantly improved yields, and therefore this heterogeneous gas-liquid system is being intensively studied.

Ozone Synthesis. A flow experiment was performed by passing a simulated air N_2 - O_2 gas composition through a 100-cc stainless steel reaction vessel placed in a Co^{60} gamma radiation field. At high flow rates and shorter residence times, increased O_3 formation is favored. At longer residence times, only NO_2 can be detected. A G -value for O_3 of 4.7 has been reached.

Radiation Engineering

High Intensity Radiation Development Laboratory. 1. *Operations and services.* Seven hundred ninety thousand curies of Co^{60} of the Mark I type of BNL standard source, activated at the Savannah River Plant and encapsulated by Lockheed, were received; 48 of the 176 sources were shipped to Hawaii for installation in the Hawaiian Development Irradiator. One hundred ninety-five thousand curies of rectangular Cs^{137} sources were received from Oak Ridge National Laboratory (ORNL) and installed in the portable cesium irradiator fabricated by the American Nuclear Corporation.

Revision of the HIRDL conveyor system was initiated; the expanded system will include load-

ing-dock facilities and will allow a choice of operating modes, including multipass, multiplaque irradiation.

2. Irradiator design. A third shipboard irradiator was inspected, modified, and loaded with 42,000 curies of Co^{60} . The unit is now successfully operating aboard ship in the Gulf of Mexico.

A four-pass conveyor, suitable for use with cesium sources, was received and its cold operation evaluated.

Design was completed of the Brookhaven Portable Cesium Development Irradiator, which uses a moving, 100,000-curie Cs^{137} source and two 6-cu-ft irradiation chambers. Procurement of two of these units was initiated by the AEC.

The design of a portable irradiation cell suitable for rapid, inexpensive, temporary location at a user's site was initiated. The device will allow a food or chemical processor to pilot a proposed operation at the user's plant without incurring a heavy capital or radiation personnel investment.

3. Source development, testing, and calibration. Qualifying tests on the BNL Mark III standard bonded Co^{60} source were initiated. This source is essentially identical to the Mark II, except that the Co^{60} thickness has been increased and the metallurgically bonded, stainless steel cladding thickness reduced in order to increase the active loading by about 20% without changing external dimensions.

Inactive prototype Sr^{90} beta sources, developed by ORNL, were evaluated. These promising sources consist of SrSiO_3 microspheres matrixed in aluminum and encapsulated in stainless steel.

Long-term corrosion studies of active and dummy Mark I Co^{60} sources were initiated. Repeated pool-air cycling has resulted in no appreciable corrosion ($<10^{-4}$ mils/year) or pitting.

Experimental apparatus was developed for the determination of the $\text{Cs}^{134}/\text{Cs}^{137}$ ratio in BNL standard cesium sources.

A dummy cesium source, heated to $>720^\circ\text{C}$, bulged significantly but maintained its leak-tight integrity.

Adiabatic operation of the modified Mark II calorimeter was verified.

4. Dosimetry. A new oxalic-acid dosimetry technique, based upon evaluation of the gaseous decomposition products, is being developed. Evaluation and testing of the ASTM standard oxalic-acid dosimetry procedure is continuing.

The dosimetry characteristics of Perspex HX were analyzed in detail. Techniques were developed for the casting of pure, thin films of polymethyl methacrylate, suitable as carriers for a variety of radiochromic dyes.

5. Cobalt-cesium comparisons. Experimental depth-dose distribution comparison studies of Cs^{137} and Co^{60} were completed for semi-infinite homogeneous targets of density 0.1 to 2.0 g/cc. Similar studies in heterogeneous target systems were started; data for regular arrays of cylindrical targets of densities 0.5, 0.8 and 1.0 g/cc were collected and analyzed.

6. Analogue simulation studies. The dependence of the $\text{Cs}^{134}/\text{Cs}^{137}$ ratio on reactor flux, in-reactor time, and postremoval decay was predicted on the analogue computer. Current cesium production from long-term storage material contains only a minor fraction of Cs^{134} . If the production of cesium isotopes were to increase to the point where relatively fresh material had to be used, Cs^{134} (2.25 yr, 1.565-Mev γ) could account for twice the specific power of Cs^{137} (30 yr, 0.567 Mev) in a typical CsCl source. A significantly more difficult shielding problem would be presented under such circumstances.

The transient temperature gradients generated in thick targets were simulated on the analogue computer.

Radiation Chemical Reactor Design Principles

One objective of work in this area is to determine the effect of mixing on polymerization rate and molecular weight distribution for a photopolymerization carried out in a partially illuminated vessel. A number of improvements in apparatus were completed during the year, with the result that impeller speeds up to 1500 rpm can now be attained, reaction cell environment temperatures can be maintained constant to $\pm 0.005^\circ\text{C}$, and actinic light intensities can be accurately controlled for the duration of an experiment.

Some experiments on mixing rates in the absence of reaction were conducted. High-speed motion pictures were taken of the dispersion of a pulse of dye injected into a water-filled reaction cell. Mixing times of the order of 1 sec were found.

In preliminary experiments on the interaction of mixing and reaction using styrene, the rate of the direct photoinitiated reaction was found to be comparable to that of the dark reaction. Changes

in the photoinitiated rate resulting from the introduction of mixing, while measurable, were small. Subsequent experiments were conducted with methyl methacrylate, for which the dark rate was found to be very small compared to the rate of the photoinitiated reaction. In the first experiments with methyl methacrylate, the mean chain lifetime of the photoinitiated reaction, deduced from the measured rate in combination with known values of the propagation and termination rate constants, was found to be of the order of 30 to 50 sec, and the transition from "perfect mixing" to "no mixing" took place only when the impeller was stopped. With 37% of the cell volume illuminated, a decrease in rate of 26% was found in going from 140 to 0 rpm. In later experiments with a small fraction of the cell illuminated and a more intense light beam, fivefold increases in rate were measured as the impeller speed was increased from 0 to 1200 rpm.

Some work on the engineering aspects of the radiation treatment of liquids and particulate media has been undertaken. Interest is centered on the problem of design to obtain a specified absorbed dose range or other index of performance in batch and flow irradiators, including in the latter category single-pass and recirculating systems.

Atmospheric Diagnostic Program

A study was initiated of the feasibility of methods of tracing sulfur dioxide from various sources in municipal areas and relating SO_2 concentrations at ground levels to meteorological conditions, with use of naturally occurring isotopes of sulfur. The $\text{S}^{32}/\text{S}^{34}$ ratio varies sufficiently in oil and coal fuels to allow sulfur to be used as a self tracer. In addition, the ratio is sufficiently different in gypsum deposits so that SO_2 from this source may be a natural tracer. The feasibility of this technique, in which a ratio mass spectrometer is used to determine the $\text{S}^{32}/\text{S}^{34}$ ratio, is being investigated.

HOT LABORATORY

Analytical Chemistry Research

The synergistic extraction of cupric and uranyl ions by several combinations of mixed β -diketones showed greater formation of mixed species when a strongly complexing ligand was combined with a

weakly complexing one. The mechanism for the synergistic extraction of cerium by tri-*n*-octylamine and thenoyltrifluoroacetone was found to be independent of whichever of three amine species predominated.

Theoretical relationships were developed for a mechanism (denoted as ECE) involving in series an electrochemical reduction, a chemical step, and another electrochemical reduction, and the computer was used to apply the theory to the solution of complex diffusion-kinetic problems. A mathematical model describing the behavior of the dropping mercury electrode gave interrelationships of current, potential, and time that agree well with known solutions for simple cases. Theoretical calculations for a second-order mechanism of the ECE type were verified by the work of others. Chronoamperometry showed that the addition of HCl and amines to the 1 and 4 positions of *o*-benzoquinones depends on the over-all equilibrium constant and the rate constant for the addition reaction.

The study of the mixed ligand complexes of Pd(II) with Cl^- , Br^- , and I^- was completed; the stepwise formation constants of the various species were measured, and the absorption spectra of the individual mixed complex species were calculated. A potentiometric study of the halide complexes of Ni, Hg, Ag, and Pd in the weakly coordinating, nonaqueous solvent dimethyl sulfone was completed, and over-all stability constants for the fully coordinated complex species were determined.

Nuclear and Radiochemistry Research

Electrophoretic measurements of the iodine oxidation states resulting from the β^- decay of Te^{132} as Te(IV) and Te(VI) in aqueous solution indicated that when the Auger process occurs in a polymeric tellurium species, the resulting charge and excitation energy may be dissipated throughout the molecule. This preservation of a sufficient number of I—O bonds results in the retention of some IO_4^- .

Electrolytic and ferrous ion reductions of TcO_4^- produce Tc(III) in pink and blue-green interchangeable forms, depending on the conditions.

A computer program was written to calculate excitation functions and to determine product yields from the evaporation of any of up to 50 desired particles (Figure 12). The probability of evaporating various heavy particles with excitation energies of 200 to 1000 MeV was shown to be

Figure 12. Residual nuclides from Tc^{100} at 200 MeV.

comparable to that of evaporating only the six basic particles (except neutrons). This markedly changes previously calculated mass distributions of residual nuclides. Comparison of the calculated and the measured excitation functions for $Ca^{48}(\alpha, \alpha n)Ca^{47}$ indicates the possibility of a low energy direct interaction in this unique doubly magic neutron-excess target nuclide (Figure 13).

Figure 13. Excitation function of the $Ar^{40}(\alpha, 2p)Ar^{42}$ reaction.

Isotope Development

Others have undertaken the supply of the special isotopes (except Mg^{28}) for which Brookhaven had previously been the sole source. This has permitted increasing the effort devoted to developing medical applications of isotopes, an area in which Brookhaven has already achieved notable success.

Applied Mathematics

The Applied Mathematics Department maintains and operates Brookhaven's Central Scientific Computing Facility, supplies scientific programming services, provides mathematical and programming consultation, and engages in applied mathematics research, programming research, and computer research and development.

COMPUTER OPERATIONS

The Computer Operations Division of the Department operates the Central Scientific Computing Facility (CSCF) which provides general, large-scale computing support for the research activities of the Laboratory.

Central Scientific Computing Facility

By the end of fiscal 1967, the CSCF consisted of three major large-scale computers, an IBM 7094 and two CDC 6600's, and two smaller support computers, an IBM 1401 and a CDC 924. The IBM 1401 was acquired in July 1966, prior to the return of the leased IBM 7044 to the International Business Machines Corporation, and was used exclusively for peripheral support of the IBM 7094. In May 1967 the second CDC 6600 computer was accepted and put into operation. A second disk-file unit for the first CDC 6600 and a Calcomp Model 835 CRT plotter also were acquired during the year. A one-million-word extended core storage unit, to be shared by the two CDC 6600 computers, is scheduled for delivery in 1968.

Computer Scheduling and Usage

The IBM 7094 computer was operated for 21 shifts/week throughout the year and was utilized to its fullest capacity. Since a CDC 6600 computer was available, IBM 7094 usage was confined to existing production programs and on-line processing of bubble-chamber film data. The conversion of many production programs from the IBM 7094 to the CDC 6600 allowed a significant increase during the year in the amount of IBM 7094 time devoted to processing bubble-chamber data. Figure 1 shows IBM 7094 usage during the past two years for productive computing only; time

used for such operations as tape mounting, hardware and software maintenance, and training has been excluded.

The CDC 6600 operation was scheduled for 15 shifts/week, with overtime shifts occurring toward the end of the year. Figure 2 shows the usage of both CDC 6600 computers for the past year. Usage shown for the first three quarters is for the first CDC 6600 only; that shown for the fourth quarter is the combined usage of both CDC 6600 computers. During the month of June 1967 CDC 6600 computing operations were handled entirely on the second CDC 6600 in order to remove the first from service for engineering modifications. The CDC 924 was used for general peripheral support of all three large-scale computers as well as for processing special small problems.

COMPUTER PROGRAMMING

The Department's Programming Division maintains the software systems for all computers in the CSCF and provides programming services and other related assistance to computer users.

Software Systems Maintenance

During the first half of the year, the CDC 6600 computer was operated with the CDC Chippewa operating system. During this period an improved operating system, named *SCOPE*, was tested extensively and some deficiencies were corrected. In January *SCOPE* replaced the Chippewa system. Features of *SCOPE* designed to improve the efficiency of Brookhaven's CDC 6600 operations (see Figure 3) were developed and further changes and corrections to the system were made during the remainder of the year. Program conversion information for users was provided through a series of lectures and a special edition of the BNL Computer Newsletter.

Programming Services

The Division continued to publish the BNL Computer Newsletter and to maintain a programmer-of-the-day consultation service for users at the computing facility. Preparation of a com-

Figure 1. Histogram of IBM 7094 computer usage at Brookhaven National Laboratory.

Figure 2. Histogram of CDC 6600 computer usage at Brookhaven National Laboratory.

prehensive manual of Brookhaven computer programming and usage was begun. In addition to programming new CDC 6600 computer problems, the Division participated in modifications of existing CDC 6600 programs required by the change in operating systems. Assistance was continued in the conversion of IBM 7094 programs for use on the CDC 6600. Two examples of specific programming activities for the CDC 6600 computer are given below.

Health Physics Data System

In cooperation with Health Physics personnel, programming was started for a data system to provide daily and weekly reports on the cumulative radiation exposure of individuals at Brookhaven. Files maintained on magnetic tape will contain individual records of those receiving the regular personnel monitoring service. The radiation exposure data, obtained daily from dosimeter readings and biweekly from film-badge readings, will be used to update individual records on the tape files. For each daily update run the system will list per-

sonal data concerning each individual for whom there was a data update entry. These listings, arranged by department and specialty groups, will indicate the amount of radiation to which each person may safely be exposed, or else the length of time that must elapse before he can safely be exposed to a particular level of a given type of radiation. This information will permit those responsible to determine readily who is available for a particular assignment involving radiation exposure.

Magnetic Spectrometer Simulation

Work was nearly completed on a CDC 6600 program being written to simulate the occurrence of particle events of the type

$$A + B \rightarrow C + D, \quad C \rightarrow C1 + C2, \quad D \rightarrow D1 + D2$$

and the detection of the resulting pairs of decay products by a "double-V" magnetic spectrometer system (MSS). The simulated MSS has two branches, each containing a magnetic field preceded and followed by arrays of wire spark-cham-

ber detectors. The program will be used to study different versions of the MSS in order to find a suitable and practical arrangement of spark chambers and magnetic fields that will permit sufficiently rapid, accurate, and unambiguous kinematic reconstructions of the events under consideration.

Using a Monte Carlo procedure governed by relativistic kinematics, the program will generate a large random sample of events. The program will then select those events in which both pairs of decay products will traverse a magnetic field – one pair through each of the two fields in the MSS.

Figure 3. Partial view of operating area in the Central Scientific Computing Facility (CSCF), showing both CDC 6600 operating consoles located side by side. The interleaving of like components of the two computers is a general feature of the CDC 6600 layout in the CSCF. With this arrangement both computers are operated essentially as a single integrated computing facility whose components are grouped by operating functions to allow a smooth over-all work flow and optimum employment of operating personnel.

For each selected event, the trajectories of its four decay products will be traced through the magnetic fields and spark chambers of the MSS. The point of intersection of each trajectory with every spark-chamber plane it encounters will be determined, and the wire coordinate closest to the intersection point in each plane will then be found. The detection efficiency of the spark chambers and the production of spurious sparks in them will be simulated by modifying the wire coordinates in each plane with an appropriate random procedure. Other procedures will account for nonuniformity in the magnetic fields. The resulting simulated records of the spark-chamber detection of events will be used as data for another phase of the program which will attempt to kinematically reconstruct the original events. The suitability of various MSS arrangements can then be studied by analyzing how effectively the original simulated events can be reconstructed from the data provided by the different arrangements.

COMPUTER RESEARCH AND DEVELOPMENT

During the past year, the activities of the Systems Engineering Group of the Department were concerned mainly with the addition of extensive on-line capabilities to the CDC 6600 installation at the CSCF. These activities involved design and development work on the Brookhaven Digital Communications Network and three auxiliary on-line systems that will be connected to the network.

Figure 4. Diagram showing major components of typical local and remote branches of the Brookhaven Digital Communications Network.

Brookhaven Digital Communications Network

An over-all design was established for the Brookhaven Digital Communications Network, which is a flexible, high-speed, computer-to-computer communications system intended primarily as an aid for increasing the productive use of some of the Laboratory's major experimental facilities. Small, inexpensive computers will be used at experiments to collect data on-line and relay them, via the network, to the central large-scale CDC 6600 computers, which can process the data rapidly and then send back results for output by the small computers. The network will also provide for auxiliary input-output stations, conveniently located to per-

mit direct use of the central computer by scientific personnel at remote points within the Laboratory.

The network will consist of a number of separate branches, each providing a direct link for sending data between a remote location and the central computers at a rate of up to one million 12-bit data words/sec. All branches of the network will be identical to one of the two types of branches whose major components are shown schematically in Figure 4. The local type of branch is a simpler version of the more general remote type. The high data rate and the use of a remote multiplexer unit enable a single branch of the network to service as many as eight computers in the same remote area. Since the network has been designed to be independent of the types of remote computers or their uses, on-line experimental data stations and remote input-output stations may be intermixed on each branch as required.

The coaxial cables for five remote branches of the network are scheduled for installation in underground conduits during the first quarter of fiscal 1968. Two branches will service the Alternating Gradient Synchrotron area; the others will service the Chemistry Building, the new Tandem Van de Graaff accelerator, and the High Flux Beam Research Reactor.

A synchronizer and a pair of data terminals were completed for the AGS branch that will be put into operation first as a prototype. Work on the local controller and remote multiplexer for this branch has reached the detailed design stage. The prototype branch will be connected to a remote input-output station, as shown in Figure 4. This arrangement will be used to test the over-all performance of prototype branch components, a prototype remote input-output station, and network control programs being developed for the central CDC 6600 and remote PDP-8 computers.

The equipment configuration for the prototype remote input-output station has been defined; it includes a PDP-8 computer, a card reader, a magnetic-tape transport, and a line printer. All units have been acquired except the line printer, which is scheduled for delivery early in fiscal 1968. The design of the PDP-8 break-state multiplexer built for the Input-Output Supervisory System (IOSS) was chosen for this application. Design and construction of the interfaces required between the PDP-8 and the input-output devices continued through fiscal year-end.

Another auxiliary system which will be connected to a local branch of the network was also under development. It will incorporate a Sigma-7 computer installed in the Physics Building, adjacent to the CSCF. Preliminary specifications for the interface to this system were completed and detailed design work was begun.

Input-Output Supervisory System

Work continued on the development of the IOSS which will be connected to a local branch of the Digital Communications Network. The IOSS will permit automatic coordination and supervision, by CDC 6600 monitor software, of operating personnel at each CDC 6600 input-output station. A PDP-8 computer will be utilized to control communications between operating personnel and the CDC 6600 computers. Teletypes for operator-computer communication and a magnetic-tape-label reader will allow the system to verify automatically that the proper magnetic tapes are mounted in response to CDC 6600 program requests.

During the past year, design was completed for a break-state multiplexer to control PDP-8 input-output for as many as seven devices, including the network connection to a CDC 6600. Design was also completed for a submultiplexer to control up to seven teletypes and permit the break-state multiplexer to handle them as a single input-output device. Both multiplexers have been built and tested. Detailed design work for the magnetic-tape-label reader was near completion at the end of the fiscal year.

PROGRAMMING RESEARCH

The programming research activities of the Applied Mathematics Department overlap and support its work in computer research and development and in mathematics research. The purpose of this activity is to develop computer software and new uses for computer systems.

Network Control Software

The development of software for controlling the operation of the Digital Communications Network was continued. The over-all operation of the network will be controlled by CDC 6600 peripheral processor programs which will communicate with control programs in the auxiliary computers con-

nected to the network. These interacting programs will allow the CDC 6600 and any of the auxiliary computers to send requests, data, and acknowledgments to each other.

The CDC 6600 programs for controlling general on-line communications through the network were designed and flow-charted. Other CDC 6600 programs were written for controlling the network branch that services the IOSS, and a corresponding control program was written for auxiliary PDP-8 computers. To obtain preliminary information on its general operation, a simulation model of the network was started in SIMSCRIPT for the CDC 6600.

Dual CDC 6600 Operating System

A study was initiated to work out the design of an efficient and convenient operating system for the future CDC 6600 configuration, which will be based on two CDC 6600 computers sharing one million words of extended core storage. The operating system will include provisions for automatically servicing the auxiliary on-line systems connected to the Digital Communications Network.

Statistical data were gathered on the performance of Brookhaven's first CDC 6600 during its normal multiprogram operations. The data were analyzed to obtain a statistical profile for typical BNL jobs being processed by the CDC 6600 and to find possible problem areas in the future operating system design. These results are being applied in a simulation study to aid in the selection of an optimum design model for the operating system.

Algebraic List Processing

Programming was started on a set of routines in LISP, a list processing language, for manipulating algebraic expressions at the symbolic level. These routines are to be used, in an on-line conversational manner through a teletype console, as a mathematical research aid in the area of algebraic problems. A LISP 1.5 processor was obtained from the University of Texas and incorporated into the CDC 6600 SCOPE operating system at BNL as a user's program library (PROLIB) feature.

MATHEMATICS RESEARCH

The mathematics research activities of the Applied Mathematics Department are intended to complement other aspects of the over-all research

effort at Brookhaven. Although the primary aim in this area is the development of a strong research program in applied mathematics, activities in other fields of mathematics that may contribute to developments in applied mathematics are included. A number of the Department's mathematical research activities are summarized below.

Algebraic Study of Stopping Variables

An algebraic approach was developed for the study of problems involved in determining when sequential observations of random phenomena are adequate and should therefore be terminated. Indications of when to stop are given by stopping variables which are functions of previous observations. Previous studies of stopping-variable problems had been analytic in nature. This new approach, however, focuses on the algebraic properties of stopping variables when they are viewed as a set on an arbitrary probability space.

A multiplication between two stopping variables was defined as follows: termination time is the minimum of the termination times of the variables of the product. With this definition, it was shown that the class of stopping variables is a commutative semigroup of idempotents. Then a basis isomorphism between a commutative semigroup of idempotents and a class of subsets of itself was used to show that the class of stopping variables is a lattice which is complete under certain conditions. Finally, it was shown that this lattice is distributive and is therefore a Dedekind lattice. Thus all the results available in the literature concerning these abstract structures are also true for the class of stopping variables.

The lattice properties of stopping variables can be used to establish a theory for representing an arbitrary stopping variable in terms of a function of extremely simple stopping variables. This aspect of stopping-variable problems is being given further study.

Systems of Simultaneous Inequalities

Research was continued on the use of generating-function techniques for solving systems of simultaneous integer inequalities. Further solutions were obtained for systems of linear integer inequalities resulting from analyses of minimum cost transportation problems. An example of this type of problem is that of determining the cheapest way of distributing stocked items from a number

of different warehouses to various destinations when the demand from each destination is known and the costs of shipping the items from each warehouse to each destination are known. The generating functions for these problems were obtained in a reasonably simple explicit form. A nonlinear version of the transportation problem was worked out to show that a class of nonlinear integer problems can also be dealt with through the use of generating functions.

An algorithm was also developed for solving systems of linear noninteger inequalities by Laplace transforms. This is a continuous analogue of the generating-function algorithm previously developed for solving systems of linear integer inequalities.

Quadratic Differential Systems

As part of a continuing investigation of n -dimensional nonlinear homogeneous differential systems and associated transforms, a study was made of differential systems of the form

$$\dot{x}_i = \sum_{j,k} a_{jk}^i x_j x_k, \quad i = 1, 2, \dots, n,$$

where conditions on the n^3 numbers $\{a_{jk}^i\}$ guarantee the confinement of trajectories to the probability $(n-1)$ -simplex: $\sum x_i = 1$. These systems of equations govern mathematical models characterized by a large population, n , of constituents that interact in pairs and are replaced through this interaction by new constituents. Results concerning existence, uniqueness, and asymptotic stability, both locally and in the large, were obtained for wide classes of these differential systems.

Stability Properties of Difference Equations

Initially, through the use of Toeplitz-matrix theory, new techniques were developed for studying the stability properties of Wiener-Hopf difference equations arising as approximations to time-dependent partial differential equations in one space variable with mixed initial-value boundary conditions. These techniques now permit boundary conditions to be included in such difference-equation studies. Although developed for the study of difference equations with constant coefficients, these techniques may also be applied in studies of difference equations that have smoothly varying coefficients.

More recently, through the use of both Toeplitz matrices and Fourier transforms, the range of this

work was extended to the development of analogous techniques for studying the stability of time-dependent difference equations in several space variables. Stability conditions for such equations have been determined. It is now possible, with a computer, to test the convergence of approximating difference equations for this important class of problems. Many other problems, such as those involving the mesh refinement of difference equations, can be reduced to this class.

Some of the results obtained from this work have a wider significance from the abstract point of view. In the course of obtaining stability criteria, some interesting results were also obtained concerning the behavior of a wide class of Toeplitz operators.

Special Mathematical Functions

In a continuing study of numerical approximations for special mathematical functions, the initial effort was directed toward the computation, to ten or more significant digits, of incomplete γ functions, including special cases such as error functions and integral exponential functions. One of the most convenient approaches available for this type of work is that of computing the residue of an asymptotic expansion of the function. This may be computed either by a power-series method or by a continued-fraction method.

The power-series method is more suitable when the arguments for these functions are close to zero, while the continued-fraction method is more suitable for larger arguments. Because of this there is a crossover point at which the value of the argument is such that both methods are equally suitable. Below this point, it is better to use the power-series method; above it, the continued-fraction method. Optimally, a practical scheme for computing a function requires a reasonable knowledge of the argument value at the crossover point. Then, when the function is to be computed for a given argument, the best computing method may be readily determined by comparing the value of the given argument with the crossover value.

As a result of this study, the crossover values for incomplete γ functions were satisfactorily determined for both real and complex arguments. In addition, a new technique was developed to accelerate the computation of continued fractions, since they sometimes converge rather slowly. The

approach employed in this study could also be usefully applied in a study of the complete γ function.

Temperature-Dependent Behavior of Ferromagnets

In the past few years, much research has been directed toward determining the behavior of various thermodynamic functions in the neighborhood of the critical temperature for both ferromagnets and gases. Recent theoretical results predict that such temperature behavior for ferromagnets is more dramatic than was previously thought. At Brookhaven a detailed and accurate picture of this predicted behavior was calculated on the basis of two well-known models of ferromagnetism: a spin- $\frac{1}{2}$ Heisenberg model, for calculations above the critical temperature, and the simpler Ising model, for calculations below it.

The spin- $\frac{1}{2}$ Heisenberg model calculations, carried out over the past three years, were based on nearest-neighbor interactions with field-dependent free energy. These calculations were aimed at obtaining, as far as practicable with available computers, complete high-temperature expansions of the thermodynamic functions for this model to determine their behavior as the critical temperature is approached from above. The series expansions were analyzed by the Padé approximant method, among others. Attention was confined to models for the following 3-dimensional Bravais lattices: simple cubic, face-centered cubic, and body-centered cubic. An extensive compendium of the relevant fundamental graphical and tabular data involved in this work is being prepared as a BNL report.

For the Ising model of ferromagnetism, numerous low-temperature, series-expansion data have accumulated in the literature during recent years.

These data were gathered and carefully analyzed to determine the structure of those mathematical functions that represent the various thermodynamic properties of ferromagnets as the critical temperature is approached from below. The Padé approximant method was employed in the low-temperature expansion of the resulting functions. As part of this work, the method was generalized in such a way that converging upper and lower bounds could be established from early power-series coefficients for a wider class of functions than was previously possible.

Wave Propagation in a Rarefied Gas

The nature of wave propagation in a rarefied gas was investigated according to kinetic theory. The results show that, for a bounded collision operator in the fundamental Boltzmann equation used to describe the molecular behavior of rarefied gases, there is a cutoff frequency above which a plane wave motion of a single wavelength will not be propagated as such through a rarefied gas. Instead, it will generally excite waves in the gas at an infinite number of wavelengths.

In a related study, convergence of the Chapman-Enskog small wavenumber expansion was investigated for different classes of model equations that are approximations to the Boltzmann equation. A general result of this study is a simple collision-frequency criterion for convergence or divergence of the expansion. For a particular model equation, which corresponds to an inverse fifth-power or Maxwell force law, the corresponding Chapman-Enskog expansion was shown to be divergent. This contrasts with recently obtained results in which convergence was shown for the rigid-sphere Boltzmann equation.

LIFE
SCIENCES

Biology

The present report provides brief summaries of projects conducted by members of the scientific staff of the Biology Department. Research is in progress at all levels of biological study, from ecology to biophysics, and is related to the development of basic information that will lead to improved understanding of the manner in which ionizing radiations affect living things and in which these effects may be used constructively for specific biological purposes. Insofar as the problems examined permit, emphasis is given to the molecular approach and mechanistic rather than descriptive studies are stressed. Thus, a common theme throughout is the correlation of macromolecular structure with biological organization and function.

A number of the projects derive immediate benefit from the availability of research reactors and particle accelerators at Brookhaven, while more specialized irradiation sources are utilized directly within the Biology complex. A noteworthy feature of the program is the number of projects that relate to studies with plants. In addition to extensive field and greenhouse facilities, specialized growth-chamber space is available for precise manipulation of the environments in which plants are maintained.

The Biology Department maintains a number of collaborative programs with visiting scientists from other institutions, both in this country and abroad, and sponsors the Brookhaven Symposia in Biology, a series of annual conferences at the Laboratory on topics of current interest in biological research. The topic of this year's symposium is *Recovery and Repair Mechanisms in Radiobiology*. The proceedings will appear as the 20th volume in the series.

PLANT SCIENCES

Ecology

The patterns of movement of substances such as radionuclides and pesticides through the environment are established by physical, chemical, and, of especial importance and least understood, biological factors. Plant and animal populations concentrate substances from the environment by a factor of as much as 10^5 . Discriminatory mecha-

nisms – concentration, dilution, and simple retention – are intrinsic to natural communities. Work in this area during the past year was focused on two important ecosystems of Long Island, an oak-pine forest (part of which is subjected to irradiation) and estuaries of the south shore. These ecosystems are closely linked in their evolution by movement of nutrients and water from the land to the estuaries and thus offer unusual opportunities for research in ecology. Two particularly significant recent findings are that (1) the forest has a mechanism for retention of nutrients, such as calcium, which normally is very efficient but breaks down when the forest is damaged severely by ionizing radiation or, presumably, some other disturbance, and (2) the changes in the estuaries resulting from man's activities are due not only to the increase in nutrients washed from the land but also to accumulation of pesticides (e.g., DDT) used for about 20 years to control insects, especially mosquitoes.

Exploitation of natural land communities, in direct proportion to severity of disturbance, reduces the capacity to retain essential nutrients and furthers losses through leaching to streams and the water table. Such enrichment of water bodies with nutrients is a type of pollution that has become a major problem in recent years. There is much to be learned about the degree to which natural communities can be disturbed before serious losses of nutrients occur, about mechanisms for conservation of nutrients, and about measures for channeling nutrients into desirable patterns. For the necessary study the forest under examination has proved useful because it provides for comparisons between intact and damaged communities.

