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Annual Report

July 1, 1963

BROOKHAVEN NATIONAL LABORATORY

Upton, Long Island, New York

Brookhaven National Laboratory is operated under a contract between the United States Atomic Energy Commission and Associated Universities, Inc. This, the fourteenth in a series of unclassified Annual Reports, gives an account of the progress of the Laboratory during the period July 1, 1962-June 30, 1963, and its plan for the future. It is submitted under the terms of Contract No. AT-30-2-GEN-16 between Associated Universities, Inc., and the Atomic Energy Commission.

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On June 2, 1963, the first photograph of nuclear interactions in the 80-in. liquid hydrogen bubble chamber was obtained. This, the world's largest operating chamber, is now available for studies of nuclear forces and the properties of subnuclear particles, with the 33-Bev Alternating Gradient Synchrotron as the source of bombarding particles. Photographs are taken from the lower gallery (right), where a central viewing port and four smaller apertures for photographic equipment are visible in the end plate of the safety chamber. Below this gallery is the hydraulic ram that serves to move the entire chamber assembly along its track, as necessitated by the experimental program. On the top platform is the high vacuum pumping system. The refrigeration equipment and the hydraulic controls are located on the far side of the chamber assembly.

ASSOCIATED UNIVERSITIES, INC.

Figure 1.

ORGANIZATION CHART

JULY 1963

THE NUMBER OF EMPLOYEES IN EACH ORGANIZATIONAL UNIT ON JUNE 30, 1963, IS SHOWN; TOTAL FOR THE LABORATORY, 2910.

Introduction

The program and activities of Brookhaven National Laboratory during the fiscal year 1963 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.

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 ma-

Figure 2.

chines of the Laboratory. They range from measurement 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

Figure 3. Cotton-topped marmoset (*Oedipomidas oedipus*) used in Biology Department studies on cell population kinetics in the epithelia of the oral cavity. The marmoset has a dentition and dental histology similar to that of other primates. Thus, study of the dental and surrounding tissues of this animal allows conclusions to be drawn about these structures in humans. In contrast to other monkeys, the marmoset has the advantage of small size (200 to 350 g), which makes it suitable for the study of cell migration by means of radioactive tracers.

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 disease, 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.

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 briefly below.

Alternating Gradient Synchrotron

The AGS, Brookhaven's 33-Bev proton synchrotron, continued to play a leading role in high energy physics research. On February 15, 1963, the machine schedule of three 8-hr shifts per day, 5 days per week, was increased to 7 days per week. Of the almost 4500 hr available for operation, 67% were used for research in high energy physics. Simultaneous flipping of targets at 3 separate locations around the ring permitted up to 6 experiments to use each machine pulse. Maximum beam intensities of 5×10^{11} protons/pulse were achieved, and beam intensities of 2 to 3×10^{11} protons/pulse continued to be routine.

On August 30, 1962, the work of breaching the main magnet enclosure to provide a beam channel to the 80-in. bubble chamber in the North Experimental Area was completed. The first elements of the separated beam to this area are in place, and preliminary tests of the optics have begun. Construction began in March of an experimental area on the southwest periphery of the ring to accommodate neutrino physics experiments utilizing the primary proton beam, which will be extracted from the AGS and conveyed to this area through a 1-ft hole in the magnet enclosure. This area is expected to be in operation late in 1963.

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

Cosmotron

The Cosmotron, a 3-Bev proton synchrotron, continued to serve as an effective tool for the per-

formance of high energy physics research. Completion of the present backlog of approved experiments will require at least two years of running time. Continued efforts to improve beam intensity have resulted in a maximum intensity to date of $>10^{12}$ protons/pulse at 3 Bev. The Cosmotron operates continuously on a schedule of 3 shifts per day, 7 days per week, with ≈ 2 shifts a week programmed for routine maintenance. Almost 8000 hr were available for machine operation, with $\approx 54\%$ being devoted to high energy physics research. Additional information on the Cosmotron is given in the section on High Energy Accelerators.

60-in. Cyclotron

The 60-in. cyclotron accelerates protons to 10 Mev, deuterons to 20 Mev, and helium ions to 40 Mev. In addition, a modification currently in progress will make possible the acceleration of He^3 ions to 30 Mev. The He^3 beam is intended chiefly for nuclear reaction studies, but it will also be useful for the production of neutron-deficient isotopes. Deflected beams up to 50 μa as well as internal and externally focused beams are available. A small external beam with momentum analysis to 1 part in 1000 is routinely used. The cyclotron was used by scientists from several Brookhaven departments as well as from 10 outside institutions during the past year. Work for outside institutions and work by guests and collaborators from outside institutions accounted for approximately half of the machine time. The principal activities involved nuclear reaction studies, production of radioactive materials for a wide variety of purposes, and the direct use of the beam for various studies of biological systems. Preliminary work to convert the cyclotron to variable-energy, sector-focusing operation was carried out.

18-in. Cyclotron

The 18-in. cyclotron, which was capable of accelerating protons to an energy of 3 Mev, was officially retired on May 28, 1963, and will be dismantled. This machine was employed for 10 years in neutron-scattering experiments utilizing time-of-flight techniques. The main magnet is being modified for use as a steering magnet at the 60-in. cyclotron.

Electrostatic Generator

This accelerator was operated for research on a routine basis with protons, deuterons, alpha parti-

Figure 4. The recently completed East Experimental Area at the Alternating Gradient Synchrotron. The original Target Building is located beyond the wall on the left.

Figure 5. A hodoscope installation, mounted on a movable railroad track, in the Alternating Gradient Synchrotron target area. This device detects forward-scattered particles. The trailer containing the data recording center is shown at the right.

cles, and He^3 ions with beam currents up to $75 \mu\text{a}$. The recent installation of a new accelerator tube increased the maximum energy at which the machine may be operated from 3.2 to 4.0 Mev and thereby increased the types of nuclei upon which significant experiments may be carried out. During the past year the machine was operated for research during 529 8-hr shifts. The highest number of shifts in any one month was 60. Approximately 6% of the time was utilized for fast neutron irradiations for the Medical and Nuclear Engineering Departments. The remainder was used mainly for physics research consisting of a variety of experimental measurements on the properties of energy levels in light nuclei. Part of this work made use of the external beam-pulsing system with which it is possible to achieve a full-width time resolution of 5×10^{-10} sec.

Graphite Research Reactor

The in-pile and beam facilities of the Brookhaven Graphite Research Reactor (BGRR), which has been in almost continuous operation since 1950, are used in a variety of programs by Brookhaven personnel and by visiting scientists and engineers from other institutions. The maximum thermal neutron flux available is $\approx 2 \times 10^{13}$ neutrons/cm²-sec. The reactor loading was increased slightly, from 607 to 615 channels, and fuel burn-up continued to average $>40\%$.

The graphite annealing procedure to repair graphite radiation damage was carried out 15 times during the past year. It was established that a maximum graphite temperature of 350°C is required to give the desired results.

During the year the shielding facility and the exponential reactor experimental facility were removed from the top of the reactor, and two new vertical holes 9 ft deep and 4 in. in diameter were drilled in the graphite.

Approximately 35 reactor holes are assigned to BNL research departments. The 9 outside organizations availing themselves of reactor facilities (for other than routine irradiation services) under various cooperative arrangements have accounted for continuous use of an average of 4 experimental holes. A complete report on the BGRR will be found in the section on Technical Operations and Services.

Medical Research Reactor

The Medical Research Reactor (MRR) was constructed for the sole purpose of exploring the

possible applications of nuclear reactors to the study of man and his diseases