The patterns of movement of pesticides are of special interest. They are similar in many ways to those of radioactive fallout, but to date the results are generally more serious. In estuaries along the south shore of Long Island the concentrations of DDT are in some instances sufficient to reduce reproduction in fish and birds and in others are within a factor of 10 of those necessary for acute mortality. Some pesticides, like certain radionuclides such as cesium-137, tend to be accumu-

Figure 1. Loss of calcium from the organic layer of an oak-pine forest. Measurements were made during the summer. The loss of calcium reflects passage of rain water through the layer. In the intact part of the forest the loss reached a maximum, after which additional precipitation caused no further loss. In the part damaged by irradiation, loss was directly related to precipitation. The loss of calcium in the intact forest apparently was under some degree of biological control. Such control probably applies to other nutrients and fallout, although the details may differ for each substance and community.

Figure 2. DDT residues in a Long Island food web. Numbers are DDT residues in parts per million. The concentration in water was <0.001 ppm. DDT moves through food chains in patterns similar to those for certain radioisotopes introduced by fallout. Carnivores and scavengers, because of their position at the ends of food chains, receive the highest concentrations, which may be greater than those in water by a factor approaching 10^6 . (The study was made in collaboration with the Biology Department, State University of New York at Stony Brook. Drawing by D. Puleston.)

lated by scavengers and carnivores and thus present special hazards to them. Many populations of carnivorous birds have declined precipitously and even disappeared from the area in recent years. The evidence that DDT is the cause seems very strong. The same applies to fish populations. Thus the problems arising in the estuaries from eutrophication are exaggerated by damage from pesticides. The work being done reveals not only the patterns of movement of substances through ecological systems but also the effects of the substances on the structure and function of the systems.

Relationships Between DNA, Nuclear and Chromosomal Volumes, and Radiosensitivity in Plant Cells

The sensitivity of plants and other organisms to ionizing radiation is a complex function of nuclear and related parameters. In continued study of this sensitivity, the correlations between nuclear volume and amount of DNA per cell and between interphase chromosome volume and amount of DNA per chromosome were found to be high and posi-

tive in 30 species of higher plants. Radiosensitivity and DNA per cell in ten of the species were not related. However, in these ten species the correlations between sensitivity and interphase chromosome volume and between sensitivity and DNA per chromosome were marked and positive. Since DNA per chromosome and interphase chromosome volume were related to sensitivity in the same way, sensitivity presumably is determined by the volume occupied by DNA in a chromosome as well as by the amount of DNA.

The nuclear volumes of cells from roots and shoots of the same plant may differ. However, the ratio of the volumes for a group of plants comprising 28 species was found to be one. Thus, reasonable predictions about radiosensitivity and DNA content can be based on data for meristematic cells of either the shoot or root.

Plant Isoenzymes

Electrophoretic separation of enzymes and other proteins on polyacrylamide gels provides a ready method for study of genetically controlled biochemical differences between species, mutants, genotypes, and stages of development in plants. The method is being applied to the genus *Nicotiana* (tobacco) to establish evolutionary patterns of isoenzymes, differences between proteins in normal and tumor-forming plants, and alterations in enzymes and other proteins caused by neutron irradiation in different hereditary types of growth. It is also being applied to other plants for similar purposes.

Leaf tissue in *N. langsdorffii* was found to contain two more forms of the enzyme peroxidase than

Figure 4. Isoperoxidases in tobacco. The electrophoretic patterns for peroxidases in leaf tissue of *Nicotiana glauca* and *N. langsdorffii*, the tumorous hybrid of these species, a nontumorous mutant of the hybrid, and tumor tissue of the hybrid are diagrammatically represented. In number of forms of the enzyme the species differ, the hybrid differs from the parents, the mutant differs from the hybrid, and tumor tissue differs from the leaf.

that in *N. glauca*. Leaves of the tumorous hybrid of these tobacco species contained the same forms of the enzyme as the parents and two additional forms. Leaf tissue of a nontumorous mutant of the hybrid contained one less form than the hybrid. Tumor tissue contained one more form than the leaves. The differences in numbers of isoperoxidases presumably reflect the genetic background of the plants. In similar work with wheat, each of some 30 varieties was found to contain 6 forms of alcohol dehydrogenase. These forms probably represent genomes derived from ancestral forms of the wheat. Introduction of a chromosome segment carrying leaf rust resistance into wheat gave rise to two additional proteins in seeds and one in leaves.

Modification of Effects of Ethyl Methanesulfonate on Maize

The mutations induced by ethyl methanesulfonate (EMS) presumably reflect specific reaction with genetic material and thus are of special interest. However, EMS damages biological material in ways not necessarily related to its mutagenic activity. As a basis for projected attempts to in-

crease the ratio of mutagenic activity to damage, conditions of EMS treatment of maize seed were sought which would minimize gross damage, specifically reduction in seedling height and survival. The mutagen was used in concentrations from 1.25 to $80 \times 10^{-3} M$. The lowest concentration has little effect, the highest causes severe damage. The findings indicate that exposure to a given concentration of EMS produces the least gross damage when the seeds are soaked in water after treatment, then dried and stored for a relatively brief period at a relatively low temperature.

Radiation Mutation Program

The facilities at Brookhaven National Laboratory are used to irradiate plant material for workers in this and other countries. About half of the irradiations are made for plant breeders who seek mutants that may serve for production of improved varieties. The others are made for geneticists concerned with the nature of mutations. Work in these areas is complementary. Reports from some of the investigators who have utilized the irradiation service are summarized below.

The American elm is susceptible to Dutch elm disease. Because of this susceptibility many areas have lost these valued trees. Dr. F.W. Holmes (University of Massachusetts) has found some resistance to the disease in progeny from seed irradiated with thermal neutrons. The resistance may represent an inheritable recessive character. Cross-pollinations among resistant elms are planned in order to introduce the resistant genes into one population.

Verticillium wilt disease is a major problem in growing mint. The varieties of mint used for oil production seldom set seed. Thus improvement of the strains by standard breeding procedures is extremely difficult, since cross-pollination is involved. Dr. M.J. Murray and colleagues (A.M. Todd Company, Kalamazoo, Michigan) have obtained eight highly resistant strains from a hexaploid peppermint exposed to x rays and neutrons. The resistant strains have approximately the same quality and growth as the original.

A major objective of peach breeding is the development of very early-ripening, large-fruited, yellow-fleshed, freestone varieties. Prof. L.F. Hough and associates (Rutgers University) obtained a selection with these qualities and also an undesirable dominant gene for "blood"-red anthocyanin flesh color associated with very early ripening. Usual procedures failed to eliminate this associa-

tion. However, by irradiation of buds a variety was obtained that ripens almost as early as the original selection but does not have the undesirable flesh color.

Dr. J.B. Powell (U.S. Department of Agriculture, Coastal Plain Experiment Station, Tifton, Georgia) exposed pearl millet seeds to thermal neutrons, to the chemical mutagens ethyl methane-sulfonate and diethyl sulfate, and to the neutrons plus the mutagens. The combined treatment induced the highest mutation rate; however, thermal neutrons were more effective than the chemicals.

Photoperiodism and Photomorphogenesis

Photoperiodism and growth of leaf and stem can be controlled by low energies of red and far-red light that probably act through the chromoprotein photoreceptor phytochrome. A new phenomenon, apparent synthesis of phytochrome, was observed in seedlings. It occurs only when the phytochrome level has previously been greatly reduced by exposure of the tissues to red light. No evidence that this process involves actual synthesis of new phytochrome protein was obtained; it might represent the reverse of the well-known "destruction" brought about by red light. Both processes may well be minor structural modifications in the molecule, since photochemical reversibility is as yet the only criterion of assay.

Further study of the effect of continuous far-red illumination on phytochrome content confirmed previous indications that phytochrome transformations in monocot and dicot seedlings differ markedly. While continuous far-red illumination is known to cause rapid phytochrome destruction in monocot seedlings such as maize and oats, it is now clear that such illumination causes no loss whatever in seedlings of peas, beans, or mustard. This is consistent with the idea that the rapid reversion mechanism previously observed in dicots converts the small proportion of Pfr (the far-red-absorbing, labile form) produced under far-red illumination to the Pr form (red-absorbing, stable) before Pfr destruction can occur.

Continuing investigation of photoperiodic flowering response in *Lemna perpusilla* (duckweed) indicates that a far-red reversal of the effect of a red interruption of the dark period, previously unobtainable, occurs if the main light period is composed of blue rather than red or white light. Under these circumstances, far-red light itself is not totally inhibitory and can thus partially reverse

Figure 5. Apparent phytochrome synthesis in apical pea stem segments. The segments, taken from plants grown in the dark, were exposed to red light for 0.25 hr starting at times indicated by the arrows. The exposures were followed by decreases in phytochrome. The increases after the low level induced by four exposures may represent synthesis of the pigment.

the inhibitory effect of red light. The dependence of dark-period reversibility on the color of the main light period has not been reported previously for any plant.

The Fine Structure of Microtubules

Microtubules found in plant and animal cytoplasm are cylindrical structures some 240 Å in diameter and up to several microns in length. Before the degrees of homology between various arrays of microtubules found in plants cells, and between microtubules of plants and animals, can be established, greater knowledge of the fine structure of these elements will be required. For this purpose a procedure has been developed for discerning more structural details of microtubules of the plant cell cortex as seen in thin section. High-resolution electron micrographs of such microtubules are selected, prints are made on film base, and portions showing segments of microtubules are diffracted. The transforms are analyzed with a microdensitometer. Results show that subunits are spaced at 36-Å intervals along the vertical files,

Figure 6. Structural details of microtubules in the cortical cytoplasm of plant cells. Because the microtubules of plant cells resist isolation, a procedure was established for using thin sections in the determination of structural details. Steps in the procedure are illustrated in the figure: (1) An electron micrograph of the microtubules ($160,000\times$). The boxed areas were subjected to light diffraction analysis. (2) The light diffraction transform of the area in the double box in (1). (3) Microdensitometric readings of the transform. The peaks in the readings indicate a 36-Å spacing of subunits. The occurrence of the peak in opposite quadrants shows the lateral arrangement of particles to be spiral about the central axis.

with a lateral association describing a spiral about the central axis. This is in good agreement with findings of others for isolated and negatively stained microtubules from animal cells. Earlier attempts to compare microtubules were limited by inability to extract these elements from the plant cell cortex. The procedure described above provides a new method for making such comparisons. Results obtained thus far support the notion that microtubules in the plant cell cortex are homologous to some found in animal cells.

Bile Pigments of Algae

Algae contain pigments structurally related to those in bile. The "bile" pigments of algae serve as important photoreceptors in photosynthesis. In current work the blue pigment, phycocyanobilin, was separated from its protein, purified, and crystallized by methods developed for this purpose. The detailed structure of the pigment was elucidated by physical methods – nuclear-magnetic-resonance and high-resolution mass spectroscopy. The structure of phycocyanobilin is like that of mesobiliverdin except for the location of one double bond and a hydrogen. The same procedures should be of value for the study of pigments from bile. Phycoerythrobilin, a red pigment from algae, was also crystallized. Its structure is not yet known in detail, but it can be transformed chemically into phycocyanobilin. A phylogenetic study of phycocyanobilin revealed it to be the chromophoric group of three distinct chromoproteins from blue-green and red algae.

Energy Conversion in Isolated Spinach Chloroplasts

The mechanism of energy conversion in mitochondria and chloroplasts is currently the center of much attention and controversy. In these orga-

nelles substrate- or light-induced electron transfer is accompanied by movement of ions and phosphorylation. The question arises whether ion shifts and phosphorylation are separately related to electron transfer, or whether ion shifts are directly involved in phosphorylation. One hypothesis proposes ion shifts as critical for energy conversion, i.e., chemiosmotic coupling. Illumination of chloroplasts at pH 6 induces uptake of H^+ (hydrogen ions) from the medium and formation of adenosine triphosphate (ATP). Uptakes observed earlier were too low to account for the photophosphorylation and thus did not support the hypothesis. In present work, however, by use of a constant-flow apparatus which avoids the inherent lag in response of the glass electrode, uptakes of about $400 \mu\text{eq } H^+/\text{mg chlorophyll/hr}$ were obtained. Such uptakes are adequate for support of the observed phosphorylation if, as predicted by the hypothesis, two H^+ are transferred per ATP formed. The observed relationship between H^+ transferred and electron flow, $2 H^+/\text{electron}$, was high and in accord with the predicted relationship between H^+ and ATP.

Macromolecular Complex of Chlorophyll and Protein From Green Photosynthetic Bacteria

Further x-ray studies of bacteriochlorophyll-protein crystals have shown that the unit cell belongs to hexagonal space group $P6_3$ rather than monoclinic space group $P2_1$, as thought previously. The side of the hexagonal unit cell is $112.5 \pm 0.5 \text{ \AA}$ and the length $98.4 \pm 0.5 \text{ \AA}$. Six macromolecules (≈ 120 chlorophylls) occupy each unit cell. Some crystals were fixed (cross-linked) with glutaraldehyde, dehydrated, and embedded in an epoxy resin. Thin sections were cut either perpendicular or parallel to the crystal axis and examined in the electron microscope. Sections cut perpendicularly showed a pattern suggesting hexagonal packing in the plane of the section. Sections cut parallel to the crystal axis showed alternate light-dark striations parallel to the axis with a spacing of $100 \pm 20 \text{ \AA}$. The dark striations are thought to be stacks of positively stained macromolecules. The amino acid composition of crystalline material suggests 4 subunits (molecular weight, 37,000), 4 disulfide links, and 20 chlorophylls per macromolecule. The kinetics of magnesium removal from the chlorophyll in the complex at low pH show that the ≈ 20 chlorophylls vary in reactivity, presumably because some are better protected from attack by hydrogen ions than others.

Figure 7. Structure of phycocyanobilin. The pigment is found in certain algae, where it serves as photoreceptor in photosynthesis. It is related to pigments found in bile. Phycocyanobilin (a) differs from mesobiliverdin (b), the structure of which was known, in substituents on pyrrole ring A.

Figure 8. Crystals of bacteriochlorophyll-protein complex from *Chloropseudomonas ethylicum*. The crystals were obtained from solution of the complex in 1 M sodium chloride-10 mM phosphate, pH 7.8. The largest crystal is 0.13 mm long.

Cell Proliferation and Metabolism in Tissue

Proliferative cells in plant and other tissue are randomly distributed with respect to stages of the mitotic cycle. Current work indicates that the distribution of cells in nondividing but potentially proliferative tissue is nonrandom. In excised roots cultured under nonproliferative conditions most cells are retained in G_1 , the period of the mitotic cycle preceding DNA synthesis. The remainder of the cells are retained in G_2 , the period following synthesis. Cells of the radicle in germinating seed are similarly distributed within periods of the cycle. Retention of cells in G_1 or G_2 after irradiation enhances recovery of DNA synthesis in the first instance and mitosis in the second. This enhancement indicates repair of radiation injury in higher plants similar to that observed in bacteria.

GENERAL PHYSIOLOGY

Radiation-Induced Aging

Long after an animal is irradiated, effects appear which closely resemble the natural aging process. By use of a method developed earlier for estimating the frequency of somatic mutations in animals, a close parallel was shown to exist between chromosome stability and both natural and radiation-induced aging. This led to the somatic mutation theory of aging, for which evidence was accumulated steadily. However, some later findings were not consistent with the simple theory. Thus, a composite theory correlating most of the information on aging was propounded. The theory proposes that aging is due to a complex series of events, some of which are mutations, and each of which has a certain probability of occurrence.

Another method for estimating mutations in somatic cells was developed recently. It involves use of a strain of mouse with a very low spontaneous incidence of liver tumors. During the regeneration that follows administration of carbon tetrachloride, tumors develop in the liver provided that the appropriate mutation is present. By use of this method it was shown that once firmly established in a somatic cell a true mutation is not repaired. This is somewhat contrary to earlier results obtained by other methods which indicated slow repair of injured chromosomes. Apparently there are at least two repair processes, one acting on true mutations during the first few hours following induction, and another operating on chromosomes during periods

of months. These repair mechanisms are largely responsible for the maintenance of the integrity of genetic material in somatic cells and are thus very important factors in aging.

Synergism Between Irradiation and Thermal Burn

Earlier work demonstrated synergism between the effects of thermal burn (3rd degree, 15% body surface) and x-irradiation. This synergism is manifested in the rat by an increase in 3 to 8-day mortality, a time period characteristic for death from intestinal injury. Recent study of mucosa mass (nitrogen, water, and total solid content) at various times following irradiation and/or thermal burn indicated changes that more directly implicate the intestinal mucosa in the synergism. In this study, the combined injuries altered the initial severity of response less than the delay in onset of repair. Thus the synergism involves inhibition of cell renewal or interference with the differentiation of crypt cells and their progression to the villi. In either case, loss of integrity of the mucosa lining accounts for the intestinal syndrome. To test the alternatives a study of the cell population kinetics was initiated using tritiated thymidine to pulse-label DNA and autoradiography of Feulgen-stained crypt squashes and villi sections for identification of cellular elements. Preliminary results indicate that the combined injuries probably do not affect cell proliferation within the crypts, but rather the process by which the crypt cells restore the integrity of damaged and denuded villi.

Oxidation Rates of Metabolic Fuels

When a C^{14} -tagged metabolite is converted to CO_2 in the body of an experimental animal such as the dog, the $C^{14}O_2$ eliminated by respiration is delayed in appearance because it is dispersed in the relatively large pool of carbonate in the body. To correct for this in estimations of how much C^{14} -tagged metabolite is being converted to CO_2 , tagged $HC^{14}O_3^-$ is injected intravenously and the ensuing pattern of $C^{14}O_2$ expiration is determined. By appropriate calculation the observed pattern is converted into that which would be expected if the $C^{14}O_2$ were supplied to the blood at a constant rate and for infinite time prior to observation. The expected pattern is then used to interpret experiments in which major metabolites of circulating blood are presented to tissues for oxidation at a constant rate of C^{14} influx. In tests with glucose- C^{14} and palmitate- C^{14} , the $C^{14}O_2$ production

Figure 9. Metabolism of C^{14} -labeled glucose and palmitate. The curves indicate the ratio of the specific activity of expired carbon dioxide at a given time to the average for times from 180 to 320 min. The curve of HCO_3^- is that expected for $C^{14}O_2$ added to the pool of body bicarbonate at a constant rate. The differences between this ideal curve and the others indicate conversion of the glucose and palmitate into intermediates before the labeled carbon appears as CO_2 .

curves differed from that expected for bicarbonate. The production of $C^{14}O_2$ from glucose- C^{14} and palmitate- C^{14} increases steadily during a 3 to 5-hr period of continuous infusion. This means that significant amounts of C^{14} , in increasing quantity, arise from the oxidation of tagged metabolites derived from the glucose and palmitate. The conversion of glucose or palmitate to other tissue constituents fills up previously untagged sources of CO_2 with C^{14} . In addition, the early course of $C^{14}O_2$ production with palmitate indicates that, for this metabolite, maintenance of a constant C^{14} content in circulating blood does not ensure a constant flux of C^{14} into the metabolic pathways yielding CO_2 . An intracellular pool of lipid must fill up with C^{14} before a constant rate of $C^{14}O_2$ production is realized.

Free Porphyrin in Duck Tissues

Normal animal tissues contain free, i.e., non-heme, porphyrins. This is well known, although quantitative data are rather limited. The significance of the presence of such porphyrins in tissue is obscure. In present work the concentrations of protoporphyrin and coproporphyrin in tissues of the Pekin duck were determined to provide a basis from which inference about significance might be drawn

eventually. In order of decreasing concentration of protoporphyrin the tissues examined were erythrocytes, liver, gizzard, heart, intestine, kidney, spleen, skeletal muscle, brain, testes, and pancreas. The concentration in erythrocytes was roughly five times those in liver through spleen, and about 30 times those in the other tissues. The concentrations of coproporphyrin in erythrocytes, liver, gizzard, intestine, and spleen were roughly equal, about three times those in heart and kidney and five times those in other tissues. At present, explanation of the differences between tissues is not obvious. A slight decrease in the total porphyrin concentration of erythrocytes occurs 5 to 10 days after x-irradiation of the animal, presumably as a reflection of the decrease in reticulocytes. Preliminary tests also indicate a slight decrease in liver.

Tracers and Permeability Coefficients

The different magnitudes of permeability coefficients obtained by direct and tracer methods have been theoretically explained. Experimental tests of the general theory are desirable. The ratio of a direct to a tracer permeability coefficient is nearly equal to

$$(p_{\text{dir}}/R_{\text{trac}}) = (R_{00} + |R_{ij}|)/R_{00}, \quad (1)$$

in which R_{00} is a resistance coefficient appearing in force-flow relations of permeation of a component through a membrane and $|R_{ij}|$ is a resistance coefficient related to the self-diffusion of a component within a membrane.

If the general theory is correct, the magnitude of $R_{00} + |R_{ij}|$ is given by

$$R_{00} + |R_{ij}| = \frac{RT}{J_j} \ln \frac{\sigma_i^\beta}{\sigma_i^\alpha} \quad (2)$$

when a stationary state experiment is performed. This quantity becomes

$$R_{00} + |R_{ij}| = \frac{RT}{\ln(\Delta\sigma_i^{t_2}/\Delta\sigma_i^{t_1})} \left(\frac{1}{n_0^\alpha} + \frac{1}{n_0^\beta} \right) (t_2 - t_1) \quad (3)$$

in an exchange experiment. In Eq. (2) and (3), R is the gas constant, T is the temperature, σ_i is the specific activity of a tracer in a homogeneous phase, n_0 are the number of moles of the component in a phase, and t is a time at which samples

of the phases are taken for the determination of their specific activities. J is the flux of the substance through the membrane, and α and β designate the homogeneous phases in contact with the membrane. If the magnitudes of $R_{00} + |R_{ij}|$ for a given membrane obtained under the two experimental conditions agree, the theory can be said to be experimentally verified. Tests on H_2O and HDO were carried out with use of Millipore filters and cellophane as membranes.

The magnitude of $R_{00} + |R_{ij}|$ obtained in tests with Millipore filters was practically the same in the stationary state as in the exchange experiments, 5.5×10^4 ergs cm^2 sec $moles^{-1}$ for $0.3\text{-}\mu$ pore size and 6.1×10^{14} for the $0.45\text{-}\mu$ size. The magnitude for cellophane in an exchange experiment was 8.0×10^{14} . P_{dir}/P_{trac} was about 5×10^6 for the filters and 11 for cellophane. R_{00} was 1.1×10^8 for the filters and 7.1×10^{13} for cellophane. It is evident that $|R_{ij}|$ does not depend greatly upon the geometrical properties of a membrane, while R_{00} is much smaller for membranes with frank pores than for cellophane. The results reported demonstrate the validity of the theory.

MOLECULAR BIOLOGY

Genetic Transformation of *Pneumococcus*

To further characterize the molecular events involved when transforming DNA is introduced into pneumococcus, the fates of homologous and heterologous DNA were compared. By use of P^{32} -labeled donor DNA, it was found that DNA from an unrelated bacterium, *Escherichia coli*, is taken up by the cells as readily as pneumococcal DNA. Furthermore, the molecular state immediately after entry is the same for both heterologous and homologous DNA. In both cases about half of the introduced material is in the form of single-stranded DNA, identified by its banding behavior in cesium chloride density gradients. Also, in both cases some donor label appears in double-stranded DNA. The density of this double-stranded material is that of pneumococcal DNA, even when *E. coli* DNA is introduced. Thus, the labeled double-stranded DNA probably reflects the synthesis of recipient DNA from mononucleotides derived from donor DNA rather than the entrance of intact double-stranded DNA into the cell. The findings support the hypothesis that the initial products formed during entry of DNA are composed equally of single strands and mononucleotides and that the

processes involved are independent of genetic homology between donor and recipient.

The subsequent fates of homologous and heterologous DNA were found to differ markedly. Single strands of *E. coli* DNA tend to persist as such within the cell. Pneumococcal DNA strands, however, rapidly disappear, apparently by genetic recombination with homologous recipient DNA, since the recovery of recombinant DNA, measured by its transforming properties, corresponds in time to the depletion of single strands. The single strands of pneumococcal DNA initially present in recipient cells are incapable of transforming others (single-stranded DNA does not enter pneumococci). However, the strands are carriers of donor genetic information, since transforming material appears when the strands are annealed *in vitro* with genetically unmarked strands. Genetic recombination in pneumococcus thus appears to involve interaction of single-stranded donor DNA with homologous regions of recipient cell DNA.

Subunit Structure of *Salmonella* Histidinol Dehydrogenase

Histidinol dehydrogenase of *Salmonella typhimurium*, determined by the structural gene *hisD*, was crystallized in high yield from an operator constitutive strain of the organism. The *hisD* gene contains two rather discrete complementation units, which suggests that native histidinol dehydrogenase, of molecular weight 80,000 daltons, is composed of nonidentical subunits. Peptide maps of tryptic digests of the enzyme reveal about one-half of the number of peptide spots expected on the basis of the lysine and arginine content of the native enzyme. One μ mole of N-terminal serine, and no other amino acid, is released per 40 mg of cyanate-treated enzyme. Treatment with dinitrofluorobenzene also indicates the presence of N-terminal serine. One μ mole of C-terminal alanine, and no other amino acid, is released per 40 mg of enzyme by carboxypeptidase digestion and hydrazinolysis. Reduced alkylated material migrates on acrylamide gel electrophoresis as a single major band which cannot be dissociated into separable, more fundamental subunits by ion-exchange or gel-filtration chromatography in the presence of 8 *M* urea. It appears, therefore, that *Salmonella* histidinol dehydrogenase may be composed of two identical subunits each with a molecular weight of 40,000 daltons, despite the existence of two complementation groups in the *hisD* gene.

Conformational Changes in DNA

The manifold biological activities of DNA, the bearer of hereditary information, require it to interact specifically with itself and other molecules. For appreciation of these biological complexities, a thorough knowledge of the conformations and interactions of isolated DNA is necessary. Current work based on measurements of changes in sedimentation rate indicates the following: The conformations and interactions of single strands of DNA depend upon the solvent and temperature. High concentrations of sodium chloride and low temperatures favor folding of single strands upon themselves, whereas high temperatures, low salt concentrations, and extremes of acidity cause the molecules to unfold completely. At equivalent concentrations, magnesium chloride has a much greater effect on the folding of single strands than the sodium salt. Reconstitution of the native structure of DNA from its separated complementary strands depends upon the degree of folding of the single strands. For such reconstitution two conditions are necessary and sufficient: (1) the native structure must be stable, and (2) the single strands must be at least partially unfolded. Aggregation of the single strands occurs under conditions such that the strands are tightly folded.

Some Aspects of the Intracellular Development of Tiny Bacteriophages

In a continuing study of the replication of bacteriophage ϕ X174, experiments with an amber mutant of the phage, which does not lyse its restrictive host, revealed an additional infective component having a lighter buoyant density in cesium chloride than the mature phage particle. The light particle contains complete single-stranded DNA, but its protein coat is easily dissociated. This particle is present at all times following infection of a restrictive host and is predominant at early times after infection. It is present prior to lysis in cultures infected with wild-type phage, but not after lysis of cultures infected either with wild-type phage or with the amber mutant under permissive conditions. Results of pulse-labeling experiments support the conclusion that the light particle is an intermediate in the maturation of phage.

The replication of another tiny bacteriophage, originally isolated from *Salmonella*, is also under study. This bacteriophage, ϕ R, is closely related to ϕ X174: size and buoyant density in the chloride are the same, and the host range is qualitatively

similar. ϕ R also contains single-stranded DNA which is converted to double-stranded forms following infection of its host. Its pattern of replication, however, is host dependent. Several temperature-sensitive and amber mutants of ϕ R have been isolated which also show altered replicative processes. Study of the nature of these differences is continuing.

Pancreatic Enzymes

The polypeptide trypsin inhibitors in pancreas protect the acinar cell from autodigestion and also specifically inhibit many, but not all, of the trypsin-like enzymes that participate in blood clotting and the release of hypotensive peptides (bradykinin and kallidin). As a preliminary to investigation of their biological role and mechanism of interaction with proteolytic enzymes, study of the intracellular distribution and chemical structure of two such inhibitors was undertaken.

Previous work has shown that, although acid extracts of bovine pancreas contain two trypsin inhibitors, only one (the Kazal type), is present in the secretion. Recent examination of the intracellular distribution of inhibitors indicates that the Kazal type of inhibitor is present in the same concentration (relative to total protein) in a purified zymogen granule fraction as in pancreatic juice. The first phase in the determination of the amino acid sequence of the bovine inhibitor (Kazal type) was completed, namely the isolation of peptides formed by action of trypsin. The 10 peptides isolated, in 40% yield or more, account for all 56 amino acids present in the parent molecule.

Two related trypsin inhibitors (containing 56 and 52 amino acid residues) were isolated from porcine pancreatic juice. The bovine and larger porcine inhibitors differ moderately in amino acid composition: eight residues out of a total content of 56. Comparison of amino acid sequences and inhibitor properties of polypeptides from the two species should provide valuable information about their biological role and mechanism of action.

Structure and Function of Enzymes

In a continuing study of the relationship between structure and catalytic function in the enzyme trypsin, a chromatographic method was developed for the purification of the bovine enzyme and its derivatives. Use of the method revealed that activation of trypsinogen gives rise to a new form of trypsin with a single internal split as well as to the

single-chain, previously known form. The new form was found to be a prominent constituent in the best available preparations of the enzyme. The forms differ in relative amidase and esterase activities. A new reagent, *p*-nitrophenyl *p*-guanidinobenzoate, was synthesized for estimation of trypsin activity. Its use improves such estimation markedly.

With the aid of these new techniques, chemical modification studies of trypsin were continued. In the catalytic region of the active center, the substrate-derived alkylating agent, TLCK, was shown to combine with histidine-46, a position homologous to the histidine residue in chymotrypsin labeled by a similar approach. *p*-Guanidinophenacyl bromide and *p*-amidinophenacyl bromide were synthesized in the expectation that, like TLCK, they would be active-site directed agents. They were, in fact, found to inactivate trypsin stoichiometrically with substratelike behavior. However, a different site of attachment resulted; histidine was not affected. It was tentatively concluded that the active center serine was etherified and that very small differences in geometry determined the outcome.

Protein Structure

Interactions between amino acid side-chains largely determine the folding of the polypeptide backbone in enzymes and define patterns of specificity and mechanism of action. An understanding of the manner in which stable conformations of the side-chains in particular regions of the structure are developed is of considerable theoretical and practical interest. The problem requires a variety of approaches that include chemical modification of side-chains, physical or chemical perturbation of side-chain interactions at the enzyme surface, and examination of variations in structure among enzymes of the same specificity that derive from different biological sources.

As an example of the modification approach, kinetic studies may be mentioned in which the reaction of bovine pancreatic ribonuclease A with 4-fluoro-3-nitrobenzene sulfonic acid was investigated over a range of *pH* and temperature to obtain information concerning the structural environment of the side-chain of lysine-41. The products of the reaction had been identified previously, and relatively simple analytical procedures were auto-

mated for the determination of these products in the reaction mixture. It was found that the well-documented reactivity of lysine-41 must be determined by the electrostatic influence due to a proximal arginine side-chain (probably arginine-39), since the quantitative dependence of the reactivity on *pH* was due to a group with a $pK > 11$. Examination of the rates at high *pH*, moreover, revealed that a reversible structural change in the molecule disrupts the configuration responsible for the special reactivity of lysine-41. This structural change is characterized by an ionization constant of about 12 and leads to the normalization of the special reactivity at lysine-41. Finally, since the *pH*-independent rate constant for reaction at lysine-41 was also measured in the range from 4° to 65°C, it was possible to deduce that the ΔH for ionization of lysine-41 is essentially normal and that therefore the primary influence on this group is the electrostatic charge of an adjacent arginine residue.

Determination of Biological Structure by x-Ray Diffraction

Progress was made in the collection of data bearing on structure and in improvements of method. Reciprocal lattice photographs of glutaraldehyde-cross-linked crystals of a chlorophyll-protein complex have yielded accurate unit cell constants and a secure space group assignment ($P6_3$) from which the packing of the complex, and some restrictions on its shape, can be deduced. These are of particular interest because changes in the crystal's absorption spectrum upon illumination are virtually identical to those of the complex in solution. Some 20,000 reflections from modified chymotrypsin have been measured, and several thousand from possible isomorphs. Investigations of the latter are well under way.

Long-life cathodes of LaB₆-Re were perfected and routinely used in the rotating-anode x-ray generator. Their lifetimes are 50 to 70 hr rather than 4 to 8 hr, as for W-Th or W-Re cathodes, and stability of the x-ray output is much improved. A computer system for on-line diffractometer control and data processing, with full capability for background computation, has been installed. Extensive programming has been done both for on-line control and for subsequent computation.

Medical Research

In developing its research program, the Medical Department has several responsibilities. It has the broad responsibility to advance medical knowledge and the more specific responsibility to advance understanding of the effects of ionizing radiations in man. Some of the investigations are directed toward beneficial applications of these radiations and toward improvement of measures to prevent or counteract their detrimental effects. Other investigations are centered on elucidation of disease states and development of improved methods of diagnosis and therapy. Investigations in these two areas complement each other, since the study of radiation effects contributes to the understanding of diseases, and vice versa, yet the pace of progress in both is controlled by the advances in knowledge of the normal biological processes of man.

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 to exploit 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 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 organization 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

A Cell-Survival Model of Acute Hemopoietic Radiation Death in Mammals

Some mammalian species, such as mice and dogs, when given a suitably large dose of x or γ rays, typically die of hemopoietic failure. Such deaths occur during a relatively restricted, critical period (e.g., 10 to 15 days postirradiation in mice), and survival through this period is usually followed by recovery of the animal. Such survival presumably means, in cellular terms, that a sufficiently large number of the necessary type of differentiated, and hence functional, cells (in the case of the mouse, granulocytes) have been produced from a relatively few primitive hemopoietic cells which survived the irradiation and subsequently proliferated and differentiated. A quantitative model of radiation mortality can be based on these ideas if the following parameters and functions are specified: (a) the average number of surviving primitive cells, $m(D)$, as a function of dose D in the lethal range; (b) the distribution of actual numbers of cells corresponding to any given average number; and (c) the distribution function for cell multiplication describing fluctuations in the numbers of functional cells per primitive cell.

For the mouse there are sufficient data on which to base reasonably good assumptions for these functions and thus to derive predicted animal mortality curves which can be compared with experimental curves. Such curves are, in general, S-shaped and can be well fitted by the cumulative Gaussian distribution function, which then pro-

vides values of the mean dose, $\bar{D}$, and standard deviation, σ , characterizing the curve. To give a numerical example, typical values for inbred mice would be $\bar{D} = 700$ rads (x rays), and $\sigma = 56$ rads, with a ratio $\sigma/\bar{D}$ (a measure of the spread or shape of the curve) of 0.08. A corresponding cell-survival curve [for (a) above] would be

$$m(D) = m(\bar{D}) \cdot \exp[(\bar{D} - D)/D_0],$$

with $D_0 = 85$ rads. Thus, experimentally $\sigma = 0.66 D_0$ ($0.66 = 56/85$). The parameter σ given by the model varies directly with D_0 and inversely as the square root of $m(\bar{D})$; specifically, $\sigma > D_0 \sqrt{m(\bar{D})}$. Thus the experimental data can be fitted only if $m(\bar{D}) > 1/0.66^2$ or 2.3; i.e., the average number of surviving primitive cells at the mean lethal dose must exceed 2.3. This value was arrived at without considering the spreading effect of fluctuations in the multiplication factor, A . If $C(A)$ is the coefficient of variation of A , it can be shown that the above expression for σ must be multiplied by $\sqrt{1 + C^2(A)}$, which increases the minimum possible value of $m(\bar{D})$.

Thus far consideration has been given only to random processes which set a lower limit on the spread in a strictly homogeneous population. The effect of biological variability of parameters is to increase the spread further. For example, it can be shown that the coefficient of variation of D_0 , $C(D_0)$, must be less than the ratio $\sigma/\bar{D}$, in this example 0.08, for the experimental curve to be fitted.

As further radiobiological data become available, both here and elsewhere, it will be of interest to make further comparisons with this model.

Response of the Central Nervous System to Irradiation

A multidisciplinary approach involving several species was undertaken to study the effects of x-irradiation on the mammalian central nervous system. Parameters for evaluating the radiation effects include neurophysiological, as evidenced by changes in the electroencephalographic (EEG) patterns of partial-brain irradiated monkeys, and functional, as indicated by changes in learning ability of forebrain-irradiated rats.

Following a single exposure of 3500 rads of 250-kVp x rays to the right visual cortex (see Figure 1), *Macaca mulatta* monkeys begin to show alterations in the photoevoked EEG response as early as 24 hr postirradiation (see Figure 2). Measured by frequency analysis, these alterations are char-

acterized by a biphasic depression in amplitude of the EEG response on the irradiated side, with the early phase lasting from 24 hr to 18 weeks and the second phase beginning in the 25th week and lasting to the end of the 44-week observation period. An interim period of equilibrium depression on the irradiated and nonirradiated sides is seen in most animals between the 18th and 25th weeks. A second order of response is also seen in a number of irradiated animals beginning at approximately the 23rd week postirradiation and is characterized by inability to evoke a fixed-frequency photic response from the irradiated visual cortex. An overriding presence of high-amplitude low-frequency activity (delta and theta waves) characteristic of injured tissues is seen at this time.

Microscopic examination shows astrocytic proliferation and changes in microglia as early as the first week which become prominent by the fourth week. Golgi Cox preparations indicate a significant reduction in the dendritic plexus of the irradiated area as early as the fourth week postirradiation, which progresses in severity throughout the 44-week observation period. Other microscopic findings include focal inflammatory reactions at 4 and 10 weeks, hyperplasia of microglia with thickening and argyrophilia fragmentation and loss of secondary and tertiary processes at 12 weeks, and myelin degeneration with areas of frank necrosis at 28 and 44 weeks postirradiation. Differing prototypes of vascular reaction, of both degenerative and progressive character, have been observed. At the ultracellular level, electron microscopy reveals changes in vessel walls and their organelles. Among the latter, the lysosomes in particular show both qualitative and quantitative reactions. Variations in synaptic complexes are evident after the 12th week, with overt changes noted after the 28th week. After 28 weeks, groups of synapses surrounded by dense glial protofibrils of an astrocytic character are prominent. Evidence of tissue repair and some myelin reorganization are also observed.

Rats are capable of learning an alternating pattern of immediate and delayed reward; the greater the delay period, the earlier patterned running appears, i.e., fast running on immediately rewarded trials, and slow running on trials with delayed reinforcement.

The effect of radiation on the learning ability of Sprague-Dawley rats was studied in a control group and two experimental groups. Single doses of 2500 or 5000 rads of 250-kVp x rays limited to

the forebrain were administered to the experimental group. Training began 4 weeks postirradiation. Each rat received 10 training trials per day for 25 days, immediate reward being alternated with delayed reward. On odd-numbered trials each rat received a 60-sec delay of reward. Data indicate that ionizing radiation of the forebrain, at both radiation levels, significantly retarded the acquisition of an alternating pattern of

Figure 1. Animal secured in position under the x-ray machine in preparation for tangential beam irradiation of the right visual cortex of the occipital lobe. The outer of two head shields has been removed for easy visualization of the irradiation setup.

Figure 2. Graph showing mean response of the right (irradiated) and left (unirradiated) visual cortices as evoked by photic stimulation of the retina at a frequency of 10 cps.

immediate and delayed reward. Histologic findings give evidence of brain edema in white matter with small areas of infarction. Blood vessels showed modest adventitial hyperplasia and endothelial hypertrophy. Astrogliosis was somewhat more evident at 5000 than at 2500 rads. A few areas of frank necrosis were observed; neurons, in general, showed little evidence of alteration.

Lens Opacification: Effects of Monoenergetic Neutrons

The extreme sensitivity to radiation of the murine lens has been shown in earlier studies at Brookhaven by improved serial slit-lamp microscopic examination and scoring techniques to demonstrate minute lenticular opacities. Meaningful interpretation of the resultant data has become possible as a result of analytical methods developed by Harald H. Rossi (Research Collaborator, Columbia University).

Mice were exposed to graded doses of x rays delivered at 2 or 100 rads/min at each of two atmospheric conditions (100% oxygen at 3 atm pressure or 6% oxygen–94% nitrogen at 1 atm pressure). The resulting four series of dose groups are being examined serially for the development of minute lens opacities in both the anterior polar and posterior subcapsular regions. Findings to date include (1) no decrease in effectiveness of these hypoxic exposures compared with room-air exposures in previous experiments, (2) a twofold greater effectiveness of exposures under hyperbaric conditions compared with those made in hypoxia, and (3) evidence of a small dose-rate effect for the hyperbaric environment.

These results are compatible with the premise that the murine ocular lens is normally in a relatively hypoxic state and that oxygenation of this tissue can make it twice as sensitive to x rays. Under the latter condition, raising the irradiation dose rate causes a small further increase in the rate of opacification.

Study was continued of lens opacity induction in mice exposed to 0.5 to 6.4 rads of 0.43-MeV neutrons, 1.0 to 60.0 rads of 14-MeV neutrons, and 6 to 48 rads of 250-kVp x rays. The relative biological efficiency (RBE) of neutrons was dose dependent and rose from a value of 10 for 100 rads of neutrons to about 60 for 0.5 rad of neutrons. At lower dose rates the RBE may exceed 100.

To date the research Van de Graaff accelerator of the Physics Department has been used for the

production of monoenergetic neutrons. However, the Van de Graaff injector formerly used with the Brookhaven Cosmotron is being modified to allow intensive investigations of the role of radiation quality in determining the degree of biological effect. The program will be carried on jointly by Brookhaven National Laboratory and the Radiological Research Laboratory, College of Physicians and Surgeons, Columbia University. Phase I of the conversion from a pulsed to a dc beam operation has been initiated. The primary objective is to realize proton and deuteron currents of maximum reliability with optimum dc performance between 100 and 150 μ A.

Medical Studies of Marshall Islanders Accidentally Exposed to Radioactive Fallout in 1954

Since 1963 abnormalities of the thyroid gland have developed in 19 exposed Rongelap people, 17 with nodules and 2 with hypothyroidism. These abnormalities are believed to have resulted from the effect on the thyroid glands of radioactive iodines absorbed at the time of the fallout 13 years ago. In none of the unexposed children have such abnormalities developed. Of the children <10 years of age when exposed, 16 (84%) were in the group of 19 developing abnormalities; only 3 adults were involved. Nodules were excised from 3 cases in 1964, 3 in 1965, and 5 in 1966. In 10 of these 11 cases the nodules were found to be benign; a 40-yr-old woman had a cancer of the thyroid gland. At the time of the 1967 survey all were found to be in good condition, with no evidence of further abnormalities. However, one new case was observed during the 1967 survey. This case and one other previously observed are the only remaining cases with nodules. Surgical removal will depend on their response to thyroid hormone therapy.

The slight degree of retardation of growth previously noted in some of the exposed children appears now to be correlated with thyroid hypofunction. The response of these children to thyroid treatment is being closely observed, and preliminary evaluation of the data shows that in at least one case, that of a stunted boy, there has been a remarkable spurt in development.

Only a few other findings in the Marshallese appear to be related to their exposure. A slight lag in complete recovery of certain blood elements was noted during the first 10 years; a slight increase in miscarriages and stillbirths in exposed women was noted during the first 4 years; and there are

Figure 3. Ionization curves obtained from pulse-height spectra measured with a 1-g/cm² CsI(Tl) scintillator. The curve for π^+ mesons had to be extrapolated from 4 in. of absorber back to the beam entrance because of the presence of other positive particles (mainly protons) in the beam which adulterated the neck of the π^+ ionization curve. The measured ionization ratio peak/neck of the π^- curve is higher than the ratio for π^+ mesons, as expected, but lower than that for protons. The mean pulse height plotted for protons shows the leveling off at maximum value in a depth beyond the Bragg peak. The momentum spread of the beams was better than $\pm 1\%$.

some persisting residua of the beta burns of the skin, including pigment changes, scarring, and the development of nevi in the areas of the burns. No leukemia or radiation-induced cataracts have been seen.

Investigations of Beams of High Energy Protons and π^- Mesons

The objective of these experiments is to determine the characteristics of π^- mesons (negative pions) with respect to their application in biology and medicine. A parasitic, low-intensity, momentum-analyzed beam of the Cosmotron has been used. In order to study the characteristics of pions only, it was necessary to eliminate beam contamination by other particles. This can be achieved, to a very limited extent, by scattering processes; however, electronic techniques of discrimination are more effective. Thus it was possible to improve the $\pi/(\mu + e)$ ratio in the negative beam by applica-

tion of a Čerenkov counter. A considerable reduction of the μ -meson count was obtained. The electron background did not change drastically, but application of an anticoincidence counter in combination with the Čerenkov counter telescope made it possible to reduce this background to about 20%. Ionization curves measured with the modified apparatus (see Figure 3) showed considerable improvement in comparison with earlier results. The relative height of the Bragg ionization peak of negative pions was measured to be $2.4/2.1 = 1.14$ larger than the peak height for positive pions. It can be assumed with good reason that this is an effect of the dose contribution of heavily ionizing particles which are emitted in consequence of a capture of a π^- meson by one of the nuclei of the absorber material. The enlarged width of the π^- peak is caused by electron contamination of the beam, which also reduces the relative height of the peak. For 20% electrons in the unobstructed beam, a factor of about 1.25 is estimated. Applying this factor raises the top of the π^- Bragg peak almost to the top of the peak for protons. This is in good agreement with former estimates which indicated that, for practical purpose, the negative pion peak will not exceed the peak height of protons of the same range.

CLINICAL AND METABOLIC STUDIES

Trace Metals in Normalcy and in Selected Disease States

This work proceeds along two lines: (1) investigation of basic premises governing the metabolism of selected trace metals, and (2) determination of the pertinence of such studies in the pathogenesis and treatment of selected human diseases.

Dr. Lucille Hurley has discovered that when normal pregnant mice are made manganese deficient, they give birth to ataxic young. These mothers issue normal offspring only if they receive a manganese supplement prior to the 15th day of gestation. The British geneticist, Mary Lyon, developed a strain of mice called pallid, which spontaneously produce ataxic young. Dr. Hurley proved that Dr. Lyon's mice will give birth to normal offspring with normal otoliths provided that the pallid mothers get large excesses of manganese early in pregnancy. At Brookhaven the following findings have been made. Pallid mice have abnormally slow turnovers of Mn^{54} ; hence they conserve manganese. Neutron activation of tissues shows normal man-

ganese concentrations in the parenchymatous organs of the pallid mice, but abnormally low concentrations in all bones studied. The bones of these mice are small and therefore fragile. Pallid mice have difficulties in absorbing manganese. These findings are of interest because similar ataxia is beginning to be recognized in humans.

The enterohepatic circulation of manganese begins in a short segment of the intestine located at 10 cm distally to the pylorus and proceeds very rapidly. A method had to be developed for very rapid, accurate collections of bile samples. With this method pulses of manganese excreted into the bile were demonstrated after its absorption from the gut had been pulsed.

A manuscript on rheumatoid arthritis now in preparation reports the following: In a group of control patients with various diseases, manganese metabolism was quite similar from one person to the next as judged by concentrations of manganese in plasma and blood, total-body turnover of Mn^{54} , and regional turnovers of this isotope conducted over the liver, thyroid, head, and thigh. Administration of excess manganous sulfate increased turnover of the metal. One patient with hydralazine disease and 7 out of 8 patients with active rheumatoid arthritis showed abnormally slow turnovers of manganese. These slow turnovers were not due to classical manganese deficiency, since the arthritics had significantly elevated manganese concentrations in their erythrocytes. Therefore a deficiency affecting only some cellular sites was proposed. This defect of manganese metabolism ties in with defects in mucoprotein and mucopolysaccharide synthesis seen in both experimental manganese deficiency and human collagen disease. The slow turnovers were corrected when the disease was treated with prednisone. This effect of prednisone was direct rather than due to the increased food intake caused by the hormone.

To determine whether changes in manganese metabolism are linked to the therapeutic effects of amino acids on Parkinsonism, the studies of DL-dihydroxyphenylalanine (dopa) have been extended to additional amino acids. The only such amino acid for which an IND* number has been obtained to date from the Food and Drug Administration is L-dopa.

The effective dose of L-dopa in treating Parkinsonism appears to be about $\frac{1}{2}$ that of DL-dopa.

*IND=investigational new drug.

Gradually increasing doses of this amino acid have reversed the symptoms and signs of long-standing disease in 3 out of 10 patients with Parkinson's disease, while beneficial effects were induced in 10 out of 10 patients. In 2 of these individuals L-dopa probably was lifesaving. In 3 of these patients, the mental processes seem to have improved. In addition to these beneficial effects there have appeared in 5 of these patients involuntary athetoid movements involving various parts of the body in 2 cases and the jaw and tongue in 3. In another patient the granulocytes decreased from 5500/mm³ to 2200/mm³, but this was corrected without discontinuing therapy. Abrupt interruption of L-dopa administration is followed by very slow re-emergence of the Parkinsonian state. The reasons for this are being studied.

Clinical Research in Leukemia With Extracorporeal Irradiation of the Blood and Cell-Labeling Techniques

Treatment of adult patients with all types of leukemia by means of extracorporeal irradiation of the blood (ECIB) has continued, although emphasis has been placed upon the chronic leukemias. The technique involves the intermittent diversion of blood from the radial artery past a source of radiation via a semipermanent arteriovenous shunt. A new Co⁶⁰ irradiator designed to allow flexibility in the dose of irradiation delivered to the blood (transit dose) was put into operation.

The median survival time of 14 patients with acute myelocytic leukemia was found to be 8.0 months. Taking into account many variables, this median survival time is equivalent to those reported after intensive chemotherapy. In addition, there is an apparent correlation of increased survival time with transit doses >340 rads.

Ten patients with chronic lymphocytic leukemia have been treated with ECIB. In view of the long spontaneous survival time in this disease (10 to 20 years), it will take many years to evaluate the effect of ECIB upon survival; however, improvement is apparent in several cases. Cell-labeling studies utilizing H³-cytidine and Se⁷⁵-methionine have yielded data on the size of exchangeable lymphocyte pools; it appears to be equal to or greater than that of the circulating pool. The preceding studies in conjunction with ECIB are providing data for construction of a model of cell kinetics in chronic lymphocytic leukemia.

Intensive study of DNA synthesis time with tritiated thymidine in normal and leukemic individuals is continuing in an effort to characterize the variance of this essential datum and to resolve the differences between the estimate of 12 to 14 hr made here and that of others (6 or 20 hr). In the course of these studies a systematic evaluation is being made of the reliability of the double-labeling technique in measuring DNA synthesis time *in vitro* and *in vivo*.

Studies on Hypertension

Experimental hypertension, like hypertensive disease, is not a single entity but may be traced to a number of causative conditions or agents, alone or in combination. The individual response is modified by inherited constitutional factors. A picture is emerging which suggests that the genetic modifier is the same in most or all of the different varieties of hypertensive disease.

At Brookhaven two strains of rat have been developed by selective breeding. One strain (R) shows a high resistance to all tested methods of inducing experimental hypertension. The other strain (S) is so sensitive to hypertensinogenic stimuli that special precautions must be taken to prevent an apparently spontaneous development of the disease.

By the simple, nontraumatic procedure of adding 8% NaCl to the diet, the two strains can be separated. S-rats develop fatal hypertensive disease, R-rats remain unaffected. This outcome is predictable in the individual case if the pedigree is known. Except for the finding of enhanced vascular reactivity to vasopressor agents in the S group, attempts to find other parameters that have a predictive value have so far failed. Prior to development of the disease, equivalent results are obtained in both strains in studies of electrolyte metabolism and renal function, and so far no difference has been found in the serum components examined. In some studies group differences have been found, but the tests involved have no predictive value in the individual case.

Efforts have therefore been focused on definition of the genetic substrate. One question still unsettled for the rat as well as for man is whether there is a multifactorial inheritance. If the R vs S trait is due to a single gene, it is sex-influenced in the same fashion as baldness in humans: dominant in males, recessive in females. Another as yet un-

answered question is whether the genetic contribution of the sire has the greater influence.

Parabiosis of R and S animals has shown that the trait can be transmitted (see Figure 4). While parabiosis of genetically equivalent partners is of no consequence, R and S partners fed a salt-rich diet show an anomalous response; hypertension develops in the R animal while the S partner enjoys relative protection. A number of explanations could account for this finding, and additional studies are in progress to permit a selection among the hypotheses. The possibility currently being investigated is that S animals produce a soluble factor which sensitizes the body to hypertensinogenic stimuli from the environment. This factor is transmittable and changes the reaction pattern of resistant animals. Ablation and injection studies support this conjecture.

Tryptophan Metabolism in Disease

In studies with sensitive radioisotopic techniques in several human subjects, attempts were made to

Figure 4. Influence on blood pressure of parabiosis between rats. The broken lines represent idealized average blood pressures of large numbers of single S and R rats on 8% NaCl chow from both published and unpublished studies at Brookhaven. The change in response to NaCl effected by parabiosis between rats, one from each strain, is apparent. From the 2nd through the 12th week, the average blood pressure of the R parabionts was higher ($p < 0.05$) than that of their S partners at corresponding times. After the 12th week, average blood pressures in the two groups were not significantly different ($p > 0.05$).

study tryptophan metabolism under normal, non-loading conditions and to determine the differences in the metabolism of tryptophan under tracer and under loading conditions. The tracer doses used ranged from 17 to 78 mg, in contrast to the estimated dietary intake in these subjects of 900 to 1000 mg and the estimated average intake of tryptophan in the United States of about 1000 mg/day. The loading doses used were 1.0 and 2.0 g L-tryptophan, not large in comparison with the 5 and 10-g loads used in many studies. As shown in Figure 5, with the 1.0 and 2.0-g loads tested, appreciably more isotope was converted to respiratory CO_2 , urinary kynurenine, and the combined kynurenine and xanthurenic acid fraction. The more rapid appearance of C^{14} in the serum in patient MM-1 after loading and the correspondingly enhanced respiratory excretion rate of C^{14}O_2 suggest that the loading dose increased the absorption of isotope from the intestine and at the same time saturated other pathways of tryptophan utilization, which left more total isotope available to be metabolized to CO_2 . Adaptation of liver tryptophan pyrrolase activity, now documented in humans, is a possible explanation of the results observed in the loading experiments. That more tryptophan was shunted into the kynurenine-3-hydroxyanthranilic acid-acetate- CO_2 pathway was demonstrated by the 2 to 4-fold increase in the kynurenine- C^{14} activity in urine.

Administration of the tracer dose intravenously rather than orally resulted in only slightly higher C^{14}O_2 levels, which appeared earlier than when an oral tracer dose was given to the same patient.

Figure 5. Expiration of C^{14}O_2 by patients after oral administration of tracer doses of DL-tryptophan-2- C^{14} , with loads of L-tryptophan in two cases.

Methods of Extending and Improving Radiographic and Isotopic Diagnostic Techniques

The ideal physical properties of technetium-99m have made it very popular for clinical scintillation scanning. It is most often used as the pertechnetate for brain scanning. In this form the nuclide also localizes to a certain extent in the thyroid, salivary glands, and stomach. The degree of localization in the thyroid has been determined by scanning methods. Trapping of pertechnetate occurs extremely rapidly, with 0.5 to 4.0% of the administered dose normally in the thyroid by 10 to 20 min. The concentration in the thyroid is highly dependent upon the presence of thyroid-stimulating hormone and can be suppressed by administration of thyroid hormone or its analogues. Hyperthyroid individuals have been found to concentrate up to 30% of the administered dose in the thyroid. The accuracy of determination of thyroïdal overactivity by technetium uptake is as good as that by radioiodine uptake.

Preliminary studies with two forms of a technetium-sulfur colloid indicate some differences in relative marrow localization. Formation of the colloid by bubbling H₂S through the pertechnetate solution at a low pH appears to be more favorable for marrow studies than formation by the use of thiosulfate.

Technetium-labeled albumin has been used for cardiac and blood-pool scanning. In the macroaggregated form excellent lung scans have been obtained with a very high efficiency of labeling. The advantages of using technetium are the rapidity and high resolution obtainable.

A new compound of technetium, Tc-DTPA (diethylenetriaminepentaacetic acid) appears to have some advantages over pertechnetate for brain scanning. Preliminary studies indicate rapid excretion (90% in 2 hr) with consequent rapid reduction in the circulating level of radioactivity. There is no preferential localization in salivary glands, which eliminates interfering areas on the scans. Larger levels of activity can be administered because of a lower radiation dose to the patient. The rapid renal excretion indicates that this preparation may be useful in evaluating renal function.

Further work has been concerned with display of the information obtained from scanning. The loss of information that is theoretically possible with data blending, with a Gaussian light spot used for image formation, has been found to be negli-

gible when the proper combination of detector collimator and light spot are used. The resultant scans are much easier to interpret because of better recognition of the pattern of isotope distribution and the elimination of high-frequency "noise."

Kinetics of Calcium and Strontium Metabolism

In previous studies employing compartmental analysis of data derived from double tracer studies in elderly human subjects, slight differences were found in a number of parameters of skeletal metabolism calculated from Sr⁸⁵ data when compared with those derived from Ca⁴⁷ data. In a study of a uniform population of rats, in which the more precise techniques of the Berman program modified for the CDC 6600 computer were used, the skeletal uptake and turnover of Sr⁸⁵ was compared with that of Ca⁴⁷. Measurement of the whole-body retention of both tracers in a specially designed rat whole-body counter demonstrated that the absolute values obtained with the strontium kinetic data did not differ significantly from those obtained with calcium. Further, the whole-body turnover of bone-fixed strontium was not significantly different from that of calcium as measured by whole-body counting. The evidence supports the assumption that strontium is a reliable tracer of calcium in skeletal metabolism, at least over a 40-day period.

The same linear compartment model was used to describe the kinetics of strontium in the rat as a function of age. Nine groups of rats ranging from weanlings to rats over 1.5 years of age were included in the study. With Sr⁸⁵ as the tracer, the numerical solution of the parameters, compartment sizes, and transfer rates was performed on the CDC 6600 computer, with use of the Berman program. The fit of the experimental data (on plasma, urine, feces, and whole-body retention) to the model was unique and mathematically consistent.

The parameters measured, with the exception of urine, decreased as a function of age in the growing animals. The accretion rate of bone was found to be linearly related to the rate of increase in body weight and to the size of the total exchangeable calcium compartment. This study also demonstrated that the same model could be used, with the same degree of reliability, to fit data from both man and rats, which indicates a qualitative similarity in the skeletal dynamics of both animals.

The advantage of the digital computer analysis is that it affords a quantitative measure of the accuracy of the calculated parameters as well as objectivity and reproducibility.

Body burdens of Cs^{137} have been measured in a selected population of 10 adult staff members over the past 7 years. The mean Cs^{137} body burden showed an increase from 1962 to a peak in August 1964, followed by a gradual fall characterized by a half-time of 500 days. The level of Cs^{137} in the body appears to be correlated with the rate of fallout.

Computers

Most of the Medical Department's computer codes have been converted for use with the CDC 6600 computer rather than the IBM 7094. The Department's utilization of the central computing facilities involves the use of previously established codes, particularly those for multicompartment analysis, radiation dose in extracorporeal irradiation of blood, separation of carbon and tritium counts in double tracer experiments, and γ -ray spectrum analysis.

Among the newer codes is one developed for use in the analysis of electron paramagnetic resonance (EPR) spectra. In its present form this code calculates synthetic EPR spectra from input data, giving information about the numbers and types of splitting centers and their splitting constants. These spectra consist of a series of overlapping Gaussian and/or Lorentzian curves whose centers are located along an axis corresponding to the magnetic field strength in the apparatus. Either the absorption spectrum or one of its derivatives may be analyzed. The distribution and frequency of the centers are determined from the input data. Certain mechanical features of the apparatus, particularly the modulation amplitude, determine the resolution, expressed as the σ , or square root of the variance, for the kind of curve used. The final composite spectrum is obtained from linear combinations of the component curves superimposed on the line pattern, or "tree," for each contributory compound in the solution being analyzed.

At present visual comparisons are made between the synthetic and experimentally derived curves. Future plans involve automatic digitization of the data and fitting of the synthetic curves to the data.

Another set of codes has been developed in collaboration with Central Islip Hospital personnel

for use in classifying mental patients. Here the input data consist of a set of scores or ratings by one or more observers, and these are compared with established disease patterns.

A code developed by the Rand Company for calculating the effects of disturbances in the electrolyte pattern of the body has been adapted for execution on the CDC 6600. Certain values such as the electrolyte concentrations in the blood plasma and the gas composition of the breath are supplied as input data, and the code calculates the values to be expected in other parts of the body on the basis of equilibria dictated by the Gibbs free energy equation and by Donnan equilibrium rules.

NUCLEIC ACID STRUCTURE AND FUNCTION

Interaction of Daunomycin With DNA

Diffraction patterns from complexes of deoxyribonucleic acid (DNA) and Daunomycin (an antitumor antibiotic) with molar ratios of antibiotic to nucleotide ranging from 0.50 to 0.01 have been obtained for several different relative humidities of the fiber environment in the range 0 to 98%. In general, the pitch of the DNA-Daunomycin complex increases with the amount of the drug bound to DNA. Pitch values as high as 50 Å have been observed for the complex. For any one specimen, pitch varied little with the fiber environment. The increased pitch and decreased intermolecular separation of the DNA-Daunomycin complex as compared with native DNA is reminiscent of the changes in the DNA structure after complexing with proflavine and ethidium bromide. In these instances, it was suggested that the unsaturated triple-ring system of proflavine and ethidium bromide was inserted between successive base pairs of the DNA. The stacking and correct contact of base pairs in the DNA chain can only be attained with successive phosphate-phosphate separations along each chain close to the maximum value if the slack in the sugar-phosphate chain is taken up by rotating successive base pairs with respect to each other, i.e., by the molecule's becoming helical. It is this slack in the sugar-phosphate chain that allows insertion between successive base pairs of a planar group as long as its thickness does not exceed 3.8 Å. Present data on the DNA-Daunomycin complex suggest that the average degree of untwisting of the DNA helix per intercalated group is closer to 12° rather than the 45° proposed for DNA-proflavine. Although DNA model build-

ing of the DNA-Daunomycin complex is limited by the chemistry of the antibiotic, those features of the intercalation interaction that would be rather insensitive to these uncertainties have been determined. If the Daunomycin is orientated after intercalation so that the saturated ring of its chromophore is in the small groove of the DNA, the long axis of the chromophore is more nearly perpendicular than parallel to the base pairs above and below it. A rather more attractive arrangement from considerations of hydrophobic forces is possible if the saturated ring is in the large DNA groove.

Ribosomal RNA: Structure and Function

High molecular weight ribosomal ribonucleic acid (RNA) makes up $\approx 50\%$ of the weight of the ribosome and $\approx 80\%$ of total cellular RNA in animal tissues. Its function remains obscure, although several concepts have been presented. Since the ribosome plays a central role in protein synthesis, knowledge of the structure of its RNA is of major importance for understanding the molecular processes of protein synthesis. Studies have been concentrated on the primary structure of ribosomal RNA from liver.

The chain length of these molecules is several thousand nucleotides. To facilitate nucleotide composition and sequence analysis on these large polymers, fragments from partial ribonuclease (RNase) digests of high molecular RNA were isolated and analyzed. Ten to 15% of the RNA (a chain length of about 400 nucleotides) contains primarily 2 of the 4 major nucleotides. This segment of RNA contains 85% guanylic and cytidylic acids and is also the most resistant part of the RNA to degradation by pancreatic and T_1 RNases. A high degree of regularity in secondary structure is postulated for this fragment because of the nucleotide pairing and resistance to nuclease attack. The results show an unbalanced distribution of nucleotides in different regions of ribosomal RNA.

Satellite DNA

In the genome of chloroplast DNA at least two regions controlling replication and the light reactions of photosynthesis are extremely "mutable." Eleven isolated and characterized photosynthetic mutants of *Euglena gracilis*, regardless of mutagenic agent, appeared to be blocked at the same point in photosynthesis, either at the light reaction of

system II or just after it. All had reduced chlorophyll content and carotenoid differences.

Photoreactivation of chloroplast DNA is inhibited by red light. The effect is not on the photoreactivation process itself but probably involves control of replication of chloroplast DNA. Inhibiting chloroplast synthesis with ethionine has shown that the red light effect on photoreactivation is not caused by red-light induced synthesis of the chloroplast.

The drug nalidixic acid (NA) has been used to elucidate chloroplast DNA replication and to determine whether proplastid DNA differs from DNA of the chloroplast. NA specifically inhibits chloroplast replication in *Euglena*. Proplastids are far less sensitive to the drug; they also exhibit "recovery" – green colony formation by dark-grown cells is restored after long incubations in the drug. NA probably affects chloroplast DNA in a way similar to that in which it affects bacteria. In bacteria NA is bactericidal only if protein and RNA synthesis are allowed to continue. In *Euglena*, the effect of NA is greatly diminished if chloroplast synthesis is inhibited either by using ethionine or by placing cells in darkness.

ANTIGENS AND ANTIBODIES

Lymphocyte Transformation

Lymphocytes from a sensitized animal exposed to the homologous antigen *in vitro* or to a non-specific agent, e.g., phytohemagglutinin (PHA), transform into large, blastlike pyrinophilic cells. Along with this morphological change is a sudden upsurge in biochemical activity. Although the liver is the main site of mammalian glycoprotein synthesis, it has been shown for the first time that lymphoid tissue can also synthesize glycoprotein.

In liver, glucosamine-1- C^{14} is largely incorporated directly into glycoprotein, with only a small amount catabolized to glucose. Similarly, lymph-node lymphocytes transformed with PHA had a 4 to 10-fold increase in glucosamine incorporation into glycoproteins, while lymph-node lymphocytes transformed with homologous antigen had a 2 to 5-fold increase. Thymus lymphocytes transformed with PHA had a similar increase in glucosamine incorporation. However, thymus lymphocytes exposed to homologous antigen had no increase in glucosamine incorporation compared with controls. Thus glycoprotein is synthesized in transforming lymph-node or thymus lymphocytes.

Differential centrifugation has shown that the predominant site of glucosamine incorporation is the particulate portion of the cell, the major site being the desoxycholate soluble (i.e., membranous) portion of the microsome fraction. Incorporation of glucosamine into glycoproteins was seen after a 1-hr incubation of lymphocytes with PHA. The nearly linear incorporation of glucosamine as the amount of glucosamine was increased suggests that lymphocytes possess the same feedback mechanism of *de novo* glucosamine synthesis as mammalian liver.

Cytokinetics of Lymphoreticular Tissue During the Secondary Antibody Response

Proliferation of lymphoid cells becomes evident in lymph nodes regional to the site of a booster injection of tetanus toxoid. *De novo* formation and rapid growth of germinal centers were observed during secondary antitoxin responses. Emphasis was given to the cellular events occurring prior to and during the sharp rise in titer of serum antibody associated with the secondary response.

Tritium-labeled thymidine, cytidine, and DL-leucine were used in autoradiographic studies of the sequence of cellular events in popliteal lymph nodes. When cytidine- H^3 was given intravenously, an increase in the initial labeling intensity of a limited number of small lymphocytes (<1% of all lymphoid cells) was observed a few hours after the booster injection of antigen. The observed increase in labeling occurred prior to the appearance of large lymphoid cells heavily labeled with tritiated cytidine. Both changes largely reflect RNA synthesis, since a significant rise of initial labeling after injection of thymidine- H^3 was not evident at this time. These findings indicate an early increase in RNA synthesis in a fraction of lymphoid cells after the booster injection of antigen. This event is paralleled but not clearly preceded in time by an intensified incorporation of DL-leucine- H^3 and, to a lesser extent, cytidine- H^3 into at least a fraction of reticuloendothelial and histiocytic cells. Although there is evidence to indicate that antigen may be retained within the cytoplasm and/or at the cellular surface, it is not known what role these cells may have in initiating antibody synthesis.

A marked increase in the initial labeling index of large lymphoid cells after injection of thymidine- H^3 occurred during the second day after the booster injection of antigen. The observed increase was concomitant with the appearance of small

germinal centers and prior to the rise in titer of serum antibody. *De novo* formation and rapid growth of germinal centers occurred at a pace unknown for primary antibody responses. It seems most probable that the germinoblasts originate from previously sensitized cells. Since some germinal centers contain as many as 200 germinoblasts at the end of the second day, a generation time of ≈ 6 hr may be postulated if the germinal centers arise from single cells. Large plasmocytoid cells appear in greater numbers from day 3 on, concomitant with the rise in serum antibody. An increase in relative numbers of mature plasma cells occurred on day 5 and later, i.e., after the serum antibody started to rise. The maximum proliferative activity of germinal centers and plasmocytoid cells occurred on day 6 and gradually subsided.

Immunological Mechanisms Studied With Extracorporeal Irradiation of Lymph

Continuation of studies on the influence of extracorporeal irradiation of lymph (ECIL) upon skin allograft rejection has revealed that the obligatory anatomical pathway of immunologically competent lymphocytes (ICL's) is through the blood to the foreign skin graft. In an obscure manner the ICL's react with the graft to initiate the sequence of immunological activation. These cells exit from the graft through the efferent lymphatics, "home" upon the regional lymph nodes, transform, and proliferate. Between the 5th and 6th days after skin grafting the cells leave the lymph nodes exclusively through the efferent lymphatics, enter the blood, and return to attack the graft uniformly, causing rejection between 8 and 10 days after grafting. When it is feasible to irradiate the lymph with transit doses >1000 rads, rejection of the grafts is prolonged as long as ECIL is continued. When the transit dose is reduced to 350 rads, a sufficient number of cells survive to attack and reject the allografts. The radiation dose-effect curve of immunologically activated lymphocytes is being established.

With extracorporeal irradiation of thoracic duct lymph of calves, it has been possible to continuously destroy lymphocytes emerging from the regional lymph nodes draining skin allografts. In these animals the serum cytotoxic activity remains low as long as ECIL is continued. Upon termination of ECIL the cytotoxin levels increase, reaching peak activity about the time of graft rejection. Appropriate experiments have suggested that this

sequence of events is the result of the destruction of the sensitized lymphocytes responsible for the propagation of the antibody response throughout the body, and that graft rejection is not essential for the production of cytotoxin. It has been possible to sensitize an animal to the antigen (cytotoxinogen) responsible for cytotoxin production without producing allograft immunity.

Kidney perfusion experiments have indicated that cytotoxinogen is firmly fixed to the graft tissue and not readily released into the plasma. Evidence was obtained that viable radiosensitive lymphocytes recognize the antigen in transit through the kidney and become committed cells capable of transferring sensitivity to the recipients.

Studies on the Mode of Action of Phytohemagglutinin

Phytohemagglutinin (PHA) induces cell division in lymphocyte cultures. Successful production of radioactive PHA by extraction of the material from beans of plants grown in tritiated water has spurred the study of the obscure mechanism of action of this agent. By autoradiographic techniques the locus of the mitogenic substance has been followed in the lymphocytes of peripheral blood cultures. Preliminary studies reveal that most of the lymphocytes show a cytoplasmic label after 4 to 6 hr of culture. Labeling of the nucleus is noted later. By 2 to 3 days, labeling in the transformed large dividing blast cells is predominantly nuclear. Chromosome preparations of these dividing cells indicate that the chromosomes are labeled.

PROTEIN STRUCTURE AND FUNCTION

Synthesis of Insulin

The pancreatic protein insulin is the principal hormone that controls the metabolism of carbohydrates in animals and human beings. Lack of insulin is the cause of diabetes, a disease that affects $\approx 2\%$ of the population of the United States. Diabetics are kept alive by injection of insulin extracted from animals, e.g., cattle and sheep. Because such treatment may be accompanied by immunological reactions, studies were undertaken to develop human insulin, a protein most unlikely to cause immunological reactions in human beings, and to synthesize modified insulin molecules that lack the antigenic character of animal insulins. Studies at Brookhaven during the past several

years have led to the first synthesis, in highly purified form, of both human and sheep insulin. More recently, highly efficient methods were developed for the isolation of synthetic insulins in high yield. As a result, during the past several months it has become possible to produce four additional insulins, including a non-naturally occurring protein that is endowed with the full biological activity of the natural hormone (see Figure 6). The synthesis of analogues of insulin in an unlimited way is now possible and, it is hoped, will lead to a better understanding of the relationship between the chemical structure, biological activity, and antigenicity of this protein.

Bioenergetic Mechanisms Involving Free Radicals

Studies have been continued on the properties of free radicals that may be involved in many of the pathways of oxidative metabolism and in the chemical reactions giving rise to some of the effects

Figure 6. Five different crystalline insulins. No. V does not exist in nature.

of ionizing radiations on living systems. The stable forms of most organic compounds contain even numbers of electrons. Free radicals are half-oxidized or half-reduced forms possessing odd numbers of electrons. The magnetic moments associated with the spins of their unpaired electrons make free radicals paramagnetic. This allows detection and analysis by the sensitive and non-destructive method of electron paramagnetic resonance (EPR).

During the year successful development was achieved of a continuous-flow apparatus for EPR at 35 GHz (*Q*-band) (see Figure 7). This has made possible great savings in material consumption, since only 3 to 7% as much reactant is required as with the more conventional 9.5-GHz (*X*-band) EPR spectrometry. Enzymic and other biochemical studies that were previously impractical have become feasible. In one application enzymic oxidations of catecholamine hormones by peroxidase were examined, and the presence of free radical intermediate forms of epinephrine and norepinephrine was confirmed, in both the presence and the absence of reaction stimulators.

Experiments were carried out to assess chemical reactions that rapidly form hydroxyl radicals ($\text{OH}\cdot$) as radiomimetic models. Analysis of EPR

results on glycine, with use of rapid flow techniques (see Figure 8), revealed an unpaired electron distribution generally consistent with published results from ionizing irradiation of single crystals at 77° K. Additional spectra from glycine peptides obtained with the chemical model system and the new *Q*-band flow apparatus showed an odd-electron distribution about the peptide bond itself that tended to confirm previous hypotheses based on pulse radiolysis and product analysis of irradiated solutions. Results with other amino acids and peptides have revealed complicated reactions with complex EPR spectra whose analysis is not yet complete, although a recently developed computer program has been of great assistance.

A program has been written for the CDC 6600 computer which calculates synthetic EPR spectra and generates magnetic tape for curve tracing and labeling by the subsidiary CalComp 836 system (see Figure 9). Comparison of the synthetic curves with experimental data serves to guide and finally to verify analyses of the latter. The program offers unusual versatility and flexibility, permitting such options as a choice of Gaussian or Lorentzian curve shapes of predetermined line widths, for use separately or in combination; selection of absorption, first, or second derivative functions; and

Figure 7. Left: Reaction-mixer and microwave reflection cavity for *Q*-band (35 GHz) EPR of rapidly flowing aqueous solutions. The cavity, shown partially disassembled, contains a micromixer within the bottom knurled portion. Tubes for reacting solutions run through the shaft; and reaction products enter the detection region in a capillary 0.24 mm in i.d. Center: A similar mixer within a microwave cavity, in place between the poles of the electromagnet of an EPR spectrometer; a holder for field modulation coils obscures the cavity. Pressurized containers for reactant solutions (graduated glass cylinders) and the liquid valving system of the flow apparatus are in the foreground. Right: General view of the EPR spectrometer. A *Q*-band microwave bridge is in place over the magnet. To the left of the control console a part of the oscilloscopic recording equipment can be seen.

Figure 8. EPR spectra and analysis of a radiomimetic reaction (hydroxyl radical formation by $\text{Ti}^{+3}/\text{H}_2\text{O}_2$) in aqueous solution, studied with the BNL *Q*-band flow apparatus. Top: Representative spectra from hydroxyl radical attack upon glycine (left) and its tripeptide (right) at different pH's. Bottom: Analysis from these and similar spectra. The absolute values (a) of the derived spectral splitting constants are given in the center column. On the right are molecular diagrams denoting the corresponding distribution of unpaired electron (spin) density. In boldface are the symbols for atoms with detectable spin density (but EPR spectra do *not* directly reflect spin localization on carbon or oxygen).

combinations of more than one spectrum, allowance being made for an offset of spectral centers and for variations in relative intensity.

Other work on the free radical nature of melanins has supported the identification of several biological pigments as belonging to that class. Thus the so-called melanin of human brain *substantia nigra* displays EPR behavior characteristic of typical melanins composed of polymeric condensed ring systems containing scattered free radical centers. Similarly, the pigment component of lipofuscin, the "age pigment," is melanoid, and lipofuscin may be pictured as a melanolipid, rather than one of the more common melanoproteins. EPR studies on bovine eyes also appear to have confirmed that the pigment epithelium layer of the mammalian retina contains melanin. Experiments undertaken more recently with a combination of X-band and Q-band EPR have revealed new detail on the reactivity of melanins which may be of biological significance.

In related investigations free radical mechanisms are being studied in melanogenesis in model reactions. Other free radical steps have recently been elucidated in the photoreactions of the visual pigment rhodopsin and its carotenoid prosthetic groups, retinal and retinol.

Further Studies on Hydroxylysine Formation and Collagen Synthesis

During the past year the mechanism of hydroxylysine synthesis has been studied in greater detail. Starting with chick embryo tissue, methods were developed for rendering soluble both the bound form of lysine which can be hydroxylated (substrate) and the enzyme "lysine hydroxylase." The chemical nature of the substrate has not been determined, but it is of high molecular weight and may be the same collagen precursor that contains hydroxylatable proline. An assay for the enzyme

based on the conversion of C¹⁴-lysine to C¹⁴-hydroxylysine was developed. The hydroxylation was found to require the presence of both ferrous iron and ascorbic acid as well as α -ketoglutaric acid (these substances are also required for hydroxylation of proline). The enzyme has been purified about 30-fold by precipitation at pH 5 followed by DEAE-cellulose chromatography. Preliminary experiments show that considerable further purification is possible by hydroxylapatite chromatography, but the proper experimental conditions have yet to be developed.

In studies on the nature and function of the hydroxylysine groups it was found that a significant proportion of the hydroxylysine in collagen is bound in such a way as to render the hydroxy amino group $-\text{CH}(\text{OH})\cdot\text{CH}_2\text{NH}_2$ unreactive to alkaline periodate oxidation. To ascertain whether this "bound hydroxylysine" is involved in holding the α chains or higher aggregates together, the bound hydroxylysine in single α chains, in dimers composed of two chains, and in the higher aggregates is being studied. In a purified α_1 - α_2 dimer from rabbit skin 22% of the hydroxylysine was "bound," whereas in a neutral-salt extracted collagen in which most of the α chains are not yet covalently cross-linked, and in the highly cross-linked insoluble collagen, the value was 40%.

The carbohydrate content of the neutral-salt extracted collagen, calculated as disaccharide units, was equivalent to the bound hydroxylysine, but in the purified dimer and in the more aggregated insoluble collagen there were twice as many disaccharide units as there were bound hydroxylysine residues. Analyses of more collagens is necessary to permit construction of an adequate model, but it may be that the α chains are synthesized with carbohydrate bound to hydroxylysine and then aggregate into tropocollagen and higher aggregates through carbohydrate linkages not involving hydroxylysine.

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

Since achieving initial criticality on October 31, 1965, the High Flux Beam Research Reactor (HFBR) has produced 10,320 MWD of energy, with 8854 MWD produced during fiscal 1967.

The fuel cycle of the HFBR lasts ≈ 21 days, after which one-half of the core (14 fuel elements)

is removed, the remaining elements are moved to different positions, and a new half-core is installed. Twelve such cycles have been completed to date, ten of them during fiscal 1967. There were two unscheduled interruptions of continuous operation during these ten cycles, caused by brief failure of the instrument air supply and a severe snowstorm.

A minor cladding failure in one fuel element caused some fission product contamination of the primary system but did not constitute a difficult operating problem.

A number of difficulties experienced with the reactor and its associated equipment prior to start-up and after initial operation were corrected during the year, and other improvements will be made

Figure 1. Experimental floor of the HFBR. This reactor, with a maximum power of 40 MW and a maximum neutron flux of 1.6×10^{15} neutrons/cm²/sec, began supplying intense beams of neutrons for nuclear research early in 1966. Nine beam holes (2 providing dual beams) bring the neutrons out through the concrete biological shield (minimum thickness, 8 ft) to various experimental systems. Several neutron spectrometers and choppers can be seen installed at beam holes. All eight spectrometers, each available for a different experiment, are under the control of a digital computer with a 32,000-word memory, which operates all the neutron detectors and monitors. It also handles all computations and accumulates and processes the experimental data, which are stored on a magnetic drum so that any run may be recalled for re-examination.

in the near future. Several of the more important corrections are described below.

1. The rattling of tubes in primary heat exchangers was corrected by making changes in the secondary water pipes connected to the exchangers.

2. The rubber seals around the neck of the reactor vessel and primary coolant pipes, which provide the containment seal for low-pressure CO₂ around the primary vessel, deteriorated rapidly because of the presence of ozone in this area. These seals were replaced with metal seals.

3. The removal of a broken anticritical grid bar from the vessel eliminated a difficult noise problem. Plans were completed to detect and deal with any further breakage in this area, although a re-

currence is considered unlikely. The loss of a single bar is not expected to impair the usefulness or safety of the reactor.

4. Holdup tanks were installed in the return lines from the four in-core and core-edge irradiation thimbles. These tanks delay transit of the cooling water from the thimbles long enough to allow radioactivity from N¹⁶ to decay, and thus a serious radiation problem in the external piping is eliminated.

Among the planned improvements are

1. Improvements in the ventilation system to permit more extensive use of hoods within the building and more efficient elimination of the tritium associated with work on the process equipment.

2. Elimination of excessive noise in the experimental area caused by ventilation equipment.

3. Installation within the reactor vessel of flow reversal valves of an improved and more reliable design.

4. Improvements in the reactor containment system to more completely satisfy the AEC operating limits for the HFBR.

Experimental Use. Research work continued to increase at the horizontal beam holes of the HFBR during the year (see Figure 1.) At each of the two dual beam holes (H-4 and H-6), two spectrometers are in routine operation. In addition, at H-4 a third facility, a neutron beam pipe, is now in operation. Spectrometers at H-5, H-7,

Research budget	Usage, %	Use charges	
		Fiscal 1967	Fiscal 1966
Physics Department			
Neutron physics	44	\$ 511,044	\$ 502,992
Structure of solids	16	184,972	180,000
Neutron diffraction studies	12	140,028	140,004
Subtotal		\$ 836,044	\$ 822,996
Chemistry Department			
Nuclear structure and inorganic chemistry	28	324,978	320,004
Total	100	\$1,161,022	\$1,143,000

Figure 2. Distribution of use charges for the HFBR.

Figure 3. Costs associated with operating the HFBR.

and H-8 continue to operate on a routine basis. Both the fast and slow choppers (H-2 and H-9) had rotor bearing failures. The fast chopper is again in routine operation, and new bearings for the slow chopper are being tested. The out-of-pile shielding for H-1 and H-3 has been completed and fitted. The collimators and special shield plugs have been fabricated and will be installed soon. Installation of out-of-pile equipment is under way.

There have been no changes in the original assignments of the experimental holes reported last year.

Five of the seven vertical irradiation thimbles have been used for making irradiations during the past year. For the Materials Surveillance Experiment, several capsules were irradiated in the core-edge facility in V-13. A similar facility has been installed in one of the in-core thimbles, V-16, for the Reactor Fuel Element Cladding Development Experiment, and several capsules have been irradiated there.

A hydraulic "rabbit" (sample handling device) for reflector thimble V-12, a mechanical rabbit for either core-edge thimble V-14 or in-core thimble V-15, and a fast pneumatic rabbit for reflector thimble V-11 are being fabricated. Until these facilities are ready, samples are being irradiated in capsules that are vented to the reactor off-gas system through a 1/4-in.-diam aluminum tube. This tube is also used to insert and remove capsules from the irradiation thimbles.

The foil irradiation facility in reflector thimble V-10 has been used extensively to irradiate samples for the Chemistry, Medical, Nuclear Engineering, and Physics Departments.

The use of the HFBR is reflected in Figure 2, which indicates the relative and specific costs to the research budgets for the operation of this reactor. The various categories of operating cost are shown in Figure 3.

Brookhaven Graphite Research Reactor

The Brookhaven Graphite Research Reactor (BGRR) was operated on a 15-shift/week basis during the year, which reduced the duty cycle of the reactor to 55%. In spite of this reduction, which was dictated by economic factors, the dependability of the facility remained high, with the reactor on line at rated power 98.7% of scheduled operating time.

There were 10 scheduled shutdowns for service and maintenance of the reactor and experimental

equipment. Six unscheduled shutdowns occurred; three were due to interruptions in incoming electrical power, one to instrument malfunction, and two to snowstorms.

The graphite structure was annealed seven times during the year with use of standard approved procedures. The results of the graphite annealing program continue to be favorable, as indicated by periodic measurements of net vertical displacement of the structure and of the width of the central air gap.

The over-all cost of operating the BGRR decreased substantially during the year as a result of the reduced duty cycle. A further reduction in the duty cycle is scheduled for fiscal 1968. (See Figure 4.)

Utilization. The use of the BGRR and associated charges for the last three years are summarized in Table 1. Work conducted at the BGRR by the various BNL Departments is described in other sections of this report. Research conducted by outside users is briefly described below.

1. Columbia University. In a cooperative program with the BNL Physics Department, the following investigations were made with use of the Columbia single-crystal spectrometer at experimental hole W-31 and the collimated beam at hole W-15: studies of molecular motions in liquid and solid methane and in different configurations of hexamethylbenzene; scattering of subthermal neutrons resulting from the motion of NH_4^+ ions in $(\text{NH}_4)_2\text{SiF}_6$ and $(\text{NH}_4)_2\text{S}_2\text{O}_8$ and of CH_3 groups in $(\text{CH}_3)_2\text{SnF}_6$; and study of mass distributions of fission fragments from spontaneous and induced fission of compound nucleus Pu^{240} .

2. Naval Ordnance Laboratory. In cooperation with the Solid State Division of the BNL Physics Department diffraction studies were made by using single crystals and a polarized beam of neutrons. In addition, powdered magnetic materials were studied with the use of a powder diffractometer.

Medical Research Reactor

The Medical Research Reactor (MRR) was operated on 172 occasions during the year and 482,649 kWh of operation were accumulated. The total integrated energy produced to date is 3,813,403 kWh. The use of the reactor since it became operational is plotted in Figure 5.

Experimental programs conducted during the year involved the determination of trace elements in tissue by activation analysis; the application of

Figure 4. Costs associated with operating the BGRR.

Figure 5. Use of the MRR.

Table 1

Summary of Reactor Use Charges

[illegible]

neutron radiography to biological materials; investigation of the cellular distribution of B^{10} in tissue by neutron autoradiographic techniques; investigation of linear energy transfer (LET) distribution in a mixed radiation field; activation of foils for calibration purposes; investigation of the efficacy of the $B^{10}(n,\gamma)Li^7$ reaction in treatment of eye tumors in rabbits; neutron flux density measurements in a mock-up of a thermal column, in connection with design studies for a pulsed reactor; the production of Gr^{51} for turnover studies in rats; and investigation of gadolinium oxide implants in conjunction with neutron irradiation, for possible use in cancer therapy.

In addition, the reactor was operated in connection with the training program for Health Physics Fellows during the summer of 1966 as part of the annual summer student program.

Two unscheduled shutdowns of the reactor occurred during the year. The first was caused by failure of a scram relay on July 26, 1966; the second, by inadvertent actuation of a manual trip by a visitor.

A piece of graphite from the center experimental hole was annealed in the MRR annealing oven during August. No energy release was evident. This piece of graphite is thought to be a good representative sample of the graphite reflector in the volume of highest neutron flux.

The method of incident damper actuation was changed during the year; instead of an air-operated piston, a weighted lever is used. The new system is fail-safe, closing on loss of air pressure or electricity, or when the incident controller is actually tripped.

IRRADIATION SERVICES AND ISOTOPE PRODUCTION

Table 2 presents a summary of the volume and income involved in providing services to outside organizations during the past three years. Both the volume and income from these services decreased by almost 60% from last year as a result of the AEC's policy of noncompetition and the increased availability of similar services commercially. With the curtailment scheduled for BGRR operations in the next fiscal year, the decrease is expected to continue.

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, 292 purchase orders were placed for radioisotopes, 42 for stable isotopes, and 38 for special materials. Against these orders, ≈ 442 shipments were received and processed. The totals for orders placed and shipments received were essentially the same as those for the previous fiscal year. Of the orders placed, 38% were for the Medical Department, 17% for Biology, 17% for Nuclear Engineering, 13% for Chemistry, 13% for Physics, and 2% 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

Table 2

Summary of Services to Outside Users
(Handling and Other Charges Included)

	Fiscal 1967		Fiscal 1966		Fiscal 1965	
	Number	Volume, \$	Number	Volume, \$	Number	Volume, \$
Reactor irradiations	237	19,484	350	26,139	291	39,200
Processed radioisotopes	269	51,080	868	135,485	854	124,472
Co ⁶⁰ sources	3	*	6	*	1	4,317
Cyclotron irradiations	0	0	10	2,889	18	4,515
Total	509	70,564	1,234	164,513	1,164	172,504

* AEC transfers - Co⁶⁰ not produced by Brookhaven.

Table 3

Source and Special Nuclear Materials on Hand
at End of Year (in kilograms)

	Fiscal year		
	1967	1966	1965
Station BZA			
Natural uranium	505	526	558
Depleted uranium	23,144	23,219	756
U ²³⁵ > 75%	633	575	288
U ²³⁵ < 75%	3,898	3,878	3,896
U ²³³	23	23	23
Pu ²³⁹	59	57	52
Thorium	820	825	854
Heavy water	53,959	53,190	54,577
Station BZB (Graphite Reactor Fuel)			
U ²³⁵ > 75%	82	79	83
Station BZC (Medical Reactor Fuel)			
U ²³⁵ > 75%	3	3	3

negotiations for the loan of valuable isotopes. The number of radium sources at Brookhaven has remained at 38, with a total activity of 5.86 curies and a value of $\approx$ \$39,500. The inventory of purchased stable isotopes valued at \$41,262 showed a slight decrease from last year's \$42,426, since consumption (\$9544) exceeded the cost of purchases (\$8323). The stable isotopes on loan decreased from 46 to 22 in number but increased in value from \$487,000 to \$798,150, exclusive of five special samples valued at about \$666,000.

Source and Special Nuclear Material Accountability

In Table 3 a 3-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 current inventory of SS materials represents a value in the range of \$15 million. The increase of about \$500,000 over last year is accounted for by fuel elements for the BGRR and HFBR and an increase in the IAEA "substitution bank" of plutonium from 1 to 3 kg.

Sylvania Electric Products, Inc., completed delivery of 916 BGRR fuel elements under last year's contract. A new contract was sent out for bids for delivery of additional BGRR fuel elements during fiscal 1968, but no contract was placed because of the reduction anticipated in fuel requirements at

Table 4

Distribution of Exposures of Individuals Receiving
Regular Personnel Monitoring Service

Exposure index range*	Calendar 1966	Calendar 1965
0.00-0.49	2719	2795
0.50-0.99	204	161
1.00-1.49	74	73
1.50-1.99	63	32
2.00-2.49	40	14
2.50-2.99	25	5
3.00-3.49	22	6
3.50-3.99	13	0
4.00-4.49	26	1
4.50-4.99	4	1
5.00 and over	0	0
Total	3190	3088

*Exposure index = $\frac{1}{2}$ of β exposure in rads + γ exposure in R + neutron exposure in Rem.

the reduced level of BGRR operation planned for next year. A contract was placed with the United Nuclear Corporation for delivery of 84 HFBR fuel elements during fiscal 1967 and 112 in fiscal 1968. Included is an option for 112 HFBR fuel elements for the following fiscal year.

Only two visits were made by inspectors from the International Atomic Energy Agency (IAEA) under the extended Four Reactors Agreement with the U.S. Government. The first visit, on October 10, 1966, constituted the eleventh inspection and was made by Mr. Yuzuru Motoda and Mr. J. Champion. The second visit, on February 29, 1967, constituted the twelfth inspection and was made by Mr. Yuzuru Motoda. These inspections involved auditing of the SS materials inventories for the BGRR and the associated accounting and operating records for evidence of diversion, and a review of facility usage in terms of peaceful purposes. The results of both inspections were satisfactory.

The annual audit of SS materials at Brookhaven and the associated accounting records and procedures was performed by the Brookhaven AEC Operations Office. In continuation of the recommendations of this and previous audits, SS material consisting of 32 kg of natural uranium, 40 kg of depleted uranium, and 5 kg of thorium was removed from inventory through waste disposal. In addition, about 1.5 kg of uranium enriched in

U²³⁵ as scrap was sent to Nuclear Fuels Services, Inc., for recovery.

As part of an AEC training program in SS materials accountability, Mr. Ichiro Hiramatsu of Japan spent several days at Brookhaven as a trainee.

HEALTH PHYSICS

The major radiation safety problem during fiscal 1967 has been control of exposures at the Alternating Gradient Synchrotron (AGS). The exposures have been primarily to γ and β radiation during shutdowns, several of which have been due to failure of machine components. To accomplish necessary maintenance and repair work in the presence of high radiation levels, it has been necessary to rigidly monitor and control the exposures of several hundred individuals on a day-by-day basis. Some reduction in exposures has been effected in recent months as a result of strenuous efforts by the AGS Operations Division.

Tritium levels at the HFBR have increased gradually, as was anticipated, and exposure control arrangements have been elaborated. The heavy water used for cooling experimental facilities has been especially bothersome in this connection. The problem is made quite difficult by the limited ventilation provided for the containment shell, which contains extensive work areas. Arrangements have been made to add records of whole-body exposures due to tritium, derived from urinalyses, to the x- γ -n exposure records kept by the Personnel Monitoring Group.

Synchrotron Monitoring and Dosimetry

Extensive measurements of radiation levels at various depths in the AGS shield were made in cooperation with an AGS group responsible for designing the additional shielding required for the AGS conversion. The in-ring and area-monitoring equipment mentioned last year has been designed. A number of units have been fabricated and placed in service.

A new system for day-by-day monitoring of personnel exposures, utilizing thermoluminescent dosimeters, has been established. A computer program has been written to keep track of integrated exposures and to normalize the record to film dosimeter results obtained by the Personnel Monitoring Group. The thermoluminescent dosimeters will be supplemented by self-reading pocket chambers where hour-by-hour exposure control is required.

Personnel Monitoring

Personnel monitoring service was provided for 3190 individuals during calendar year 1966, a 3% increase over 1965. Film dosimeters were provided for ≈ 6700 visitors. The distribution of exposures for the 3190 persons regularly monitored is shown in Table 4. The maximum single acute exposure was 1.33 Rem. All exposures were < 3 Rem per 13-wk period, and in no case was the prescribed limit on integrated exposure exceeded. However, as shown in Table 4, there was a substantial increase in exposures in the higher ranges, with 130 individuals receiving 2 Rem or more during 1966 as compared with only 27 the previous year. Most of this increase resulted from exposures received in connection with operation of the AGS.

Radioactive Waste Disposal and Reclamation

Routine testing of the efficiency of filter units throughout the Laboratory was continued with use of the DOP method. In addition, a fluorescent aerosol and uv light are being used to locate leaks.

Reclamation of contaminated equipment continues to be a highly profitable operation. A vapor-blast facility has been placed in service and is proving to be very useful for cleaning small objects with jets of steam, abrasive, and compressed air.

Data relating to the liquid waste system are presented in Table 5. The amount of gross beta activity leaving the site in the stream to which the effluent is discharged totaled 48.2 mCi during the fiscal year, and the average concentration was 4.60×10^{-8} $\mu\text{Ci/cc}$, which is 4.3% of the applicable AEC standard. The activity in the cooling-air effluent from the BGRR stack was relatively constant, with an average discharge rate of 10,300 Ci of Ar⁴¹, 0.003 Ci of I¹³¹, and 0.073 Ci of H³ per day.

Steel tanks are now being used to package concrete made from the radioactive slurry produced by the liquid waste evaporator. They replace the concrete vaults used previously and eliminate concern for possible leaching of activity by rain. The change has been possible because of the reduced level of activity in the slurry.

Environmental Monitoring

A monitor has been developed that is capable of measuring Ar⁴¹ concentrations of 2×10^{-9} $\mu\text{Ci/cc}$ at the 95% confidence level with a time constant of < 1 min. It consists of a pressure vessel containing a

Table 5
Summary of Liquid Waste Data

	Fiscal 1967	Fiscal 1966
Input to filter beds, gal/day	973,300	950,600
Output from filter beds, gal/day	749,400	720,100
Net loss in filter beds, %	21.5	24.3
Stream above discharge point, gal/day	20,200	8,450
Stream at site boundary, gal/day	761,500	783,300
Rainfall, in./mo	4.1	2.8
	Gross beta	Tritium
Activity concentration at input to filter beds, Ci/cc	6.1×10^{-8}	8.0×10^{-6}
Activity concentration at output from filter beds, Ci/cc	4.8×10^{-8}	6.5×10^{-6}
Activity concentration at site boundary, Ci/cc	4.6×10^{-8}	6.3×10^{-6}
Activity at input to filter beds, mCi/mo	6.8	880
Activity at output from filter beds, mCi/mo	4.2	560
Activity at site boundary, mCi/mo	4.0	550

Figures are averages for each fiscal year.

2.4-liter beta detector composed of sheets of plastic scintillator. Air compressed to 120 lb/in.² is passed between the scintillator sheets. Beta particles from Ar⁴¹ are counted by a 5-in. photomultiplier tube. The monitor is being used in conjunction with meteorological instrumentation to check the accuracy of existing atmospheric diffusion equations. It is especially valuable for measurements beyond a few kilometers and for studies of the short-term fluctuations that occur in atmospheric dispersion at ground level.

During fiscal 1967 the highest external radiation level at the site boundary occurred at a point north of the gamma forest source and averaged 4.29 mR/wk. This may be broken down into three components of 1.93, 0.78, and 1.58 mR/wk due to background, Ar⁴¹ from the BGRR, and the forest source, respectively. The permissible level is 500 mR/yr, or an average of 10 mR/wk. Samples of air particulates, including both longer-lived natural and fallout isotopes, averaged 0.211 pCi/m³ of gross beta activity. The average activity in precipitation was 28.6 nCi/m²/mo as compared with 7.1 nCi/m²/mo last year. The increase was due mostly to heavy rainout of tropospheric activity, amounting to 269 nCi/m², during January 1967.

Laboratory Safety

For the third consecutive calendar year, the injury frequency rate at BNL remained below 3.00 injuries per million man-hours worked. The 1966

rate of 2.12 is the lowest in BNL history. The cost for New York State workmen's compensation benefits (borne by the Laboratory) dropped to 15¢ per \$100 of payroll.

Fire and property damage losses continue at a minimum, the 1966 total being \$27,131, of which \$4631 was from fire. Included in the total were a hydrogen-air explosion in a cryogenic purifier and a small alkali-metal fire. Neither incident involved any injuries.

During fiscal 1967 considerable activity centered on the AEC-sponsored Accelerator Safety Committee, with attention focused on hydrogen explosion prevention. BNL has four representatives on this 21-man committee. The committee met at Brookhaven in October 1966 and prepared the final draft of its guide, which is now being circulated. In addition, an AEC Electrical Safety Committee has been formed; it includes an electrical engineer and a special hazards engineer from Brookhaven.

The Laboratory's program for emergency breathing apparatus has been reorganized, and systematic inspection, maintenance, and training procedures have been instituted. About 150 of these units are distributed about the Laboratory for use if building occupants have to enter a noxious atmosphere in an emergency for rescue or other vital functions.

A comprehensive review was made of fire protection for BNL reactor facilities and recommen-

dations were submitted. Additional safeguards already installed include two large, dry-chemical hose stations at the HFBR where a potential paraffin fire hazard exists.

The preparation and issue of Fire and Safety Standards continues with the issue of No. 7, Piping and Equipment Identification; No. 8, Stairs, Ramps, Ladders, and Floors; and a revision of No. 1, Automatic Fire Alarm Systems.

The major function of personnel in the Safety Services Office continues to be that of providing consultant services to the various departments and experimenters. Routine "program" activities are limited to accident investigation and safety inspections.

MECHANICAL ENGINEERING

During the past year the 191 members of the Mechanical Engineering Division were assigned as indicated in Table 6.

In the Nuclear Engineering Department, members of the Division have continued to provide engineering, design, procurement, and construction assistance for the HFBR. With full power operation of the HFBR, excessive tube vibration was discovered in the primary coolers. It was suppressed after extensive changes had been made in the secondary water flow through the coolers. Most of the work was performed during shut-downs to minimize interference with the experiments. Since a leak in the tube side of the primary coolers will contaminate the cooling-tower water system with tritium, a holdup tank will be installed to minimize the effect of such a leak. This vessel will be capable of storing the entire volume of the cooling-tower water system. The preliminary and detailed design inside the HFBR building is being done, and in addition support is being given to the architect-engineer on the entire project.

For the Reactor Physics Division, a fast source assembly utilizing a split core with one movable table has been designed and is nearing completion. A plutonium exponential experiment with a Pu-Al fuel lattice has been designed, as well as a pulsed-reactor critical assembly with a split core and one movable table and a mock sodium coolant to study the physics of fast reactor assemblies. A design study was prepared for a critical experiment that could provide for a wide range of fuel-to-sodium ratios and temperatures.

For the Radiation Division, a recessed γ -cell facility was put into service and the conveyor in

Table 6

Assignment of Mechanical Engineering Division
Personnel as of June 30, 1967

	Engi- neers	Designers and draftsman	Secretarial and clerical
Accelerators			
Advanced accelerator development	3	1	
AGS	9	22	1
AGS conversion			
Magnet ring	9	8	
Linear accelerator	5	10	
Experimental planning and support			
Floor operations	7	2	
Cryogenics and design	9	8	
Administration	1		1
Central Design	1	7	1
Chemistry	1		
Nuclear Engineering	6	17	
Physics			
Bubble chambers	15	17	
General	11	18	
Safety	1		
Total	78	110	3

Total personnel - 191

the High Intensity Radiation Development Laboratory was converted from 1-pass, intermittent-type operation to 1-pass, continuous-flow operation. A portable Cs^{137} irradiator was designed for the AEC; it is a self-contained lead-shielded device weighing ≈ 18 tons and occupying 300 ft³ of space. This device utilizes the BNL patented moving source principal in which the source moves from its storage cask into the irradiation chamber and back with each radiation cycle. Thus the need for a package carrier system, with its size limitations, is eliminated.

A marine irradiator capable of exposing large living fish to radiation from a Co^{60} source was designed and loaded for the Medical Department. Work on the Mark III standard bonded Co^{60} irradiation source has progressed to the stage of procuring 60 units. These have the same exterior dimensions as the Mark II source, but contain 68 grams of Co^{60} instead of 52, and the thickness of the steel cladding is 10 mils rather than 15.

For the Heat Transfer Group three test sections were designed to obtain liquid-metal heat transfer

data. The preliminary design of the condensing potassium heat transfer facility was completed, and procurement and fabrication have begun. In addition, design work was begun on the conversion of the forced-convection single-phase sodium potassium loop to a multipurpose sodium heat transfer loop.

Three forced-convection sodium loops were designed for the Metallurgy and Materials Science Division. Two of these, rated at 10 gal/min and 1500°F, are to be used for testing possible fast reactor materials. The third is an isothermal 1000°F, 6-gal/min analytical facility that will provide a source of controlled purity samples and will be used for sampling technique evaluations and as a test stand for instrumentation. An engineering proposal was prepared for a hydrogen storage system for use with an internal combustion engine or a fuel cell in work on the reduction of air pollution from automobiles.

In the Physics Department the design of experimental apparatus for the HFBR was the main concern. Experimental accessories such as a variable collimator system, counter shield, beam-pipe spectrometer, and triple-axis assemblies have been completed for the US-1 spectrometers installed in experimental beam holes H-4 through H-8. In addition, a neutron electron moment apparatus was designed and put into operation in beam hole H-8 as part of an experiment to observe a dipole moment.

Installation of both fast and slow neutron choppers was completed, and both systems are now in partial operation. The fast neutron chopper has been in continuous operation at speeds of only 10,000 rpm because of bearing problems. The slow neutron chopper has been in limited operation at design speeds of 12,500 rpm, but continuous operation has not been possible because of difficulties encountered with the horizontally shafted rotor bearings. To resolve this problem a bearing development program has been planned. Apparatus will be set up in the spin test facility and used to test a new bearing system featuring flooded oil lubrication.

It was found that the horizontally shafted rotor system had to be balanced to a much higher degree than was possible commercially. Field-balancing equipment was used to reduce the dynamic imbalance of the horizontally shafted rotor, and a system resonance and high vibration levels were successfully eliminated. In addition, an air turbine

was procured and put into operation at the spin test facility as a drive for overspeeding rotors. It is capable of supporting rotors weighing as much as 1000 lb and running at speeds of up to 25,000 rpm.

For the capture γ -ray spectrometer in experimental hole H-3, the primary shield, collimator, water box, main access detector box, air bearings, and plate have been completed and installed. A prototype air bearing for use in moving the detector box was constructed and tested, with excellent results. This spectrometer will utilize a servo-controlled inductosyn system to couple the first crystal axis and arm in a 2:1 ratio. Operation of the spectrometer with this system, which is expected to be completed by January 1968, can be either manual or controlled by computer.

Installation has been completed of the primary radiation shield and beam plug for the polarization spectrometer in hole H-1, and preliminary work has been started on a cold neutron moderator to be used at hole H-9. This will consist of a capsule of liquid hydrogen, maintained at low temperature by a helium refrigerator through which the neutron beam will pass.

Design and fabrication of a cable-operated "rabbit" have been completed, and it has been successfully tested. The rabbit will handle samples up to 0.50 in.³ in volume and is expected to be installed at the HFBR early in fiscal 1968. A pneumatic radiation facility for irradiation of small samples of a few milligrams is also under development. A working prototype in which helium is the propellant has been built, and a pellet velocity of 40 ft in $\frac{1}{10}$ sec has been achieved. Since such high velocities produce problems of wear in the rabbit, additional developmental work is scheduled.

A large amount of specialized apparatus has been produced for high energy research, including a polarized target cryostat and differential Cerenkov counters. The counters have a theodolite stage for use in aligning and positioning an array of wire spark chambers. Prototype wire spark chambers that use individual strands of 2-mil-diam stainless steel wire have been constructed and tested. A winding mechanism has been constructed that is capable of winding wire at the rate of 600 ft/min, with spacings of 20, 40 or 80 wires/in. A chamber under test at the AGS has been pulsed 8 million times with good results.

Personnel assigned to the Tandem Van de Graaff project have been engaged in liaison work with the architect-engineer designing the building

and facilities. Design work is also in progress on the beam transport system, beam tube hardware, negative ion source, and insulating gas control panel. An engineering study was made and completed for the Dynamitron gas-handling system. The conversion of the 60-in. cyclotron to a variable frequency cyclotron has been completed. The vacuum chamber is being evacuated, and it is expected that a beam will be obtained shortly.

Personnel assigned to the Bubble Chamber Group have continued work on high-speed cameras for the multipulsing of the 80-in. bubble chamber. A prototype pneumatically advanced camera has been completed: the film is blown into a shaped pocket and later, during AGS pulses, is wound on a take-up reel. Work on a hydraulic expansion system has progressed to the point of designing a piston actuator for this chamber, for installation next year. The 80-in. bubble chamber has operated on hydrogen, deuterium, or a 1:1 neon-hydrogen mixture during the operating year.

The 31-in. bubble chamber, which is the modified 20-in. chamber, has been assembled and tested and is in experimental operation. This chamber incorporates new coils giving a central field of 23,000 G, a hydraulically driven expansion system, and bright-field optics utilizing Scotchlite illumination. It has been used in experiments all year, including some involving a deuterium-neon mixture.

Much effort was expended in the preparation of a Title I report on the 14-ft cryogenic bubble chamber and on the 7-ft test facility program. Items of equipment for the test program include a helium refrigerator of 240-W capacity, a 5000-gal liquid hydrogen vessel, and a 1000-liter liquid helium Dewar. The test-vessel hydrogen container, magnet Dewar, and vacuum chamber are all under construction. The hydraulic ram and control valves, as well as the reinforced Fiberglas epoxy piston, are scheduled for delivery later this year. The superconducting material has been selected and is in production, while the necessary coil-winding equipment is being constructed at BNL.

During fiscal 1967 the Chemistry Department had full-time resident engineering support. Engineering assistance in the solar neutrino experiment continued with the design of a system to remove perchloroethylene vapor from the detector-tank effluent and separate the argon from the

helium gas stream in a charcoal trap cooled to 76° K. A liquid nitrogen container was designed which could either be towed, carried on a truck body, or mounted on a mine car. The Ar^{37} samples will be counted in three low-level gun-barrel facilities cast into the wall of the Chemistry Building.

An apparatus has been designed to detect short-lived radioactive, atomic, and molecular beams in flight. It consists of an evacuated scattering chamber, 8 ft long and 1×1 ft in cross section, containing a scintillation counter, a radioactive source chamber with an independent vacuum system, and a beam capture and pressure control device. Provisions have been made to add a 10,000-rpm beam-velocity selector and a cross-beam injector.

With assistance from the Cryogenics Group, a cryostat to measure vapor-liquid isotopic fractionation in two-component systems has been designed. The sample chamber has a 35-cc volume and is designed to operate at pressures up to 2000 psi and at temperatures ranging from -270° to $+65^\circ\text{C}$, with a temperature accuracy of better than 0.001°C .

Three projects were completed for the Molecular and Crystal Study Group. The first was an automatic cold-stream apparatus to maintain x-ray or neutron diffraction crystals at near liquid nitrogen temperature in a bath of cold nitrogen gas. The second was a miniature Joule-Thomson refrigerator mounted directly on a goniometer head for single-crystal neutron diffraction. The third project involved the redesign of an apparatus for use with an HFBR spectrometer. New encoders and encoder drives were added so that data could be programmed by the computer center.

Members of the Mechanical Engineering Division have performed major tasks for the Conversion, AGS, and Experimental Divisions of the Accelerator Department. In the linac section of the Conversion Division, work is proceeding on the final design of the 200-MeV linear accelerator injector for the AGS.

Development programs are continuing on various accelerator components. A short, 2.2-cm-aperture quadrupole was tested at fields $>12\text{ kG/cm}$, with good results. This design is being scaled for beam focusing in other drift tubes. A prototype, multistemmed drift-tube design under consideration will allow the multiple stems to contact the drift tubes without affecting the stability of alignment. Brazing techniques have been developed for the assembly of drift-tube stems and bodies. A

number of critical components, including rf seals, vacuum bellows assemblies, tuners, and drift tubes, have been tested at high rf power, ≈ 15 megavolt meters, and have proved satisfactory.

The final drift-tube table and linac-tank dimensions have been set, which has allowed basic design concepts to be frozen and fabrication drawings prepared. A purchase order has been placed for copper-clad steel for the linac tanks, and discussions have taken place with potential fabricators. A major effort has been the preparation of specifications and layout of facilities to allow the architect-engineer to start detailed building design. This involves the layout of equipment in the buildings and provision for the various services, such as coaxial transmission lines and cable routes.

Basic rf structure studies are continuing and a number of scale models have been designed, fabricated, and assembled. These consist of multiple structures to which modifications can be made as required.

Work has continued on the development of the 5-MW rf system and associated coaxial transmission lines. Coaxial components 3½ and 12 in. in diameter have been made and tested, and the amplifiers of the drive chain are also under test with the associated water and compressed air systems. Developmental work on heavy electronic systems is complete, and mechanical packaging of the components has been initiated. A prototype cabinet for the heavy electronics has been designed and is being fabricated. Rf power output loads of various capacities have been designed and fabricated and are under test for use with the high-power rf system.

In the Conversion Division, specifications and developmental work have been completed for the main magnet vacuum chambers, and bids are being solicited. These chambers will have elliptical bellows between the coil ends to allow for adjustment of the magnet while under vacuum, and their flanges are designed to use all-metal vacuum seals clamped with a V-band single-screw clamp. The chambers are insulated from the magnet core by flame-sprayed aluminum oxide coatings, and from each other by a vitreous ceramic coating on the flanges. The chambers are designed to accommodate pickup electrodes in the 2-ft straight sections and have a vacuum pump associated with each magnet module. Orders have been placed for the 150-liter/sec ion pumps for the vacuum

chambers, and design of the spectral injection and ejection vacuum chambers is proceeding.

The remote survey program for the main magnets involves the use of a theodolite viewed on a TV screen. A special commercial instrument is being procured, and an attachment for a conventional commercial instrument is being developed as well.

A new, main-magnet bus-bar system has been designed which will bring the conductors below the top edge of the magnet and allow for convenient placement of quick disconnects. A 2-magnet section has been mocked up in aluminum, and bus work for two magnets is being fabricated from actual copper bus. A voltage drop test was performed on the quick disconnect which will also be used to check temperature rise. Detailed drawings of all the standard sections have been completed.

Preliminary designs for the rf cavity have been made; four accelerating gaps will be incorporated in each 10-ft straight section with larger diameter ferrites. Calculations for the cooling of the ferrite are being made, and methods of brazing the tube assemblies are under investigation. Final design of the cavity must await the selection of the actual ferrite to be used.

A system of bundled pipes that will slip into the proposed electrical sleeves penetrating the tunnel sides has been designed and trial pieces have been built. A model of a magnet cross-slide, as well as a lightweight drive system that can be driven remotely, is being fabricated. This should make possible remote alignment as well as remote survey of the magnets.

A water manifold that will automatically disconnect supply and return water when the magnet is lifted has been designed, built, and tested. A newer, less expensive model is in the design stage, and methods of connecting the manifold to the coil to minimize radiation damage are being tested on the 2-magnet mock-up.

In the Experimental Division of the Accelerator Department, increased effort is being devoted to three aspects of the experimental program at the AGS: design and fabrication of experimental equipment; planning, rearrangement, and operation of the experimental floor; and cryogenic design and distribution of cryogenic liquids.

In the Design Group a film scanner and digitizer was built for scanning 70-mm bubble-chamber film. This unit is now in operation, and three

more are being fabricated. Special features of the film scanner are a single-lever control adjacent to the scanning area, rapid rewinding or advance of the film, parts easily accessible for servicing, and a special, high-performance, lens projection system.

A beam transport system was designed and installed for test beams at the G-10 target area. The 60-ft-long system contains three tapered brass collimators and an automatic beam stopper. All components are inside the vacuum system. A radius arm for moving a 100-ton 48D48 magnet has been designed and will be operational in July 1967. This radius arm uses a hydrostatic film-support device and is driven by a gear motor linked to a rubber wheel.

The Cryogenics Group has completed design and fabrication of a solid hydrogen target and superconducting magnet experimental system. The system consists of a closed-cycle, 4.2° K helium refrigerator with two compressors, a gas holder, freeze-out purification, a remote Joule-Thomson expansion valve, a superconducting magnet Dewar, and a hydrogen purification system. The liquid helium is used to cool the superconducting magnet and also to solidify the gaseous hydrogen, the magnet enclosure being used as a heat sink. It takes ≈ 6 hr to solidify 86 cc of hydrogen, which upon solidification takes on the appearance of a single crystal.

The Cryogenics Group, in addition to performing work for the Accelerator Department, has designed and installed many pieces of cryogenic apparatus for other departments of the Laboratory, including the Chemistry Department, the Supply and Materiel Division, the Physics Department (the Bubble Chamber Group in particular), and the Reactor Division. It is also responsible for the distribution of liquid hydrogen; in the past year 100,000 liters were handled. The group is now involved in the preliminary design and cryogenic requirements of a cold neutron moderator facility for the HFBR.

The high-gradient test column at the AGS has produced oscillation-free beams with maximum intensities of 250 mA. Construction of the first operational high-gradient accelerating column is continuing, with use of a metal-ceramic combination having matched thermal coefficients of expansion to minimize thermal stresses. A specially designed baseplate is being fabricated which should further reduce stress between the metal and the ceramic. In addition, various techniques of applying the epoxy cement used to bond the metal to

the ceramic are being tested in an attempt to obtain higher strength and flexibility.

The rf system of the 50-MeV linac is being modified to provide 3-port instead of 1-port excitation of the linac. Two additional openings have been bored in the undersides of linac tanks Nos. 2 and 10 to take 10-in.-diam coaxial line, and loop assemblies have been installed to match the power supply to the tank.

Design has been completed on all the major components for the slow external beam. The 480-transistor-bank power supply for the ejector magnet has been installed in a special house outside the ring. A movable pipe installed in a sleeve that connects the house and the ring through the tunnel wall contains the large power leads and provides cooling water for the ejector magnets. The parts of the septum and ejector magnets are on hand and are being readied for thermal testing and magnetic measurement. Materials that would minimize organic vapors were selected, and an aluminum oxide coating was used for coil insulation.

The magnets are mounted on a drawer assembly that slides into the vacuum box and provides easy access for maintenance purposes. A remotely controlled motor drive permits a total of 2 in. of adjustment with a digital readout of the magnet position.

Design and fabrication of instrumentation for the slow beam are in progress. Suitable flags will be mounted on the beam line, and ports will be provided to enable TV cameras to view the flags. A secondary emission chamber will be used to measure beam intensity.

The carriage assembly and ram mechanism of the septum and ejector magnets of the fast external beam system have been redesigned to ensure greater reliability. The vacuum seal will be a welded disk metal bellows, which has been tested to a life of 6×10^6 cycles for a 3-in. stroke. The components needed to modify existing units and to build complete spares have been ordered. Components in each of these units will be interchangeable.

An all-metal-seal target box with two target and airlock systems was installed at G-10. The gaskets are of Inconel-X plated with lead and indium. They fit into the standard O-ring groove, previously used with Viton "O" rings, and use the existing bolt system. Seals have been successfully made against stainless steel, aluminum, glass, and ceramic. Electrical insulation between the vacuum chambers is supplied by ceramic-coated stainless

steel inserts. With these techniques an all-metal, nonorganic vacuum system can be provided in critical locations before the conversion of the AGS is completed. Additional reliability and better vacuum are being obtained by installing sputter-ion vacuum pumps where needed. Two 700-liter/sec pumps have been installed on the G-10 vacuum box.

An all-metal-seal radiation-resistant airlock has been designed which in addition to fulfilling standard functions can be remotely adjusted in the vertical as well as radial coordinates. Furthermore, its major functional parts are interchangeable. This has all been done in about one-half the previous volume.

Central Design Group personnel provided engineering service for the Chemistry, Biology and Medical Departments and for the Reactor and Photography Divisions and supported the activities of the Physics, Accelerator, and Nuclear Engineering Design Groups.

Several machines were developed for the Photography and Graphic Arts Division, and existing equipment was redesigned. Revisions were made to the equipment used in rapid retrieval of information from the Division's extensive collection of negatives.

An adjustable, multidetector positron scanner was developed for the Medical Department, as was a rotating turntable for irradiation of animals. In addition, a constant-temperature vessel and a

new facility with an elevating mechanism for x-ray apparatus were designed.

For the Biology Department a multiple-flask rotating device was designed and developed for growing cultures used in biological experiments, as was apparatus for critical point drying. The purpose of the latter is to preclude the distortions caused by the surface tension generated when a specimen is allowed to dry in air prior to being placed in a high vacuum. The process involves the substitution of another substance for the water in the living cells, the substituted liquid being one whose critical point is at a temperature near room temperature. First the water is replaced by absolute alcohol, then the alcohol by amyl acetate, and finally the amyl acetate under pressure by carbon dioxide. The apparatus consists of a pressure vessel with intricate baffling, high-pressure piping, gauges, needle valves, rupture disk safety valves, a gas tank, a water baffle, and a heating unit.

MACHINE SHOPS

The Central Shops Division provides the Laboratory with on-site fabrication and repair of experimental equipment, vendor fabrication, inspection and quality control, and the repair and maintenance of machine tools. In addition, the Division manages the machine-tool acquisition and replacement program and the machine-tool and small-tool standards programs and is responsible for the selection, training, and placement of all machinists, welders, and sheet-metal mechanics.

Intra-Laboratory requisitions for on-site fabrication, men-on-loan, and short-order jobs accounted for 161,300 productive man-hours in fiscal 1967, an increase of 6.7% over fiscal 1966. A total of $\approx 11,500$ productive man-hours were charged for performance of work within the Departments that could not be carried out in the shops, such as assembly and modification of large or fixed experimental equipment. The short-order work accounted for about 13% of the total work load. The distribution of the machine shops work load among the various Departments is shown in Table 7. The average monthly backlog of work in the Division increased from last fiscal year, most noticeably during the last months of the year. This was due in part to increased activity in connection with the AGS conversion program.

Many of the jobs submitted to the Central Shops Division required machining, welding, and

Table 7
Contributions to Machine Shops Work Load
(% Man-Hours)

	Fiscal year		
	1967	1966	1965
Accelerators			
AGS	24.4	16.1	14.1
Cosmotron	0.9	4.1	5.2
Biology	1.6	4.0	4.2
Chemistry	3.9	4.7	3.5
Instrumentation and			
Health Physics	0.5	0.9	1.0
Medical	2.5	3.1	2.5
Nuclear Engineering	21.8	22.1	26.2
Physics	36.4	35.9	31.3
Reactors	5.3	7.2	9.1
Miscellaneous	2.2	1.4	1.9
Outside contracts	0.5	0.5	1.0

Figure 6. Apparatus (goniometer) for positioning a detector in relation to a target and accelerator beam for precise measurements of angular distribution and correlation of γ rays.

sheet-metal work to very close tolerances. Frequently it was necessary to develop special fabrication techniques through close coordination between the designer and machine shops personnel. The availability within the Division of tape-controlled drilling, milling, and boring machines, plasma-arc cutting equipment, and electric-discharge machining equipment has made it possible for the scientists and design engineers to use special materials and fabrication operations that would otherwise be impossible or too costly to incorporate into their designs. In addition, the availability of precision inspection equipment has made it possible to ensure that the finished equipment meets the tolerance specifications imposed by its intended use.

An instrument that enabled the Division to demonstrate its ability to fabricate parts, assemble, and test to completion is shown in Figure 6. This unit was designed to position a γ -ray detector accurately for measurement of angular distribution and correlation. The design exemplifies the

Figure 7. Form for a cryogenic quadrupole magnet. This form, made entirely of stainless steel, is 5½ in. in diameter and 25 in. long. Specifications were very stringent as to size, uniformity, and angular position of the cavities formed by the rings and longitudinal wedges.

Figure 8. Inspectors checking the housing for 80-in. long neutron collimators used with a spectrometer at the HFBR. The housing has four channels to hold collimators of varying degrees of collimating accuracy. The insert shows an end view of two collimators mounted in the housing and the target used for measuring straightness of the channels.

many phases of the Division's operations, including close-tolerance machining, sheet-metal work, welding, precision engraving, assembly, and inspection. The requisitioner receives a completed instrument ready for installation and use.

Another job that was particularly critical as to dimensional and angular tolerances was a form for a superconducting quadropole magnet (Figure 7) which was 25 in. long and 5 $\frac{3}{8}$ in. in diameter and consisted of ≈ 75 separate stainless steel pieces. Each of the 10 coil clamps consisted of 4 quadrants held to a tolerance of ± 30 minutes of arc. Each quadrant was slotted internally and drilled to position seven accurately machined wedges. The end use of this coil form required that the cavities be held to extremely close tolerances as to size, angular position, and uniformity.

The need for accurate collimation of the neutron beam for use with spectrometers at the HFBR has resulted in the utilization of a unique technique. The collimators were 80 in. long, and the

specified straightness and flatness over this length was 0.001 in. The technique used consisted of making a sandwich of aluminum spacers and stainless steel shims, the shims being wider than the spacers and projecting equally on each side of the spacers. These sandwiches were composed of various thicknesses of shims and spacers to provide the collimator openings required. Very careful preparatory work was required to make and machine these spacers and shims and assemble the loading and plating fixture. Two such assemblies at a time were mounted on opposite sides of an accurately machined fixture, and metal was electrically deposited to grasp the protruding edges of the shims. The deposited metal was built up until thick enough to form the side walls of the collimator. The excess metal was then machined to an accurate fit with the collimator housing, and the aluminum spacers were dissolved with a caustic solution. The various collimators made in this manner were then loaded into a housing (Figure

Figure 9. Radiation shield for use with a capture γ -ray spectrometer. The wedge-shaped cavity for the collimated beam tube will contain a liquid to maintain shielding integrity when the tube's position is changed.

8) which can be rotated about its longitudinal axis to allow the experimenter to bring the properly spaced unit into position quickly and precisely.

The two stainless steel cylinders that serve as the housing for the neutron collimators discussed above were machined in the heavy machine shop and inspected for parallelism and straightness to ± 0.0001 in. in the Division's temperature-controlled inspection area. Each of the 8 rectangular openings (4 in each cylinder) was inspected optically throughout its entire length at intervals of 2 in. in both the horizontal and vertical planes. This was accomplished by the use of a specially designed target and a Farrand alignment telescope with optical micrometers. For each run 72 measurements were required, and several runs were made to ensure accuracy. Figure 8 shows an inspector taking a typical measurement of one of the rectangular openings; the insert shows the ends of two of the collimators mounted in the housing.

Associated with the neutron collimators and supporting the cylinders is the H-1A spectrometer's forward collimator housing and snout, a Meehanite casting weighing ≈ 5135 lb as cast. Fabrication of the casting and machining were handled by the Division's Vendor Fabrication Section. Inspection of the bearing diameters and angular bore measurements to seconds of arc were carried out by the Division's inspectors with Laboratory inspection equipment transported to the vendor's plant.

Figure 9 shows the liquid radiation shield for the capture γ -ray spectrometer. Because of its size and completed weight of 7000 lb, it was designed to be fabricated in two halves to facilitate handling and assembly and to allow for corrections for straight-line deviations resulting from welding stresses. The section through which the beam tube runs is filled with fluid; other internal compartments are filled with paraffin or cement. The cylindrical sections rolled in the sheet metal shop were fitted to those cut by the plasma-arc machine. The photocell tracer unit on this machine, which follows an accurate line drawing, controls the cut so precisely that the plates fit the assembly without further handling or machining. Coordination of the fabrication procedures between the designer and the Division's supervisors made it possible to construct this unit almost entirely in the sheet metal and welding shops. Only a minimum of machining was required; hence the machine shops were able to direct their efforts to other phases of their heavy work load.

Electric discharge machining (EDM) has continued to be useful in solving many design problems because of its ability to remove metals of all degrees of hardness and with odd-shaped geometry without distortion. While EDM is a slower process than conventional machining, it frequently lends itself to solving a problem more easily and efficiently than normal machining procedures. Cutting long thin slots in different materials has al-

ways been a costly and time-consuming process. Slots for a number of neutron collimators have averaged 0.012 in. wide by 0.0625 in. deep and 12 to 36 in. long. With conventional milling operations the dulling of the cutter, tooth breakage, and wander make it difficult to hold the necessary close tolerances on size, spacing, straightness, and squareness. Figure 10 shows a typical side plate which was machined to size and drilled by conventional machining methods and slotted by EDM. Extremely accurate and close spacing through the use of optical measuring, together with a choice of a wide range of electrode materials, has allowed the experimenter to use significantly thinner spacers. EDM has also made it possible to machine small-diameter and odd-shaped holes of greater size and depth in materials which normally cannot be machined or would require extremely specialized equipment and time-consuming techniques.

The Division maintains a section to handle vendor fabrication work for which no on-site facilities exist or to reduce the backlog in overloaded central shops or staff shops. At times complete assemblies may be contracted to a vendor for fabrication, with inspection and assembly done at the Laboratory. More frequently, however, some parts of large projects will go off site, the balance of fabrication being done by the Laboratory's shops. The difficulty of locating acceptable vendors with time to handle large and heavy machining and welding continues; the Laboratory's Vendor-Survey Group, in which Central Shops' personnel take an active part, has spent many added hours on this problem. During fiscal 1967 the Division used the services of 49 different vendors, with a total of \$105,660 involved.

The Inspection and Quality Control Section maintains inspection stations in all the Division's shops and provides 100% inspection of all parts fabricated within the Division, as well as complete inspection of all vendor-fabricated items handled by the Division. Periodic calibration of the Laboratory's precision measuring tools, field inspection of scientific apparatus during fabrication, and assistance in setting up research equipment are a few of the areas covered by this group. During the year 10,246 different jobs involving about 59,000 pieces were inspected. Measuring the spacings of 856 wires 0.002 in. in diameter that had been strung on a Fiberglas frame is typical of the many assignments received from the various scientific groups.

The position of each of the 856 wires had to be verified at three points along its length. This was accomplished by using a Sheffield Cordax 200 coordinate measuring machine, with a Hewlett Packard digital recording attachment giving a permanent printed tape of the measurements made.

The Division's Machine Maintenance Section provides repair service for all the Laboratory's machine tools, generators, and pumps and many of the other large pieces of machinery on site. The Section also stocks many replacement parts for machine tools to minimize down-time during repairs. In addition, it carries out scheduled routine maintenance in the form of lubrication and adjustment of central and staff shop machinery.

Under the Laboratory-wide machine tool program, purchases continue to be made of replacement machinery for old, worn tools; during the year about \$219,600 was spent on replacements and additional equipment for both central and staff shops. The need to handle larger and heavier pieces of material in the fabrication of experimental equipment has been responsible for the purchases of additional heavy machinery in the Central Shops. This year's acquisitions included a band-type cutting machine with a 24-in. $\times$ 24-in. $\times$ 6-ton capacity and a second large-swing hollow-spindle lathe.

The Inspection and Quality Control Section acquired the following instruments to further serve the scientific groups: a Profilometer that can measure surface finishes at the bottom of "O" ring grooves and in recesses of the order of 0.1 μ in. and is equipped with a semiautomatic tracing and recording device to produce a permanent record of the finish on parts; an Ultraron, which is a rotary table capable of measuring concentricity and cylindricity of parts to 10 μ in. and wobbles on rotating parallelism to 50 μ in; and a microptic precision clinometer capable of measuring angles to 0.5 seconds of arc, which will be used to locate positions on large jigs and fixtures, level machine ways, and set up angular work on machines. It will also be used for the inspection of large parts in general.

The Laboratory program of buildings and modifications has provided the Division with new quarters for graphite machining by rearranging space in the light machine shop building. The improved lighting and ventilation in the area now occupied by this group have increased the efficiency of personnel and made possible better uti-

Figure 10. Typical side-plate for a neutron collimator. The insert is an enlarged view of the shape of the slots produced by the EDM process.

lization of machinery. The construction in 1967 of three new lunch rooms outside the fabrication area has released valuable floor space for shop work.

TECHNICAL INFORMATION

The responsibilities of the Information Division include the operation of the Research and Classified Libraries, the editing, processing, and distribution of Laboratory reports, patent review, and many of the aspects of public information and education. These activities are discussed below.

With the assistance of the staff of the Architectural Planning Group, final plans for additions to and the renovation of the Research Library have been prepared. The additional much-needed space will be occupied by books, scientific journals, and documents. Renovation of the existing structure will permit more convenient arrangement of personnel working space and a more suitable location for reference materials and abstracting and indexing journals.

The Library's relationship with neighboring libraries continues to develop. In the matter of inter-library loans, cooperation is increasing notably. During recent months the Library participated in an experimental loan service sponsored

by the New York State Library. This project is intended to provide rapid copying of research materials through the use of teletype and facsimile transmission. On the local level, the Librarian participated in studies made by the Long Island Library Resources Council, of which he is a Trustee, to determine ways in which reference and research materials at Suffolk and Nassau County colleges, universities, and special libraries could be used by students and scholars in the two counties.

The greatest increase in the use of library facilities was in the loan of materials to other libraries. Filled requests averaged 48 per month. The circulation of books, journals, and reports to the BNL scientific staff reached the highest figure yet recorded.

The collection of unclassified reports, now one of the most complete in the Northeast, has presented a storage problem. Older material, formerly assigned to several locations, has now been assembled in one area. The entire collection was reviewed for the purpose of eliminating duplicate copies.

Demand continues for translations from the Russian scientific literature. An increase was noted this year in requests for translation from English into Russian of abstracts of papers to be presented by staff members at international conferences. On a number of occasions the Library's Russian translator served as an interpreter for Soviet visitors.

Table 8

	Fiscal year		
	1967	1966	1965
Patent clearances	1367	1155	1208
Preliminary invention reports	—	3*	37
Records of invention	54	39	26
Patent applications	22	22	14

*Discontinued during fiscal 1966.

A careful study was made for the purpose of replacing the earlier bound volumes of several scientific journals with microfiche editions. Although more than 1000 volumes were considered, only 100 were replaced with microfiche copies because of the strong preference of the scientific staff for the original printing.

In the Classified Library, the work load remains at approximately the same level as in past years. The annual inventory revealed total holdings of more than 16,000 documents, of which 7000 are secret. One formal classified report was issued and distributed during the year. Many classified holdings, no longer needed, were destroyed after the AEC's Division of Technical Information had confirmed their expendability.

A further increase was noted in the number of scientific and technical manuscripts originating from BNL-supported research and published in the open literature. During the year a total of 1240 items (including abstracts of speeches) was processed by the Division, as compared with 1017 in the previous year. The activities of the Editorial Section in processing formal Laboratory reports remained at about the same level as in recent years.

The film library, which contains an extensive collection of 16-mm motion pictures on many aspects of nuclear science and related topics at both popular and professional levels, was kept very active, especially during the winter months. Films are lent, free of charge, to schools, civic groups, and research institutions in Suffolk and Nassau Counties. During the fiscal year 372 such loans were arranged.

The BNL Patent Office is responsible for the review and clearance for patent matters of all scientific and technical manuscripts covering the Laboratory's research. The number of inventions reported by this office during fiscal 1967 exceeded that for the previous year by about 25%. This in-

Table 9

	Fiscal year		
	1967	1966	1965
Photographs	14,565	12,979	14,188
Photomicrographs	9,682	6,201	2,729
Lantern slides	14,952	13,840	14,551
Prints	60,231	51,258	51,851
Film processed, ft	5,810,049	3,815,853	3,781,043
Charts & graphs drawn	5,433	4,348	4,217
Motion picture footage	20,706	32,011	37,435

crease probably results from an increase of $\approx 18\%$ in the number of scientific manuscripts processed. The number of patent applications was equal to the previous high, exceeding the long-term average by about 60%. A summary of the activities of the Patent Office during fiscal 1967 and the two previous years is given in Table 8.

During May, the Head of the Information Division served as Director of the Technical Information Center at the Atoms in Action Exhibit at Ankara, Turkey. This exhibit, one of the US AEC's Demonstration Centers in foreign countries, is designed to stimulate public interest in the peaceful uses of atomic energy, as well as to assist scientists in the host country in the development of their own research programs.

TECHNICAL PHOTOGRAPHY AND GRAPHIC ARTS

The volume of work produced by the various sections of the Division has increased appreciably during fiscal 1967. The production figures for the Photography Group are given in Table 9. The recent surge in the number of photomicrographs is attributable to the recording on film of fission tracks in mica in connection with a Chemistry Department study of high energy fission cross sections. This work has been completed.

An administrative aide has been added to the Division's staff to assist in budget and fiscal areas.

Considerable effort has gone into establishing a retrieval system for photographic negatives. This involves microfilming the negative collection on 16-mm film, with each image associated with a digital code describing the nature and content of the photograph. Thus a rapid search can be made for a particular item or for all items satisfying the search conditions. The image so found is displayed on a screen together with its negative number.

Since the equipment was designed primarily for documents, optical, mechanical, and electronic modifications were required; these have been completed. In association with library personnel and with help from the research departments, a thesaurus of key words to be used in the coding is nearing completion.

The "Brookhaven Spectrum," a 25-min film about the varied aspects of the Laboratory's program, was completed under contract with Owen Murphy Productions and is being well received as it is used in the Laboratory's public information activity. It is also being distributed by the AEC and by the U.S. Information Agency in various language versions and is an official Government entry in European film festivals.

The motion picture medium has also been used by the Photography Group to record and report aspects of the research program. For example, the filming of various stages of the work on Parkinson's disease for the Medical Department is being continued, and the irradiation of bacon in the High Intensity Radiation Development Laboratory was made the subject of a short film.

There has been interest in using the CRT plotter of the CDC 6600 computer to produce animated motion pictures of chemical and physical processes in both mono and stereo versions. Effort was expended in this regard in association with the Nuclear Engineering Department.

Two new film-processing machines for continuous-tone and line materials were acquired in a continuation of the effort to mechanize, as much as possible, an operation that is essentially a custom service. The addition of a Log-etronic enlarger which provides automatic control of contrast is another step in this direction.

Production statistics representing the major accomplishments of the Graphic Arts Group are given in Table 10.

Table 10

	Fiscal year		
	1967	1966	1965
Photo-offset impressions	14,850,193	14,390,880	12,891,113
Quick Copy impressions	6,586,014	5,335,952	4,803,934
Reports and booklets, copies produced	86,355	80,625	75,805

Five technical reports were subcontracted for typesetting and printing during the year through the U.S. Government Printing Office in New York City. This office also negotiated a contract for bookbinding BNL 989 (C-48), *Brookhaven Symposia in Biology, Number 19*, with a commercial bookbinder, since the capabilities of the Laboratory's equipment did not permit binding within its own printing plant.

Some of the larger reports produced within the BNL printing plant during the year are listed below.

	Pages	Total impressions
<i>Bulletin of the Medical Department, August 1966</i>	83	287,000
<i>Neutron Cross Sections, Second Edition, Supplement No. 2, BNL 325: Volume IIB</i>	422	2,236,600
<i>Volume IIC</i>	436	2,310,800
<i>Brookhaven Symposia in Biology No. 19, Energy Conversion by the Photosynthetic Apparatus, BNL 989 (C-48)</i>	528	2,376,000
<i>Summer Institute on Spectral Theory and Statistical Mechanics, BNL 993 (T-422)</i>	346	397,900
<i>Annual Report, July 1, 1966, BNL 994 (AS-20)</i>	246	615,000
<i>Annual Report, Nuclear Engineering Department, December 13, 1966, BNL 50023 (S-69)</i>	194	174,600
<i>Medical Survey of the People of Rongelap and Utirik Islands Eleven and Twelve Years After Exposure to Fallout Radiation (March 1965 and March 1966), BNL 50029 (T-446)</i>	174	200,100

Quick Copy work has shown a marked increase. A second shift working in conjunction with a radio-directed pickup and delivery service has meant same-day or overnight delivery on most jobs. These improvements have diverted a satisfying amount of work from departmental Xerox machines to the faster and more economical equipment of the Graphic Arts Group.

Slides are now being prepared on photographic typesetting machines rather than on typewriters. As a result their quality and readability have been greatly improved. Further refinements are currently being made.

Approximately 42,000 plates for use on the single-sheet offset presses were made during fiscal 1967 by the Photo-direct process. A Bruning copier, which makes offset plates by the electro-

static process, has been acquired. This machine will be used whenever advantageous, about one half of the time, at an average saving of \$0.25 per plate.

The 41-in. Robertson camera installed during the year has proved to be most useful. The simultaneous exposure of multiple originals has saved considerable time, especially in the case of half-tones. The handling of large originals has been greatly simplified, with resultant labor savings.

The Division's crowded conditions were alleviated somewhat during the year. A 500-sq-ft trailer was attached to the Photography Building; this made possible the installation of the two processing machines mentioned above. Flooring-over of the upper part of a utility room resulted in more efficient organization of the second floor space, which now includes a much-needed projection and conference room. In the Graphic Arts Group two small offices became available and were converted into a machine room to house Quick Copy equipment.

INTERNATIONAL COOPERATION

The spirit of international cooperation in science is greatly fostered by the many arrangements whereby foreign scientists come to work at Brookhaven and Laboratory scientists attend overseas meetings and conferences. In addition, BNL is involved in formal programs of cooperation with the Greek Nuclear Research Center (Demokritos) and the Puerto Rico Nuclear Center.

The first of these programs, initiated late in 1965, has continued during the past year with exchanges of scientists between the two laboratories. Visiting Greek scientists from the Center have participated in research in the life sciences in the Biology and Medical Departments. Brookhaven has continued to send experts in several fields of specialization to Athens to discuss problems and research of mutual interest to the two laboratories. Eight members of the Chemistry, Physics, Biology, and Instrumentation Departments have participated in short visits to the Center, where they covered many topics, ranging from neutron diffraction studies of crystal structure to data-processing problems in high energy physics, and gave a series of seminars in their fields of specialization.

Currently the Laboratory is preparing to send to Demokritos, as part of an equipment loan program initiated in 1966, a surplus fluorometer for the

study of fluorescence of organic compounds and a spectrophotometer for chemical analysis.

Because of the large financial commitment made by Demokritos to a high energy physics program (Greece is a member of CERN), it is expected that cooperation and consultation in the digital analysis of bubble-chamber photographs will be intensified in the near future, and the experience accumulated at Brookhaven in this field will be made available to Demokritos.

The cooperative program between the Laboratory and the Puerto Rico Nuclear Center was established in 1961. It took definite shape soon thereafter when a BNL physicist spent a year (1962-63) helping to initiate research work in neutron diffraction at the Mayagüez reactor. More recently (1965-66) the head of the BNL Solid State Physics Group spent six months at the Rio Piedras laboratory of the Center in San Juan, helping in the development of a program on organic semiconductors. The neutron diffraction program is now well established, with three full-time scientific staff members operating two neutron spectrometers and an x-ray diffractometer. The organic and semiconductor program is also well into a productive stage. Scientists in both programs are publishing their work regularly in recognized scientific journals.

As these projects have developed, assistance from Brookhaven has declined in measure. Through correspondence and occasional visits, close contact has been maintained between scientists from Brookhaven and the Center, but this contact is now principally through a number of joint research projects. Collaborative research during the past year included a neutron diffraction project to study the magnetic structures of MSb_2O_4 compounds (where $M = Fe^{+2}, Mn^{+2}, Ni^{+2}$). Work on $FeSb_2O_4$ has been completed, and studies of the Mn and Ni compounds are expected to be finished in fiscal 1968. A joint project in the organic and crystal program was also initiated to investigate the effects of radiation on the properties of anthracene. In this connection electron spin resonance studies are being carried out at Brookhaven, and laser experiments are under way at the Center.

There are certain areas in which continued cooperation from Brookhaven can be very beneficial to the Center's solid state program. Computing facilities in Puerto Rico are limited and, particularly for some of the needs of the neutron diffraction group, inadequate. No substantial improvement in this situation can be expected in the im-

mediate future. Technical problems with equipment constitute the other main area in which continued assistance is needed. In addition, continuation of the cooperative and professional contacts that have been established on a more limited basis in other research activities will help to promote the general development of science at the Center and at the University of Puerto Rico.

During the year, Brookhaven also contributed to a program of cooperative activities between the

U.S. and the Indian Atomic Energy Commission. A BNL reactor physicist spent about one month participating with Indian representatives in a technical and economic evaluation of reactor systems and nuclear fuel cycles, designed to exploit India's estimated reserves of thorium and uranium. In addition, an experimental reactor physicist from BNL devoted about one month to assistance in planning India's future reactor physics research program at the Atomic Energy Establishment.

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 third successive year, the number of regular staff members at Brookhaven increased by $\approx 5\%$ during the 12 months ending May 31. Turnover remained at a significantly high level: 53 scientists and engineers were appointed to the staff, and 31 terminated their appointments. Comparative year-end statistics for 1967 and 1966 are shown in Table 1.

During the past seven years, the number of salaried visitors employed as of May 31 has ranged from a low of 103 to a high of 122. Postdoctoral Research Associates accounted for 75% of these appointments this year. Turnover in this category was particularly high because of the limited term of these appointments. During the year 38 recent graduates began postdoctoral research investigations and 35 completed their terms. Of the latter, 15 were promoted to the regular staff.

Although the number of scientists and students holding nonsalaried appointments has more than doubled in the past seven years, the number participating at the Laboratory on a full-time basis (as of May 31) has not varied appreciably from the average of 58 per year.

Table 1
Scientific Staff and Students on May 31, 1967 and 1966

	Regular staff		Visitors			
			Salaried		Nonsalaried	
	1967	1966	1967	1966	1967	1966
By appointment category						
Staff						
Senior Scientist	83	78	1	1	66	56
Scientist	166	153	3	10	135	139
Associate Scientist	150	154	11	10	163	152
Assistant Scientist	65	57	9	9	110	98
Research Associate	—	—	82	79	75	72
Students						
Junior Research Associate	—	—	3	6	135	112
Research Assistant	—	—	0	0	81	101
Total	464	442	109	115	765*	730**
By academic degree						
Ph.D. or M.D.	330	312	102	103	525	493
Master	58	54	3	6	82	96
Bachelor	70	72	4	6	148	124
No degree	6	4	0	0	10	17

*56 of these appointees were at BNL on a full-time basis as of May 31, 1967.

**62 of these appointees were at BNL on a full-time basis as of May 31, 1966.

Table 2

Classification of Visiting Scientists and Students Participating in BNL Program
for One Month or More, June 1, 1966 – May 31, 1967

	Guests and salaried visitors							
	More than 3 months		Less than 3 months		1966 Summer program		Total	
	Salaried	Guest	Salaried	Guest	Salaried	Guest	Individuals	Institutions
University staff	20	39	9	63	79	43	253	123
Thesis students	6	23	2	20	3	7	61	30
Student Research Assistants	1	10	0	9	117	36	173	75
Subtotal	27	72	11	92	199	86	487	164 different
Industry	2	3	0	1	2	0	8	8
Other institutions	14	36	16	19	3	13	101	59
Total	43	111	27	112	204	99	569	231 different

Table 3

Consultants' Services

	Fiscal year		
	1967	1966	1965
Total contracts in effect June 30	109	98	91
Number of consultants used	58	59	61
Number of man-days of service	478	472	495

May 31, instead of June 30, was used in Table 1 to exclude from the statistics more than 300 visitors who participated at Brookhaven only during the summer months. Similarly, the year ending May 31 was used in Table 2 to avoid including participants in two summer programs.

Table 2 lists the numbers of visiting scientists (not including salaried Research Associates) and students who worked at the Laboratory for cumulative periods of one month or more. The total of 596 individuals is within 1% of comparable totals during each of the three previous years. This degree of similarity is coincidental rather than by design. In addition to those included in the table, 290 scientists and students worked at Brookhaven for less than one month.

Table 3 shows the extent to which consultants' services have been employed during each of the past three years.

Summer Program for 1967

Arrangements have been made for 320 visiting scientists and students to work at the Laboratory during the summer of 1967. Of this number, 135 are staff members from colleges, universities, industrial organizations, and other institutions, and 185 are students.

Special groups include 124 students in the Laboratory's 16th annual summer student program and 19 Health Physics Fellows.

Employment

Throughout fiscal 1967 the Laboratory employed a total of 379 persons. As of June 30, 1967, the population, exclusive of guests, research collaborators, and temporary appointees, was 3333, ten fewer than last year (see Figure 1). Table 4 illustrates the employment experience for this period.

The need for technically specialized personnel continued and was difficult to satisfy, particularly in the fields of data processing and electronics.

The Laboratory participated in the Youth Opportunity Campaign with satisfying results. A total of 21 trainees were employed in technical and clerical jobs in the Government's program for culturally and economically deprived young people.

Figure 1. Laboratory growth.

Wage and Salary Administration

A new wage and classification system for weekly technical and clerical employees was developed during the latter half of the fiscal year. The new system, instituted July 1, 1967, retains the principal features of the former system except that seldom-used job titles and labor grades have been eliminated. Under the new system a single wage schedule with four expanded wage levels replaces the former technical and clerical schedules which, combined, contained 20 wage grades covering about 100 job classifications.

Employees will be classified in a broad generic sense and assigned to the job level that most accurately reflects their performance of assigned duties.

Formerly, automatic increases were granted only on January 1 and July 1 until the employee attained the proficiency rate of his wage level. Under the new wage system, automatic increases will be granted at 6-month intervals based on the employee's entry date into his particular wage level. After attaining the proficiency rate of this level, the employee will be evaluated for merit increases at the annual personnel review.

Training and Education

The tuition refund policy was revised from the 50% reimbursement previously in effect to the following, starting July 1, 1967:

1. An employee taking courses at the undergraduate level will be reimbursed for 75% of the total tuition cost.

Table 4				
Employment Statistics*				
	June 30, 1967		June 30, 1966	
Scientific staff**	563		547	
Scientific				
professional staff	389		390	
Nonscientific staff	2381		2406	
Total	3333		3343	
Turnover data	Number	1967 Annual rate (%)	Number	1966 Annual rate (%)
<u>Accessions</u>				
Scientific staff**	114	21	113	21
Scientific				
professional staff	56	14	82	22
Nonscientific staff	238	10	276	12
Total	408	12	471	14
<u>Separations</u>				
Scientific staff**	98	18	93	17
Scientific				
professional staff	57	15	49	13
Nonscientific staff	263	11	231	10
Total	418	13	373	11
<u>Net Accessions</u>				
Scientific staff**	16	3	20	4
Scientific				
professional staff	- 1	- 1	33	9
Nonscientific staff	- 25	- 1	45	2
Total	- 10	- 1	98	3

*Figures do not include 112 temporary summer non-student employees. Guests and temporary student employees are included in Table 2.

**Including Research Associates and visitors.

2. Upon receipt of a baccalaureate degree subsequent to July 1, 1967, an employee may be reimbursed for the remaining 25% of tuition costs. This reimbursement will be made only for courses required for the degree and taken after July 1, 1967, but not more than five years prior to receipt of the degree.

3. An employee who has completed his baccalaureate degree will be reimbursed for 100% of his tuition costs for all courses at the graduate level.

This year 196 employees attending 14 academic institutions recovered reimbursable expenses under the Laboratory's tuition refund policy.

Labor Relations

Contract negotiations between the Oil, Chemical, and Atomic Workers Union, Local No. 8-652, representing 23 Reactor Division and 6 Hot Laboratory wage employees, began January 12, 1967. A new contract providing a wage increase of $\approx 5\%$ and incorporating some minor changes in language was agreed upon on April 13, 1967. The agreement continues to be for an indefinite period with a provision for reopening by either party on 90-day written notice.

A supplemental agreement was reached between Directly Affiliated Local Union No. 24426, AFL-CIO, and Associated Universities, Inc., on February 6, 1967, to allow the communications clerks and messengers to be represented by DALU.

The membership of DALU voted on April 5, 1967, to transfer their affiliation to the International Brotherhood of Electrical Workers and are now Local No. 2230.

Employee Services

With the inception of Medicare on July 1, 1966, BNL's medical plan for persons 65 years of age and over was changed to a Medicare Major Medical Plan. This plan provides coverage for most of the expenses excluded by Medicare.

As of February 1, 1967, the Laboratory permitted Retirement Plan participants to allocate up to 75% of their retirement premiums to College Retirement Equities Fund, the variable annuity plan. Previously, the maximum CREF allocation permitted was 50%.

ARCHITECTURAL PLANNING

The following major facility projects with a total value of slightly more than \$65,000,000 were initiated, under construction, or completed during fiscal 1967.

- Tandem Van de Graaff Accelerator
- AGS Service Building addition (AUI administered)
- Animal laboratories
- Low-level radiation counting facility for clinical research
- Lecture Hall-Cafeteria
- Site utilities
- AGS conversion (AUI administered)

The contracts for architect-engineer and construction work are held by the AEC and administered by its Brookhaven Office except for the AGS Service Building and AGS conversion projects, portions of the site utilities project, and certain

equipment and furnishings for the Lecture Hall-Cafeteria and animal laboratories. These latter contracts are held by Associated Universities, Inc., and administered at BNL by the Architectural Planning Division, which also acted on behalf of BNL in all other work to provide the liaison required from early planning through construction.

Smaller projects initiated or undertaken during fiscal 1967 amounted to \$1,550,000 under the General Plant Projects program. There were about 150 of these minor additions to, or modifications of, facilities for the research and supporting staff, as well as miscellaneous site improvements. Many of these presented special engineering problems and required considerable engineering effort. As in the past, Architectural Planning and Plant Engineering worked closely to coordinate many of these projects; in several cases Plant Engineering undertook management of the construction. The general plant projects exceeding \$50,000 were as follows: underground electrical system, Cornell Avenue; installation of computer cable network; addition to the bubble chamber works area; modification and addition, Research Library; emergency electric generating plant; and warehouse, AGS area.

The Architectural Planning Division coordinates the issuance and reporting of all proposals for accelerator and reactor additions and modifications (ARAM projects) and participates to a considerable degree in the engineering and design of a number of these projects.

Early in 1967 the Division began preparing the facilities section (buildings) of the budget request for fiscal 1969. This involved site locations, preliminary building plans, cost estimates, and description for the projects listed below (total estimated cost, \$13,400,000).

- Applied Science Building, Phase II
- Technical Services Building
- Electron Accelerator
- Molecular Biology Laboratory
- General plant projects, fiscal 1969

During fiscal 1967 Architectural Planning continued to assist the Physics Department in delineating the scope of the proposed 14-ft cryogenic bubble chamber. Assistance was given to the Accelerator Department in connection with evaluation of Title I design for the AGS conversion.

PLANT MAINTENANCE

Primary activities of the Plant Maintenance Division include maintenance and operation of all

Table 5
Manpower Utilization

Type of work	Fiscal 1967		Fiscal 1966	
	Productive man-years	Percent of total work	Productive man-years	Percent of total work
Maintenance, repairs, and utilities operations	154	41.4	150	41
Major maintenance programs	2	0.5	2	1
Facility improvements	4	1.1	4	1
Research program support	110	29.6	116	32
Building janitor services	94	25.3	80	22
Decontamination	2	0.5	3	1
Hot Laundry operation	6	1.6	7	2
Total	372	100.0	362	100

Table 6
Costs of Supplies, Materials, and Contracts

	Fiscal 1967	Fiscal 1966
Maintenance and utilities materials	\$ 356,509	\$ 337,295
Major maintenance materials and contracts	512,729	433,165
Facility improvement materials	436,598	521,128
Building janitor supplies	70,419	61,647
Decontamination	976	687
Hot Laundry	9,252	15,011
Fuel oil	464,871	416,503
Electricity	1,838,201	1,756,098
Total	\$3,689,555	\$3,541,534

Laboratory buildings, utilities, grounds, and heavy mobile equipment; provision of janitorial and Hot Laundry services; supplying skilled craftsmen and laborers for work on research programs; and renovation and modification of buildings.

Building space requiring maintenance and operation was higher by 15% (318,000 sq ft) in fiscal 1967 than in 1966, due primarily to occupancy of the Chemistry Building and the Physics and Applied Mathematics Building in the spring and summer of 1966. Total building space is now 2.5 million sq ft.

Research program support by craftsmen and general laborers amounted to 114 man-years in fiscal 1967, compared with 118 man-years in 1966.

During the year, facility modifications and major maintenance programs costing \$1,250,000 were planned, designed, and carried out. Major improvements were made in buildings occupied by

the Nuclear Engineering Department and the Supply and Materiel, Plant Protection and Security, Personnel, and Central Shops Divisions. Additions were made, existing facilities were modernized, and space was rearranged for optimum usefulness. Improvements in warehousing space, initiated in fiscal 1966, were continued in 1967. Adequate heating, lighting, and fire protection were provided in three older warehouses. Structural modifications and overhead doors, ramps, and platforms were planned and installed to provide for efficient storage and handling of materials.

The reliability of electric power and communication circuits continues to improve, and the removal of one mile of overhead power and telephone lines on Brookhaven Avenue and North Upton Road has enhanced the appearance of the site.

The utilization of manpower and the distribution of costs within the Division for fiscal 1966 and 1967 are summarized in Tables 5 and 6.

PLANT PROTECTION AND SECURITY

The Plant Protection and Security Division continued to perform its assigned functions during fiscal 1967.

Although the scope of the security function at the Laboratory has contracted substantially since Brookhaven's early days, the Laboratory nevertheless continues to maintain an extremely active security clearance program. At the end of fiscal 1967, about 600 employees and affiliates required active "Q" clearance, and about 300 had active "L" clearance. These clearances are required for access to classified material and documents at the Laboratory. They also give Brookhaven scientists and technical personnel full access, when necessary, to restricted data, both at BNL and at other laboratories and institutions.

The physical growth of the Laboratory and the expansion of its research programs have necessitated ever-increasing emphasis on the Laboratory's plant protection program. The increase in this aspect of the Division's functions has been met through adaptation of industrial plant protection techniques and practices to the specialized require-

ments of Brookhaven. During fiscal 1967, closed-circuit television continued to be used in the reactor complex, with gratifying results in effectiveness of operation and economy of manpower. 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 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. During the year, fire-fighting equipment was increased and modernized, mutual aid fire-fighting agreements with nearby communities were continued, and training in fire-fighting was accelerated.

Fortunately, there were no major fires at the Laboratory during fiscal 1967. Responses to fire alarms are tabulated below.

	1967	1966	1965
Responses on site	213	196	177
Responses off site	6	7	8
Investigations	67	106	104
Total	286	309	289

Table 7
Summary of Operations

	Fiscal 1967	Fiscal 1966
Number of procurements	38,316	38,191
Value of procurements	\$24,694,049	\$28,100,000
Number of receiving actions	46,992	46,539
Number of stores issues	368,681	340,914
Value of inventory turnover	\$ 3,990,725	\$ 3,605,263

In addition, excess serviceable equipment representing a cost avoidance of \$853,054 has been acquired.

Table 8
Distribution of Personnel

Division	Staff	Technical and clerical	Fiscal 1967 total	Fiscal 1966 total
Purchasing	24	19	43	41
Supply and Materiel	11	81	92	92
Systems and Data Processing	20	12	32	28
Total	55	112	167	161

BUSINESS MANAGEMENT AND ADMINISTRATION

Comparative statistics for the Business Management and Administration functions are presented in Tables 7 and 8.

Purchasing

Foremost among the activities of the Purchasing Division during the year was the mechanization of the purchasing effort into an integrated system also involving the Supply and Materiel and Fiscal Divisions. To date output from the computer has furnished weekly status reports on all orders, and this has significantly aided the expediting function. In addition, several trial runs have been made for computerized analysis of bids involving large numbers of stock items. These preliminary runs have proved the value of this technique, which will be used extensively as soon as the runs have been verified.

In January representatives of the Division were requested to visit AEC Headquarters in Germantown, Md., to explain the BNL Offer of Sale concept to members of the AEC contract and legal staff and representatives of the Small Business Administration. The Offer of Sale concept has since been expanded to cover many items in the mill supply category. The concept now covers purchases of standard equipment and components that are not inventory items.

A self-appraisal of the Division's service center functions was conducted. As a result, operations were streamlined with subsequent savings in man-hours. In addition, the Purchasing Division's master plan has been revised and updated to include new projects. Among them is the adaptation of the AEC's Management Information System, as well as the development of a totally integrated mechanized system in which data are captured at the source and perpetuated throughout the system for other organizations that may require the same data for their operations.

The approval level of BNL orders by the AEC will be raised on July 1, 1967, from \$10,000 to \$25,000. This change in approval limit should expedite the procurement cycle.

In connection with the training and development program, several members of the Division attended seminars on the use of computers in the administrative area and on Government contracting techniques. A seminar on cost and price analysis was also conducted at the Division's request by AUI's Internal Audit Staff. Staff members of the AEC and the National Radio Astronomy Observatory, Greenbank, W. Va., also attended this seminar.

The expediting effort has been expanded and improved with the aid of mechanized reports. As a result many more orders for materials and supplies are being delivered on or before the delivery date called for in the order.

Because of the unusual nature of computer procurements, new detailed procedures have been devised and a Computer Procurement Committee has been established. This committee includes representatives from the Purchasing Division, the Applied Mathematics Department, and the Instrumentation Division.

All work contracted in 1964 and 1965 for the solar neutrino experiment in South Dakota has been completed. The major contracts for excavating the chamber site at the 3800-ft level of the

Homestake Mine, construction of a 100,000-gal tank, and filling the tank with perchloroethylene were completed in a highly satisfactory manner, and the equipment is now ready for experimental use.

Supply and Materiel

The Supply and Materiel Division has continued to analyze and re-evaluate key areas within its organization in order to achieve a more effective and efficient working operation. In line with this, the Division has updated and revised its 5-year master plan in an effort to keep abreast of the expanding scientific programs and yet maintain the present level of personnel.

The storage facility has been completed and is now on a computerized program that will make possible greater cross-utilization and machine control of equipment held for future use.

The Inventory Management Section has as a continuous project the inclusion of all inventory items on extended-term procurement actions, as well as the establishment of quantity break information for as many items as possible. The Quality Control Section has made a concerted effort to establish Federal specifications for all inventory items and to designate as many items as possible for procurement through the General Services Administration. These two sections, in conjunction with the Stores operation, have established a listing of all items considered to be sensitive, restricted, or for limited withdrawal. These items are coded so that timely computer reports can be made to all Departments on the withdrawals made by their personnel.

The survey to evaluate office machines by age, time in use, and manner of use has been completed, and a computer program has been established for scheduled inspection, maintenance, and replacement of all office machines.

The Property Management Section, in conjunction with the Administrative Data Processing and Fiscal Divisions and a representative body of major users, has completed and published a totally revised capital equipment record unit catalogue. The capital equipment master file is being updated and is about 75% complete. This effort will continue through the current capital equipment physical inventory and will be completed early in fiscal 1968.

The Supply and Materiel Division will continue to modernize and renovate its facilities, wherever practical and feasible, and to decentralize opera-

tions wherever possible, in line with the Division's policy of bringing the materials closer to the user while maintaining central administrative control.

Systems and Data Processing

The capabilities of the Systems and Data Processing Division were taxed heavily in all areas of operation during the fiscal year. Improvements in almost all the Division's systems were considered, evaluated, and subsequently installed. New computer systems were designed, programmed, and implemented to satisfy significant innovations to the capital equipment, central shops, purchasing, and communications charge report processes. Services were expanded to include a maintenance scheduling system for BNL office equipment that provides effective, informative, and timely maintenance schedules for each repair technician. A purchasing-invitation bid-and-award analysis system was activated which depicts the monetary significance and relationship of vendor bids received. New or revised procedures were instituted to establish input/output handling requirements, controls, machine schedules, and keypunch specifications on all new computer concepts.

In the operations area, increasing volumes, expanding systems demands, and a continuous need for testing and debugging processes necessitated a 2-hr extension of the daily computer schedule. Current usage now approximates maximum capacity. In November 1966 the main Univac solid-state storage drum was replaced over a 3-day period. Despite this, and the intermittent failings attributed to the age and extensive use of peripheral units, a satisfactory performance record was achieved. To ensure the continued timely generation of critical reports, computer backup arrangements have been implemented and will remain in force during the conversion to a new computer.

Planning for the installation and application of the Division's new IBM System/360 (Model 30) computer was a major accomplishment. Management objectives were established in sufficient detail to provide a firm basis for determining the sequence in which the existing Univac applications would be converted to the new system. Decisions were made on the extent to which existing methods, procedures, and machine functions could be revised to obtain the maximum advantages of the new and more powerful computer configuration. Intermediate and longer-term goals were evaluated with regard to improved scheduling of inter-

nal operations and service to customers. Requirements were also defined for special computer features and for all support units dealing with the transition to 80-column card equipment.

To cope with the sophisticated capabilities of the System/360, the Division has expended the equivalent of two man-years on programmer training. This has made it possible to choose the COBOL programming language and take advantage of the benefits and flexibilities available under the various operating systems. In order to digest all operational requirements and make effective utilization of available software packages, utility-type programs, and the system's teleprocessing capabilities, a comparable training effort is planned for fiscal 1968.

Many members of the programming staff are now engaged in full-time programming for the new system, while others continue to devote some time to reduction of the programming backlog and maintenance of the Univac system. Because of the broader manpower base required for the development and implementation of the new computer systems, approval for the addition of two programmer/analysts to the staff was obtained. To assist in this area, key operating personnel have been engaged in the analysis of the conversion systems and program planning now in process.

STAFF SERVICES

The Staff Services Division is composed of 62 persons, including housing, travel, and mail clerks, telephone and teletype operators, automobile and truck mechanics, janitors and matrons, and appropriate supervisory personnel. In addition, two AUI pilots are associated with Staff Services.

The Division provides the following services for members of the Laboratory staff and visitors.

Housing

On-site housing includes 1 to 4-bedroom family units, men's and women's residences, and guest houses. The quality and quantity of on-site housing has been improved. Total capacity (nearly 850 persons) is fully utilized each summer. Billeting, billing, and janitorial maintenance are accomplished by the Housing Office. The triennial rental rate survey pursuant to Bureau of the Budget Circular No. A-45, completed early in fiscal 1967, resulted in increased rentals which went into effect January 1, 1967.

Travel

A complete Travel Office is maintained. Tickets, travel reservations, and accommodations are obtained for all personnel traveling in an official capacity. During the year tickets and associated reservations for space and cars for more than 5700 trips were handled. The Laboratory has been successful in negotiating agreements resulting in reduced rates for hotel and motel reservations and car rentals under certain circumstances for Laboratory employees on official travel status.

Telecommunications

Telephone, telegram, and teletype services for the Laboratory are operated by the Division. At present 1820 lines and 3000 telephones are installed. Economies resulting from the application of standards and guidelines have more than offset the increased costs that accompany normal growth, with the result that total telephone cost decreased during fiscal 1967.

Mail

A mail distribution service is maintained to effect frequent pickup and delivery of United States and interoffice mail at each of 98 Laboratory mail drops. In addition, standard distribution lists are maintained, and an Elliott Dymatic 7000 addressing machine is employed to facilitate efficient preparation of material for distribution to appropriate personnel.

Transportation

About 25 vehicles are available on a trip basis for official business purposes. Limited driver service is also available when use of a passenger-operated vehicle is not practical.

Motor Vehicles

The entire fleet of vehicles is acquired, maintained, assigned for use, rotated in assignment, and readied for disposal by the Division. Most vehicles are assigned to user departments or divisions and operated on a subpool basis to eliminate the need for drivers, dispatchers, and radios. Total mileage this year was 1.46 million, or 430 miles per employee.

Food Service

Food service is provided by a concessionaire in the dining room of the Brookhaven Center, in a

cafeteria, and by an assortment of vending machines. Maintenance of the buildings and equipment employed and direct liaison with the concessionaire are responsibilities of the Division.

Special Staff Services

The Laboratory is host annually to more than 150 scientific seminars, conferences, and other meetings. Each requires all or some of the above services and in some instances additional services unique to the situation. The necessary planning, acquisition, and coordination of these services are additional functions of the Division.

CONFERENCES, PUBLIC INFORMATION, AND EDUCATION

On January 23 Mr. Erwin D. Canham, Editor-in-Chief of the *Christian Science Monitor*, was the third AUI Distinguished Lecturer. His subject was "The Future of the Printed Word." The fourth lecture in this series was given on April 3 by Sir Isaiah Berlin, philosopher, author, and diplomat, on the subject of "Irrationalism." The Distinguished Lecture series calls for single talks by individuals outstanding in their fields of endeavor, without regard to their connection with science.

At the dedication of the new Chemistry Building on October 14, US AEC Chairman Glenn T. Seaborg was the principal speaker. Following the dedication ceremonies, a seminar on "Chemistry in the 70's" was held, at which Professors Anthony L. Turkevich of the University of Chicago and William N. Lipscomb of Harvard University were the principal speakers.

Three major conferences were held at BNL during the fiscal year: Properties of Liquid Metals, September 19-23, sponsored by the AEC and the International Union of Pure and Applied Physics; National Superconductivity Meeting, November 9-11, sponsored by the AEC; and the 20th annual Biology Symposium, entitled "Recovery and Repair Mechanisms in Radiobiology," June 5-7.

In addition, a number of smaller meetings were held, as follows: AEC General Advisory Committee, July 12-14; AEC Materials Branch, August 1-2; Advisory Panel on Radiation Safety of the AEC, August 11-12; Second Accelerator Safety Committee Meeting, October 25-28; a meeting of the Cross Section Evaluation Working Group, November 14-16; AEC Reactor Materials Meeting, November 29-30; AEC Advisory Committee on

Reactor Physics Meeting, December 5-6; Magnetohydrodynamics-Electrohydrodynamics Panel, March 10; Neutron Cross Section Advisory Group Meeting, April 13-14; the 21st AEC Metallography Group Meeting, May 10-12; High Energy Discussion Group Meeting, May 12; another meeting of the Cross Section Evaluation Working Group, May 24-26; presentation of the Solid State-Materials Science Program, June 8-9; and a subcommittee meeting of the European and American Nuclear Data Committee, June 19-20.

The Laboratory's Naval Reserve Research Company was host to other Reserve Officers from Long Island for a tour of BNL research facilities on October 21.

Nine lectures in the BNL Lecture Series were delivered during the year by staff members, who discussed their work, and by two scientists from outside installations who had been invited to lecture on their specialties.

Three National Science Foundation teachers-in-training seminars, comprising 134 persons, were given talks on the Laboratory's research and tours through the major facilities. In addition, five groups of teachers totaling 107 persons toured the Laboratory.

The U.S. Military Academy at West Point sent a total of 110 senior engineering students to tour the Laboratory at various times during the year. Four groups of graduate students from other academic institutions, 52 individuals in all, also visited BNL.

The Medical Department was host to about 100 nurses during fiscal 1967.

The 13th annual High School Visitors' Day, held on October 22, was attended by about 4500 students representing 208 high schools and 41 junior high schools. The ninth College Visitors' Day was held on October 29, with about 1200 undergraduate students representing 82 colleges in attendance. The 17th annual Visitors' Day, held

on November 5, was attended by more than 6000 people.

On February 10, BNL observed the 11th Science Youth Day in commemoration of Thomas Alva Edison's birthday. Especially invited top science students and editors of school papers from Suffolk County high schools spent the afternoon familiarizing themselves with the various types of computers in use at the Laboratory.

During the year the following foreign groups visited the Laboratory: 9 Chinese War College officers, July 19; 15 Soviet Bloc scientists, following a High Energy Conference, September 14; 12 French National Naval Architect Corps Engineering School officers, September 26; 22 German members of a Radiology Study Group, September 27; 12 students from the Technical University of Denmark, October 19-20; and 17 students from the University of Groningen, Netherlands, June 23-24. All these visitors are included in the total of 669 foreign scientists who came to Brookhaven during fiscal 1967.

Continuing its program of public information to neighboring communities, the Laboratory arranged for 17 speeches by staff members to civic, educational, and other groups.

The Public Information Office continues to experience an increased demand from students and teachers for assistance in preparing science projects and term papers. Many requests for information on nuclear science were also received from science writers and the lay public. Most of these inquiries can be met adequately by mailing the appropriate literature from the extensive stock of information sheets and pamphlets now available, but some require more personalized attention. In some cases, the best solution is to invite press representatives to visit the Laboratory and interview the appropriate scientist. Every effort is made to encourage such visits and thus contribute to improving the public's understanding of Brookhaven's research.

Appendix A

PUBLICATIONS, JULY 1, 1966 – JUNE 30, 1967

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, 1966. BNL 994 (AS-20).

Annual Report, Nuclear Engineering Department, December 31, 1966. BNL 50023 (S-69).

Conference Reports:

Brookhaven Symposia in Biology No. 19. *Energy Conversion by the Photosynthetic Apparatus*. BNL 989 (C-48).

Proceedings of the National Topical Meeting on Reactor Physics in the Resonance and Thermal Regions: An Addendum, February 7-9, 1966. BNL 50004 (C-48).

National Superconductivity Information Meeting, Brookhaven National Laboratory, November 9-11, 1966. BNL 50038 (C-49).

Process Radiation Development Program Summaries, Sixth Annual Contractors Meeting, United States Atomic Energy Commission Headquarters, Germantown, Maryland, September 26-27, 1966. BNL 50042 (C-50).

Brookhaven Lecture Series:

43. *The Ordered Bed Breeder Reactor*, W.E. WINSCH. BNL 50044 (T-454).

55. *Early History of Associated Universities and Brookhaven National Laboratory*, N.F. RAMSAY, Harvard University. BNL 992 (T-421).

57. *Health Physics Problems of High Energy Accelerators*, F.P. COWAN. BNL 50005 (T-429).

62. *Energy Conversion in Photosynthesis*, J.M. OLSON. BNL 50051 (T-458).

66. *Looking at Matter With Particles*, H. PALEVSKY. BNL 50059 (T-462).

High-Temperature Liquid-Metal Technology Review:

Vol. 4, No. 4, August 1966. BNL 50021 (PR-22).

Vol. 4, No. 5, October 1966. BNL 50030 (PR-23).

Vol. 4, No. 6, December 1966. BNL 50034 (PR-24).

Vol. 5, No. 1, February 1967. BNL 50048 (PR-25).

Vol. 5, No. 2, April 1967. BNL 50054 (PR-26).

Vol. 5, No. 3, June 1967. BNL 50068 (PR-27).

Bibliographies:

Bubble Chambers Bibliography Supplement I, M. COMSTOCK. BNL 8083-Suppl. I.

*Also included are those listings from the last annual report [BNL 994 (AS-20)] for which complete reference information was not then available.

SCISRS Newsletter, Part A, Reference and Bibliography. BNL 50061A (L-391).

SCISRS Newsletter, Part B, Isotope Listing. BNL 50061B (L-391).

Informal Reports:

Selected Cryogenic Data Notebook, BUBBLE CHAMBER GROUP. BNL 10200.

14-Foot Cryogenic Bubble Chamber Project, Title 1 Cost Estimate. BNL 10550.

14-Foot Cryogenic Bubble Chamber Project, Title 1 Report. BNL 10700.

Bulletin of the Medical Department, Brookhaven National Laboratory, August 1, 1966. BNL 10722.

14-Foot Cryogenic Bubble Chamber Project. BNL 11400.

Miscellaneous:

Neutron Cross Sections, BNL 325, Second Edition, Supplement No. 2:

Vol. IIB, Z = 41 to 60.

Vol. IIC, Z = 61 to 87.

Progress Report of Work Sponsored by the Fuels and Materials Branch, Division of Reactor Development and Technology, United States Atomic Energy Commission (Official Use Only): Quarterly, July 1 – September 30, 1966. BNL 50020 (T-440).

Annual, January 1 – December 31, 1966. BNL 50039 (T-451).

Quarterly, January 1 – March 31, 1967. BNL 50052 (T-459).

Quarterly, April 1 – June 30, 1967. BNL 50065 (T-466).

Weekly Bulletin 20, No. 5-52; 21, No. 1-3.

Weekly Selected Reading List 19, No. 12-52; 20, No. 1-9.

STAFF PUBLICATIONS AND ABSTRACTS

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- SCHWARZSCHILD, A. - See KISTNER, O.C.
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- SKILLICORN, I.O. - See BAUMEL, P.; CRENNELL, D.J.; DORNAN, P.J.; GOLDBERG, M.; SCARR, J.M.; SCHUMANN, T.G.
- SKJEGGESTAD, O. - See CANTER, J.; HILL, D.G.
- SMOLUCHOWSKI, R. - See DIENES, G.J.; WILSON, W.D.
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- TAKAHASHI, K. - See SCHARFF-GOLDHABER, G.
- TEIGER, J. - See GIACOMELLI, G.; LEONTIC, B.A.
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- WORWETZ, H.A. - See BAMBERGER, J.A.; WHETSTONE, C.N.
- WRIGHT, J.A. - See LEVINE, M.J.
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Reactor Division

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Sept. 1966	BNL 50015 (T-436)
Oct. 1966	BNL 50018 (T-439)
Nov. 1966	BNL 50026 (T-443)
Dec. 1966	BNL 50032 (T-448)
Jan. 1967	BNL 50037 (T-450)
Feb. 1967	BNL 50043 (T-453)
Mar. 1967	BNL 50047 (T-456)
Apr. 1967	BNL 50050 (T-457)
May 1967	BNL 50056 (T-461)
June 1967	BNL 50063 (T-464)
- TICHLER, P.R. - See Kinne, G.C.

Appendix B

OFFICERS AND SCIENTIFIC AND PROFESSIONAL STAFF

Maurice Goldhaber, *Director*
 Clarke Williams, *Deputy Director*
 (retired June 30, 1967)
 Victor P. Bond, *Associate Director*
 Rodney L. Cool, *Associate Director*
 Charles E. Falk, *Associate Director**
 George H. Vineyard, *Associate Director*
 R. Christian Anderson, *Assistant Director*
 William J. Catacosinos, *Assistant Director*
 G. Norris Glasoe, *Assistant Director*
 Samuel Tucker, *Assistant Director*

G. Kenneth Green, *Chairman*, Accelerator Department
 Yoshio Shimamoto, *Chairman*, Applied Mathematics Department
 C.H.W. Hirs, *Chairman*, Biology Department
 Richard W. Dodson, *Chairman*, Chemistry Department
 Horner Kuper, *Chairman*, Instrumentation and Health Physics Department
 Eugene P. Cronkite, *Chairman*, Medical Department
 Warren E. Winsche, *Chairman*, Nuclear Engineering Department
 R. Ronald Rau, *Chairman*, Physics Department
 Irving J. Polk, *Head*, Mechanical Engineering Division
 Robert W. Powell, *Head*, Reactor Division

J. Georges Peter, *Director*, Architectural Planning
 (retired November 30, 1966)
 Vincent R. O'Leary, *Budget Officer*
 Lewis R. Burchill, *Controller*
 Dennis Puleston, *Information Officer*
 Charles F. Dunbar, *Legal Counsel*
 N. Peter Rathvon, Jr., *Associate 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
 John C. Alderman
 Theodore Alper
 David A. Barge
 Mark Q. Barton
 Kenneth Batchelor*
 (assigned from
 Rutherford High Energy Laboratory,
 England)
 Gerald W. Bennett

*Terminated before July 1, 1967.

Arnold Benton
 David Berley
 Richard A. Beth
 John W. Bittner
 John P. Blewett
 Leroy N. Blumberg
 Richard B. Britton
 Hugh N. Brown
 Theodore Carides
 Alberto G. Carlucci
 Charles A. Casey
 Richard L. Cassel
 Renate W. Chasman
 Peter J. Clarke
 Johannes Claus
 George W. Cornish, Jr.

James G. Cottingham
 Joseph A. Curtiss
 Per Fridtjof Dahl
 Gordon T. Danby
 Donald A. Davis
 Edward W. Dexter
 Henry M. Doupe*
 Emory G. Egler
 Arthur J. Enright*
 Jean Faure*
 (assigned from
 Commissariat à l'Énergie Atomique,
 Saclay, France)
 Arnold V. Feltman
 Horst W. J. Foelsche
 Eric B. Forsyth

John D. Fox
 Robert S. Frankel
 Martin Fruitman
 Sheldon Fuchs
 John J. Gabusi
 Bernard D. Garfinkel
 William Gefers
 Salvatore T. Giordano
 Joseph W. Glenn, III
 Eileen C. Gran
 Harald Hahn
 Henry J. Halama
 Joseph P. Hannwacker
 William E. Harrison, Jr.
 John C. Herrera
 Charles J. Hoch
 Garrett A. Hughes
 Robert S. Hulliger
 John W. Jackson
 David D. Jacobus
 Kurt Jellett
 Tohru Kamei
(on leave from Univ. of Tokyo, Japan)
 Henry Kasha
 Ralph R. Kassner
 John T. Keane
 Vincent J. Kovarik
 John H. Lancaster
 Ronald F. Lankshear
 Robert A. Larson
 Lawrence B. Leipuner
 Gerald S. Levine
 Su Tang Lin
 Isador J. Livant
 Walter Livant
 Robert E. Lockey
 Robert A. Loper
 Edward A. MacDougall
 Alfred W. Maschke
 Harvey McChesney, Jr.
 Austin D. McInturff
 Lowell McLean
 Andrew J. McNerney
 Walter W. Merkle
 Peter A. Montemurro
 Melvin Month
 William H. Moore, Jr.
 Gerry H. Morgan
 Donald W. Mueller*
*(assigned from
 Los Alamos Scientific Laboratory)*
 Ronald J. Nawrocky
 Albert C. Nerenberg
 Barbara Ann Norman
 Leslie W. Oleksiuk
 Jean M. Oostens
 Arthur N. Otis, Jr.
 George Parzen
 Robert L. Pease
 Jens C. Pettersen

*Terminated before July 1, 1967.

Martin Plotkin
 Sepp J. Prunster
*(on leave from Physikalisches Staatsinstitut,
 Institut für Experimentalphysik, Hamburg,
 West Germany)*
 Eugene C. Raka
 George Rakowsky
 Raymond H. Rheaume
 David S. Robertson*
 Everett J. Rutan
 William B. Sampson
 Ralph T. Sanders
 James R. Sanford
 Albert J. Schoenemann
 Mykola Sereda*
 Joseph F. Sheehan, Jr.
 Edward E. Shelton
 Malcolm H. Slade*
(postdoctoral appointment)
 Theodorus J.M. Sluyters
 Lyle W. Smith
 Anastasios Soukas
 Joel W. Spinner
 Julius Spiro
 Raymond J. Stefanski
(graduate student from Yale Univ.)
 Colin D. Stewart
 Robert C. Talsma
 Timothy E. Toohig
 Arthur Tranis
 Clarence M. Turner
 Arie van Steenbergen
 Uriel Vogel
 Ching Lin Wang
 Thomas P. Wangler*
(postdoctoral appointment)
 Arnold R. Watts
 Irwin Weitman
 Theodore L. Werntz
 George W. Wheeler
 Richard L. Witkover
 Samuel P. Yamin
(postdoctoral appointment)

Applied Mathematics Department

Yoshio Shimamoto, *Chairman*
 Barry S. Arbeit
 George A. Baker, Jr.
 Roger R. Baldwin
 Lydia Bargiuk
 Roquez Bejarano*
 Steven Bender
 Carmen M. Benkowitz
 Harold C. Berry
 Kenneth J. Brightman
 Alfred G. Burns*
 Graham H. Campbell
 Hong-Bo Chiang
 John E. Denes
 Dennis Eisen*
 Kenneth R. Fannin

Margaret C. Frantz*
 Jerry M. Friedman
 Kurt Fuchel
 Michael D. Goldfarb
 Charles I. Goldstein
 Frederick J. Hamilton
 Arthur D.S. Harris
 Janet I. Head
 Sidney Heller
 Sin Hitotumatu
*(on leave from
 St. Paul's Univ., Tokyo, Japan)*
 Richard S. Horwitz
 Jeanne C. James*
 Richard D. Jenks
 Joseph Kahane
 Anatoly Kandiew
 Minato Kawaguti
 Isidore Kleiner*
 Joshua K. Kopp
 Leslie L. Lawrence
 Alvin A. Legerlotz
 Marc Leopold
 Irwin Lewis
 Robert B. Marr
 Bruce A. Martin
 Gerald M. Nonte
 Stanley J. Osher
 Larry S. Padwa
 Ilse H. Perlman
 Arnold M. Peskin
 Joel D. Pincus
 Marc Platt
 George Rabinowitz*
 Dysart A. Ravenhall
 Nechemiah Reiss*
 Stuart S. Rideout
 Robert N. Salerno
 Carole J. Saurino
 Niels F. Schumburg
 Arthur B. Scott
 Susan M. Sevia
 Morris Skibinsky
 Sharon Spark
 Irwin Steinberg*
 Morris M. Strongson
 Melvin Tainiter
 James K. Thurber
 Ralph A. Trondle
 Betty Weneser*

Biology Department

C.H.W. Hirs, *Chairman*
 Joseph J. Abata
(postdoctoral appointment)
 Emory T. Adams, Jr.
(postdoctoral appointment)
 Nicholas Alonzo
 Ira H. Ames
(postdoctoral appointment)

Karl P. Baetcke
(*postdoctoral appointment*)
Donald G. Baker
Diana C. Bartelt
Arnold M. Becker
Chitranjan Bhatia*
(*postdoctoral appointment*)
Clara A. Bjerknes
Guy Blaudeau
Peter Bodlaender
(*postdoctoral appointment*)
Robert W. Briggs
Marcello C. Buiatti*
(*postdoctoral appointment*)
Alice J. Burton
Kathryn E. Carlson
Roger W. Carlson
Barbara A. Cartwright
David J. Chapman
(*postdoctoral appointment*)
Theodore Chase, Jr.
(*postdoctoral appointment*)
David T. Clarkson*
(*postdoctoral appointment*)
William J. Cole
(*postdoctoral appointment*)
Nicholas C. Combatti
William J. Crotty
(*on leave from New York Univ.*)
Howard J. Curtis
Richard G. Cutler
(*postdoctoral appointment*)
Carol A. Czernick
Margaret Dallyn*
Rosemarie Dearing
Jeanette J. DiCarlo
Marilyn S. Doscher*
(*assigned from*
American Cancer Society, Inc.)
Florence T. Dunne
Winston R. Dykeman*
Marshall G. Elzinga*
Frieda M. Englberger
Murray J. Ettinger
(*postdoctoral appointment*)
Daniel S. Fackre*
Gad Feinstein
(*postdoctoral appointment*)
Aurelie M. France
(*graduate student from Tulane Univ.*)
Walter J. Geisbusch
Om K. Ghei*
(*postdoctoral appointment*)
Ashish K. Ghosh*
(*postdoctoral appointment*)
Joseph S. Giordano, Jr.
David M. Glick*
(*postdoctoral appointment*)
Benjamin F. Graham, Jr.*
(*on leave from Grinnell College*)

*Terminated before July 1, 1967.

Bill Greenberg
Lewis J. Greene
Eleanor Grist
Kenneth L. Grist
Gary E. Hart*
(*postdoctoral appointment*)
William S. Hillman
Geoffrey Hind
Mary H. Hines*
Yoshihiko Hirono
(*postdoctoral appointment*)
Julie Hitt
Richard A. Houghton, III
Sadao Ichikawa*
(*postdoctoral appointment*)
Ikuo Ino
Alexandra H. Jahn
Andrew L. Johnson*
Helen J. Kelly
J. Raymond Klein
Donald Koenig
Willard L. Koukkari
(*postdoctoral appointment*)
Bernt W. Krebs*
(*postdoctoral appointment*)
Jadwiga H. Kycia
Sanford A. Lacks
H. George Latham, Jr.
Myron C. Ledbetter
Robert A. Love, Jr.
Kodumudi M. Marimuthu
(*on leave from Univ. of Michigan*)
James O. Martin
(*postdoctoral appointment*)
Dorothy M. McFadyen*
W. Arthur McKee
Barbara McMillan
Rosario R. Modesto
Jean H. Moutschen*
(*on leave from*
Univ. of Liège, Belgium)
David L. Mulcahy
(*on leave from Univ. of Georgia*)
Herbert Y. Nakatani
Charles H. Nauman
Marta Nawrocky
Leslie F. Nims
Regina Ann Nordstrom
John M. Olson
Theresa F. Petty
James J. Phelan
(*postdoctoral appointment*)
Virginia Pond
Sheldon B. Pravda*
Vernon N. Reinhold
(*postdoctoral appointment*)
Nancy L. Roettinger
Anne F. Rogers
Richard N. Ruffing
John J. Ruscica
Lloyd A. Schairer

Peter D. Schopfer
(*Volkswagen Foundation Fellow*)
Duane D. Schroeder*
(*graduate student from Tulane Univ.*)
Susan S. Schwemmer
Roslyn Shapanka
Elizabeth K. Shaw
Elliott N. Shaw
Harold W. Siegelman
Harold H. Smith
Robert L. Smith
(*postdoctoral appointment*)
Arnold H. Sparrow
Rhoda C. Sparrow
Sylvia S. Springhorn
Carol A. Staley
Robert Steele
William J. Stegeman
F. William Studier
Catarina S. Takahashi*
(*on leave from*
Univ. of São Paulo, Brazil)
Keith H. Thompson
J. Philip Thornber
(*postdoctoral appointment*)
John J. Tilley, Jr.
Arlene L. Ulrich
(*postdoctoral appointment*)
Alan G. Underbrink
(*postdoctoral appointment*)
Jack Van't Hof
Elizabeth A. Weaver
Robert G. Woodley
George M. Woodwell
Ruth V. Wright
Shizuko Yagi
Joseph D. Yourno

Chemistry Department

Richard W. Dodson, *Chairman*
Lloyd Abrams
(*postdoctoral appointment*)
Augustine O. Allen
Michael Ardon
(*on leave from*
Hebrew Univ. of Jerusalem, Israel)
Knut Bachmann*
(*on leave from Technische Hochschule,*
Darmstadt, West Germany)
Elizabeth W. Baker
Bernard R. Baker*
Raymond C. Barile
(*postdoctoral appointment*)
Allan L. Bednowitz
(*postdoctoral appointment*)
Ivan Bernal
Benon H. Bielski
Jacob Bigeleisen
Jean P. Bocquet*
(*NATO Fellow*)

Daeg S. Brenner*
(*postdoctoral appointment*)
Christos S. Capellos
(*postdoctoral appointment*)
Lui-Heung Chan
(*postdoctoral appointment*)
Joseph C.Y. Chen*
David R. Christman
Yung Yee Chu
James C. Cobb*
Philip Coppens
Lester M. Corliss
James B. Cumming
Eileen P. D'Arcy*
Raymond Davis, Jr.
Thomas Dorfmueller*
(*assigned from Federal Ministry
for Scientific Research, West Germany*)
Stanton Ehrenson
Horst Elias
(*on leave from Technische Hochschule,
Darmstadt, West Germany*)
Norman Elliott
Nils E. Erickson
(*on leave from Technische Hochschule,
Darmstadt, West Germany*)
Robert A. Esterlund*
(*postdoctoral appointment*)
Fausta R. Faucitano
(*on leave from Univ. of Pavia, Italy*)
Juan M. Figuera
(*postdoctoral appointment*)
Eena-Mai Franz
Gerhart Friedlander
Lewis Friedman
Janusz M. Gebicki*
Kodasseri P. Gopinathan
(*postdoctoral appointment*)
James R. Grover
Angelo Guarino
(*on leave from
National Research Council, Rome, Italy*)
Robert J.C. Hagemann*
(*on leave from
Commissariat à l'Énergie Atomique,
Saclay, France*)
Walter C. Hamilton
Garman Harbottle
(*on leave to IAEA, Vienna, Austria*)
Julius M. Hastings
Erich O. Hechtl
(*postdoctoral appointment*)
Shiu K. Ho*
(*assigned from Aerospace Corporation*)
Jerome Hudis
Heinrich E. Hunziker*
(*postdoctoral appointment*)
Adolph P. Irsa
Takanobu Ishida*

Malayappa Jeevanandam*
(*postdoctoral appointment*)
Miltiades Karayannis
(*postdoctoral appointment*)
Paul J. Karol
(*postdoctoral appointment*)
Seymour Katcoff
Edward O. Kazimir
(*graduate student from Fordham Univ.*)
John D. Kelley
Charles L. Kibby
(*postdoctoral appointment*)
Kent A. Klanderman*
(*postdoctoral appointment*)
Siegfried R. Krutzik
(*postdoctoral appointment*)
Walter Kunnmann
Roger A. Lalancette
(*postdoctoral appointment*)
Sam J. LaPlaca
Elliot Lebowitz
(*postdoctoral appointment*)
Jacob B. Leventhal
(*postdoctoral appointment*)
Peter Lieberman*
(*graduate student from Brooklyn College,
City Univ. of New York*)
John A. Markisz
(*assigned from Columbia Univ.*)
Harold R. Martin
(*postdoctoral appointment*)
Louis J. Massa
(*postdoctoral appointment*)
Ross McPherson*
(*postdoctoral appointment*)
Toshihiko Migita
(*on leave from Gumma Univ.,
Tenjin-Cho Kiryu, Japan*)
Elizabeth G. Moorhead*
(*postdoctoral appointment*)
Thomas F. Moran*
Stamatios G. Mylonakis
Beverly J. Nine
Elinor F. Norton
John C. Norvell
(*graduate student from Yale Univ.*)
Johann Oesterreicher
(*postdoctoral appointment*)
Mato Orhanovic
(*postdoctoral appointment*)
Catherine T. Paul
Morris L. Perlman
Franz Plasil*
(*postdoctoral appointment*)
Carol S. Redvanly
Louis P. Remsberg, Jr.
Slobodan V. Ribnikar
(*on leave from Boris Kidrich Inst.
of Nuclear Science, Belgrade, Yugoslavia*)
J. Keith Rowley
William Rubinson

Reuben M. Rudman
(*postdoctoral appointment*)
Edward V. Sayre
Stuart E. Scheppele*
(*postdoctoral appointment*)
Werner F. Schmidt
(*postdoctoral appointment*)
Harold A. Schwarz
David Seewald
(*postdoctoral appointment*)
Stanley Seltzer
Anisbert S. Sequeira*
(*IAEA Fellow*)
Shih-Ping Shen
(*assigned from Univ. of Pennsylvania*)
Frederick J. Silkworth, Jr.
Richard D. Spratley*
(*postdoctoral appointment*)
George A. Stassinopoulos
(*graduate student from New York Univ.*)
Kenneth W. Stevens
(*postdoctoral appointment*)
Raymond W. Stoenner
K. Suryanarayanan
(*graduate student from Boston Univ.*)
Norman Sutin
Robert Thomas
(*postdoctoral appointment*)
Sydney O. Thompson
Armin K. Tippe
(*assigned from Fritz Haber Inst.
der Max Planck Gesellschaft,
Berlin, West Germany*)
Benjamin van Zanten*
(*on leave from Vrije Universiteit,
Amsterdam, Netherlands*)
Michael J. Welch
(*postdoctoral appointment*)
Theresa J. Welch
Ralph E. Weston, Jr.
Hans M. Widmer
(*postdoctoral appointment*)
Ronald Withnell
Alfred P. Wolf
Max Wolfsberg
Huei-Ying Yao
(*postdoctoral appointment*)
Patricia K. Zimmerman

Instrumentation and Health Physics Department

Horner Kuper, *Chairman*
Abraham Arnold*
John W. Baum
Robert M. Brown
Michael J. Butler
Miodrag S. Carapic
(*on leave from
Inst. Boris Kidric, Belgrade, Yugoslavia*)
Robert J. Champagne*

*Terminated before July 1, 1967.

Robert L. Chase
 Lester A. Cohen
 Robert D. Colvett
 Frederick P. Cowan
 John B. Deitz
 D. Gerd Dimmler
 Carl H. Distenfeld
 Joachim Fischer
 Charles W. Flood, Jr.
 Charles F. Foelix
 John A. Frizzola
 Lee Gemmell
 William J. Hartin
 William A. Higinbotham
 Andrew P. Hull
 John F. Jacobs
 Marco A. Jamini
 John J. Kelsch
 Kazuo Kemmochi
*(assigned from
 Japan Defense Agency, Tokyo)*
 Hobart W. Kraner
 Peter S. Littlefield*
 Robert O. McClintock
 Charles B. Meinhold
 William Michaelson
 Constance M. Nagle
 Anthony Nappi
 Casimir Z. Nawrocki
 Michael J. O'Brien
 David Ophir
 James P. Palmer
 Smith G. Pearsall
 Leigh F. Phillips
 Margaret A. Poole*
 David W. Potter
 Veljko Radeka
*(on leave from
 Inst. Ruder Boskovic, Zagreb, Yugoslavia)*
 Seymour Rankowitz
 Gilbert S. Raynor
 Edwin J. Rogers
 Martin J. Rosenblum
 Jesús I. Sanchez
*(on leave from Junta de Energía Nuclear,
 Madrid, Spain)*
 Edward J. Scalsky*
 George E. Schwender
 Barry J. Shepherd
 Stanley I. Silverman
 Irving A. Singer
 Maynard E. Smith
 Branko Soucek*
*(on leave from
 Inst. Ruder Boskovic, Zagreb, Yugoslavia)*
 Robert J. Spinrad
 Raymond W. Stong
 Sanford E. Wagner
 Gaylord N. Wall
 Stanley Wood

*Terminated before July 1, 1967.

Mechanical Engineering Division

Irving J. Polk, *Head*
 John R. Aggus
 Richard W. Aichroth
 Richard C. Albert
 Joseph E. Allinger
 Richard C. Amari
 Frank H. Atkinson
 Robert D. Baldwin, Jr.
 Joseph A. Bamberger
 Alden J. Banslaben
 Paul Bezler
 Thomas J. Blair
 Robert Blesch*
*(on leave from
 Argonne National Laboratory)*
 Frank P. Brooks*
 Donald P. Brown
 Thomas W. Brown
 Robert H. Browne
 Vernon J. Buchanan
 Ronald W. Burgess
 Leonard N. Chimienti
 Thomas M. Coyle
 Rudolph Damm
 Jack E. Detweiler
 Carmine DiLullo
 Basil DeVito
 Arthur C. Dick
 Carlo Ferraro, Jr.
 Carl R. Flatau
 Edward H. Foster
 John J. Fuhrmann
 Donald W. Gardner
 Robert J. Gibbs
 Jules B. Godel
 Carl L. Goodzeit
 Charles L. Gould
 Pierre Grand
 Melvin E. Griffing
 John J. Grisoli
 Eugene E. Halik
 Charles R. Hedberg
 John J. Hennessy
 Rudolph S. Hodor
 Kenneth C. Hoffman
 Daniel Hooper
 John N. Hopping, Jr.
 Hendrik Houtsager*
 Hank C.H. Hsieh
 Donald W. Huszagh
 Eugene Jablonski
 Jack E. Jensen
 Marshall G. Jones
 David A. Kassner
 Andrew Kevey
 John T. Koehler
 Calman Lasky
 Paul LeDoux
 Nathan Levenson
 Boris M. Lomonosoff

Joseph Lypecky
 Stanley J. Majeski
 Paul Mandel
 John G. Marinuzzi
 Robert J. McCracken
 Raven B. McKenzie-Wilson
 Thomas F. McKinley
 Hugh T. McTeague
 Anthony P. Meade
 Kurt F. Minati
 Mordechai Montag
 George Nugent
 Adolph Oltmann
 Frederick O. Pallas
 Nicholas J. Parrinello
 Francis C. Pechar
 Paul A. Pion
 Carl J. Pozgay
 Arno Raag
 Clive E. Reed
 Morris Reich
 Louis E. Repeta
 Wesley G. Ripperger
 George Ritzert*
 Eugene W. Rogers
 Albert P. Schlafke, Jr.
 William J. Schneider*
 Joseph C. Schuchman
 Anthony Semplicino
 Stewart Senator
 Donald B. Sisson*
 Gerard E. Tanguay
 Charles Theisen
 Harvey J. Thomas
 Reese D. Thomas
 Helmuth Thorwarth
 Dietrich Trocha
 Vincent Troisi, Jr.
 Stanley L. Ulc
 John C. Walker
 William G. Walker
 Irving J. Winters, Jr.
 Donald H. Wright
 Arieh Zahavi

Medical Department

Eugene P. Cronkite, *Chairman*
 Emil R. Adamik
 Robert E. Aronson
 Harold L. Atkins
 John L. Bateman
(assigned from Columbia Univ.)
 Mervyn C. Berman*
*(on leave from
 Univ. of Cape Town Medical School,
 Republic of South Africa)*
 Donald C. Borg
 Arland L. Carsten
 Arjun Dev Chanana
 Stanton H. Cohn
 Spencer L. Commerford

Robert A. Conard, Jr.
 George C. Cotzias
 Lewis K. Dahl
 Nicholas Delihias
 Ruth M. Drew
 Ralph G. Fairchild
 Arnaldo C. Foradori
(on leave from Univ. of Chile, Santiago)
 Rosemary A. Gellene
 James Z. Ginos
 Wolfgang P. Gordon
(assigned from Mount Sinai Medical and Graduate Schools, New York)
 Frank J. Grady
(assigned from Columbia Univ.)
 Michael L. Greenberg*
(on leave from Mount Sinai Hospital, New York)
 Ernest A. Gusmano*
(medical associate)
 Leonard D. Hamilton
 Lawrence V. Hanks
 Wolfgang Hauser
 Peh P. Ho
(assigned from Mount Sinai Hospital, New York)
 Junichi Iwai
(on leave from Univ. of Tokyo, Japan)
 Mahendra P. Jamuar
(Damon Runyan Fellow)
 Darrel D. Joel
 Horton A. Johnson
 Stanley L. Johnson
 Panayotis G. Katsoyannis
 Charles W. Kim
 Knud D. Knudsen
 Kazuo Kubo
(medical associate)
 Anthony F. Lo Monte
 Robert A. Love
 Harvard Lyman
 Georges R. Mathieu*
(on leave from Fondation Curie, Paris, France)
 Monty J. Montjar
 Maria Nicolaidou
(on leave from St. Sophie's Children's Hospital, Athens Univ., Greece)
 Nobuyoshi Oji
(on leave from Osaka Univ. Medical School, Japan)
 Norbert I. Overweg
(assigned from Mount Sinai Medical and Graduate Schools, New York)
 Paul S. Papavasiliou
 Howard R. Pate
 Mildred Pavelec

Nina B. Pluss
 Edwin A. Popenoe
 Kedar N. Prasad*
 Kanti R. Rai
(Eastern Leukemia Association Fellow)
 Paul N. Reilly
 James S. Robertson
 Charles V. Robinson
 Herbert Savel*
 Lewis M. Schiffer
 Max A. Schmaeler
 Gerald P. Schwartz
 Arlen R. Severson
(assigned from National Inst. of Health)
 Walton W. Shreeve
 Clyde R. Sipe
 Richard D. Stoner
 Rita F. Straub
 Pierre A. Stryckmans*
(on leave from Inst. Jules Bordet, Brussels, Belgium)
 Dimitrios M. Theodoropoulos
(assigned from Mount Sinai Medical and Graduate Schools, New York)
 George M. Tisljar-Lentulis
 Andrew M. Tometsko*
 Edgar A. Tonna*
 Anthony C. Trakatellis
 Donald D. Van Slyke
 Melvin H. Van Woert*
 Paul C. Vincent
(American Cancer Society Fellow; Fellow of the National Health and Medical Research Council of Australia)
 Roderich W. Walter
(assigned from Mount Sinai Medical and Graduate Schools, New York)
 Richard S. Welsh
(assigned from American Heart Association, Inc.)
 Clyde Zalut

Nuclear Engineering Department

Warren E. Winsche, *Chairman*
 Peter D. Adams
 George Adler
 Arnold L. Aronson
 Seymour Aronson
 Michael J. Attardo
(postdoctoral appointment)
 Clemens Auerbach
 Allan Auskern
 David S. Ballantine
(on leave to US AEC, Washington, D.C.)
 Charles B. Bartlett
(on leave to US AEC, Washington, D.C.)
 Wishvender K. Behl*
(postdoctoral appointment)

Morris Beller
 Fritz Bloch
 John S. Bookless
 William Bornstein
 Joseph S. Bryner
 Albert W. Castleman, Jr.
 John Chen
 Jack Chernick
 Joe G.Y. Chow
 Evelyn A. Cisney*
 John T. Clarke
 Peter Colombo
 John F. Conant
 Helen R. Connell
 Noel R. Corngold
(on leave to California Inst. of Technology)
 Anita J. Court
 George E. Cunningham*
(assigned from Isochem, Inc.)
 John H. Cusack
 Hywel A. Davies
(postdoctoral appointment)
 Russell N. Dietz
 Robert F. Doering
 Roy F. Domish
 John J. Dorning, Jr.
 Kenneth W. Downes
 Orrington E. Dwyer
 James J. Egan
 Leonard C. Emma
 Lester G. Epel
 Seymour G. Epstein
 Jack Fajer
 Peter T. Fallon
 Antonio G. Faucitano
(on leave from Univ. of Pavia, Italy)
 Joan F. Felberbaum
 Stephen W. Feldberg
 Richard M. Felder
 Howard L. Fine
 Albert H. Fleitman
 Jack J. Fontana
 Joseph Forrest
 Bernard R. Fox
 Leonard Galanter
 James M. Galligan
 Meyer Garber
 Narciso García
(graduate student from State Univ. of New York, Stony Brook)
 Theodore W. Gilbert, Jr.
(on leave from Univ. of Cincinnati)
 Althea Glines
 Murrey D. Goldberg
 Rubin Goldstein
 Robert W. Goodrich
 Barry M. Gordon
 Leon Green
(on leave to IAEA, Vienna, Austria)
 Margaret W. Greene

*Terminated before July 1, 1967.

David H. Gurinsky
 John C. Hasson*
*(graduate student from
 Polytechnic Inst. of Brooklyn)*
 Loranus P. Hatch
 Michael A. Helfant
 Robert L. Hellens
 Eric Hellstrand*
(on leave from AB Atomenergi, Sweden)
 Joseph M. Hendrie
 Raymond J. Heus
 Frank B. Hill
 Manny Hillman
 Leif R.D. Hjarne
(on leave from AB Atomenergi, Sweden)
 Peter J. Hlavac
 Frederick L. Horn
 Chia-Jung Hsu
 Anthony P. Ingraham
 Hugh S. Isaacs
 Robert J. Isler
 Stanley D. James
 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
 Henry Kramer*
 Theodore J. Kreiger
 Krishnaswamy Krishnamurthy
*(on leave from
 Atomic Energy Establishment,
 Trombay, India)*
 Lawrence E. Kukacka, Jr.
 Daniel F. Leahy
 Gerald S. Lellouche
 Melvin M. Levine
 Steven Lewkowitz
 George C. Lindauer
 Hans Ludewig
(postdoctoral appointment)
 Joseph Lukeian*
 Raymond A. Mackay
(on military leave of absence)
 Donald R. MacKenzie
 Benjamin Magurno
 Bernard Manowitz
 Victoria L. May
 James J. McNicholas
 S. Bradford McRickard
 Donald J. Metz
 Paul A. Michael
 Julius Milau
 Francis T. Miles
 Bertram Minushkin

*Terminated before July 1, 1967.

Horoshi Mizuta*
*(on leave from
 Nippon Atomic Industry Group Co., Ltd.,
 Tokyo, Japan)*
 André J. Mockel*
*(on leave from
 Université Libre de Bruxelles, Belgium)*
 Sophie O. Moore
 M. Luis Muga
(on leave from Univ. of Florida)
 Said F. Mughabghab
 Albert C. Muller
 Leonard Newman
 Akira Nishihara*
*(assigned from
 Asahi Glass Co., Ltd., Yokohama, Japan)*
 Philip F. Palmedo
 Guyon P. Pancer*
 Raymond J. Parsick
 Arthur Paskin
 Sol Pearlstein
 James P. Phelps
 Richard C. Potter*
(postdoctoral appointment)
 James R. Powell, Jr.
 Thomas F. Prach
 Glenn A. Price
 Augustus Prince
 Jacob Pruzansky
 Surendra N. Purohit*
(on leave from AB Atomenergi, Sweden)
 Chad J. Raseman
 James J. Reilly, Jr.
 Powell Richards
 Francis X. Rizzo
 Anthony Romano
 Michael A. Rothbart
 Alexander Sabosto
 Jerome Sadofsky
 Francis J. Salzano
 César A. Sastre
 Clifford H. Scarlett
 Ursula M.R. Schulze
 Donald G. Schweitzer
 John T. Sears
 Bal Raj Sehgal
 Thomas V. Sheehan
 Eiji Shikata*
*(assigned from
 Japan Atomic Energy Research Inst.,
 Tokai-mura)*
 Louis M. Shotkin
 Robert M. Singer
 Louis M. Slater
 Peter Soo
(postdoctoral appointment)
 John L. Speirs*
 Suresh C. Srivastava*
(postdoctoral appointment)
 Louis G. Stang, Jr.
 John R. Stehn

Meyer Steinberg
 Thomas E. Stephenson
 Gerald Strickland
 Herbert Susskind
 James W. Sutherland
 Hiroshi Takahashi
 Ignatius Ning-Bang Tang
 Silvio J. Tassinari
 Morton A. Tavel*
 Troy H. Tidwell, Jr.
(on leave from North Texas State Univ.)
 Richard J. Tivers
 Walter D. Tucker
 William J. Tunney
 Edwin J. Tuthill
 James O. Tveekrem
 John D. Van Norman
 Stephen J. Wachtel
 Jean I. Wagner
 Jekutiell J. Wagschal*
(postdoctoral appointment)
 Charles H. Waide
 John R. Weeks
 Eugene V. Weinstock
 Allen J. Weiss
 Jerome Weiss
 George G. Weth
 Robert G. Wilson
 Virginia H. Wilson
 Henry H. Windsor
 Edward Wirsing, Jr.
 Richard H. Wiswall, Jr.
 Lowell Yemin*
 Wen-Shi Yu
 Martin S. Zucker

Physics Department

R. Ronald Rau, *Chairman*
 Robert J. Abrams
(postdoctoral appointment)
 Sabine Ahrens
 David E. Alburger
 Rahim A. Al-Kital*
(IAEA Fellow)
 Jean Allitti
*(on leave from
 Commissariat à l'Énergie Atomique,
 Essone, France)*
 Harvey A. Alperin
*(assigned from
 U.S. Naval Ordnance Laboratory)*
 José L. Alvarez-Rivas
(postdoctoral appointment)
 Eric W. Anderson
 Richard Arndt
 Alick Ashmore*
*(on leave from
 Queen Mary College, London, England)*
 Elliot H. Auerbach

Charles P. Baker
 Virgil E. Barnes
 Robert H. Bassel
 John A. Benjamin
 Robert H. Bergoffen
 Bernard T. Bertman
 Mulki R. Bhat*
 Edward J. Bleser
 Harry R. Blieden
 Frank A. Blood, Jr.
(postdoctoral appointment)
 Haywood Blum
 Martin Blume
 Gunter Brunhart
 Brian Buck
 John S. Butterworth
*(assigned from U.S. Army Research Office,
 Durham, N.C.)*
 Richard A. Carhart*
(postdoctoral appointment)
 Allan S. Carroll
(postdoctoral appointment)
 Lai-Him Chan
(postdoctoral appointment)
 Yau W. Chan
 Chellis Chasman
 Robert E. Chrien
 Eugene L. Church
(assigned from Frankford Arsenal)
 Suh Urk Chung
(postdoctoral appointment)
 Jack A. Cockrill
 Victor W. Cohen
 Isaac W. Cole
 George B. Collins
 Philip L. Connolly
 Martyn J. Cooper*
(postdoctoral appointment)
 Daniel M. Corley
(graduate student from Univ. of Maryland)
 Ernest D. Courant
 David E. Cox
 Paul P. Craig
 David J. Crennell
 Kathleen M. Crennell
 Bernard B. Culwick
 Stephen A. Cutler
 Arthur C. Damask
 Christopher J.S. Damerell
*(assigned from
 Rutherford High Energy Laboratory,
 England)*
 Myron Danzig*
 William C. Delaney
 Eduardo de Rafael
(postdoctoral appointment)
 Edward der Mateosian
 James A. DiCarlo
(postdoctoral appointment)

George J. Dienes
 Robert P. DiNardo
*(graduate student from
 Stevens Inst. of Technology)*
 William P. Dodd
 Jean V. Domish
 Peter J. Dornan
(postdoctoral appointment)
 Guy T. Emery*
 Victor J. Emery
 Cavid Erginsoy
 Vincenzo Flaminio
*(on leave from
 CERN, Geneva, Switzerland)*
 Kenneth J. Foley
 Hugie L. Foote, Jr.
 William B. Fowler
 B. Chalmers Frazer
 Joseph L. Frieses
 Giorgio M. Giacomelli*
(on leave from Univ. of Bologna, Italy)
 Eli Glazer
 Allen N. Goland
 John J. Golden, Jr.
 Malcolm Goldberg
 Samuel A. Goudsmit
 John J. Gould
 Paola Guidoni*
(on leave from Univ. of Rome, Italy)
 Edward L. Hart*
 Sigrun Hechtl
(postdoctoral appointment)
 Patrick J. Herley
(assigned from Picatinny Arsenal)
 Benjamin H. Hertzendorf
 William J. Hilger*
 David G. Hill
 Donald V. Hirst
 John Hornbostel
 Paul V.C. Hough
 James J. Hurst, Jr.
 Frederick R. Huson
 George J. Igo*
*(on leave from
 Los Alamos Scientific Laboratory)*
 Shelby P. Jessup
 Robert A. Johnson
 Tom Joldersma*
(graduate student from Ohio Univ.)
 Keith W. Jones
 Roger S. Jones
 Sidney H. Kahana*
 George R. Kalbfleisch
 Walter R. Kane
 David T. Keating
 Ian R. Kenyon
 Stuart H. Kern
 Tadashi Kikuchi*
(assigned from Syracuse Univ.)
 Ottmar C. Kistner
 Thomas A. Kitchens, Jr.

Abe I. Korn
*(graduate student from
 Queens College, City Univ. of New York)*
 Saul Krasner*
(assigned from Picatinny Arsenal)
 Thaddeus F. Kycia
 Kwan Wu Lai
 Franklin T. Langdon
 James D. Larson
 John A. Leake
(postdoctoral appointment)
 Barbara Lebowitz
 Kurt Lengweiler
 Boran A. Leontic
 Paul W. Levy
 Kelvin K.Y. Li
 Seymour J. Lindenbaum
 Frederick P. Lipschulz
(postdoctoral appointment)
 Max Lipsicas*
 Georges W. London
*(on leave to
 École Polytechnique, Paris, France)*
 Robert I. Louttit
 William A. Love
 Dierk Luers
 Arne Lunby
*(assigned from
 CERN, Geneva, Switzerland)*
 Mario A. J. Mariscotti
*(on leave from
 Univ. of Buenos Aires, Argentina)*
 Brian R. Martin
(postdoctoral appointment)
 Peter L. Mattern
(postdoctoral appointment)
 Michael McKeown
 Thomas J. McMahon
(assigned from Carnegie Inst. of Technology)
 Daniel McSweeney*
 Jack Menes
 Filippo Menzinger*
(postdoctoral appointment)
 Wesley J. Metzger
(postdoctoral appointment)
 Daniel N. Michael
(postdoctoral appointment)
 Louis Michel*
*(on leave from
 Inst. des Hautes Études Scientifiques,
 Bures-sur-Yvette, France)*
 David J. Miller
(postdoctoral appointment)
 Vincent J. Minkiewicz
 Paul M. Mockett
 Jaime B.A. Moragues
*(assigned from
 Comisión Nacional de Energía Atómica,
 Buenos Aires, Argentina)*
 Thomas W. Morris
 Bernard Mozer

*Terminated before July 1, 1967.

Alfred H. Mueller
(*postdoctoral appointment*)
George T. Mulholland
Yorikiyo Nagashima
(*assigned from Univ. of Rochester*)
Joseph A. Nardi, Jr.
Robert Nathans
John R. O'Fallon
(*assigned from Univ. of Michigan*)
Salvatore Oliva*
John W. Olness
Claude J. Ouannes
(*on leave from*
Centre National de la Recherche Scientifique,
Paris, France)
Tom Oversluizen
Daniel P. Owen
(*graduate student from Cornell Univ.*)
Satoshi Ozaki
Harry Palevsky
Robert B. Palmer
Robert S. Panvini
(*postdoctoral appointment*)
Peter D. Parker*
Laurence Passell
Simon Pasternack
(*Editor of The Physical Review*)
Helmut Paul*
(*on leave from Österreichische*
Studiengesellschaft für Atomenergie,
Vienna, Austria)
Ronald F. Peierls
Francis C. Peterson
(*graduate student from Cornell Univ.*)
Robert H. Phillips
Stanley J. Pickart
(*assigned from*
U.S. Naval Ordnance Laboratory)
Jerry L. Pietenpol
(*postdoctoral appointment*)
Edward D. Platner
Alan R. Poletti
David C.L. Price
(*postdoctoral appointment*)
Albert G. Prodell
Carroll A. Quarles, Jr.
Dusan Radojicic*
David C. Rahm
Neville W. Reay*
(*assigned from Univ. of Rochester*)
Clarence R. Richardson*
Dennis E. Rimmer*
(*assigned from*
United Kingdom Atomic Energy Authority,
Harwell, England)
Herbert Ringel
(*graduate student from*
Queens College, City Univ. of New York)

*Terminated before July 1, 1967.

Robert A. Ristinen
(*on leave to Univ. of Colorado*)
Paul C. Rogers
David C. Rorer
Roy Rubinstein
David G. Ryan
(*assigned from Cornell Univ.*)
Terence M. Sabine
(*on leave from*
Atomic Energy Commission, Australia)
Vance L. Sailor
Mark Sakitt
Nicholas P. Samios
John T. Sample*
(*on leave from Univ. of Alberta, Canada*)
James M. Scarr
(*postdoctoral appointment*)
Gertrude Scharff-Goldhaber
Robert I. Schermer
Richard W. Schopps*
Ivan Schroeder
(*assigned from*
National Bureau of Standards)
Otto W.-B. Schult
(*on leave from Florida State Univ.*)
Thomas G. Schumann
(*postdoctoral appointment*)
Arthur Z. Schwarzschild
Gen Shirane
Ralph P. Shutt
Jovan M. Simic
(*postdoctoral appointment*)
Ian O. Skillicorn
Olaf Skjeggstad
(*on leave from*
Univ. of Oslo, Blindern, Norway)
Gary A. Smith
Joseph E. Smith
John H. Sondericker
Carmelo A. Spirio
Rudolph Sternheimer
Leo Stodolsky*
(*postdoctoral appointment*)
David L. Stonehill*
Richard C. Strand
Myron Strongin
Andrew W. Sunyar
Richard J. Sutter
Stuart K. Tewksbury
(*graduate student from Univ. of Rochester*)
Pedro A. Thieberger
Dallas G. Thompson*
Alan Thorndike
John A. Tjon*
(*on leave from*
Univ. of Nymegan, Netherlands)
Peter D. Townsend*
(*assigned from Picatinny Arsenal*)
George L. Trigg
(*Editor, Physical Review Letters*)

William L. Trousdale
(*on leave from Wesleyan Univ.*)
T. Laurence Trueman
Frank Turkot
William A. Tuttle
Hiromichi Umebayashi
(*postdoctoral appointment*)
Erminia Vaccari
Vance D. Vander Burg
Martinus J. Veltman*
(*on leave from*
CERN, Geneva, Switzerland)
Robert L. Warasila*
Ernest K. Warburton
Oren A. Wasson
(*postdoctoral appointment*)
Richard E. Watson
Medford S. Webster
Harvey E. Wegner
David M. Weigand*
Joseph Wenner
William B. Whitten
Gian Carlo Wick
(*on leave to Columbia Univ.*)
Colin Wilkin
(*postdoctoral appointment*)
Erich H. Willen
Ernest Windschauer
Estarose Wolfson
Yasusada Yamada
(*on leave from Osaka Univ., Japan*)
Joel R. Yellin*
(*postdoctoral appointment*)
Luke C.L. Yuan
Charles A. Zuroff*

Reactor Division

Robert W. Powell, *Head*
Frederick Allenspach
Michael H. Brooks
William J. Brynda
Paul Colsmann
Francis A. Dugan
John J. Floyd
John R. Halpin
Gerald C. Kinne
Paul E. Mamola
Charles L. Osborne
John A. Penney
Jack E. Phillips
dePuyster G. Pitcher
Seymour R. Protter
Walter H. Reed
Ronald J. Reyer*
Dudley Thompson*
Paul R. Tichler
Anthony C. Wood*
(*assigned from*
Atomic Energy Commission, Australia)

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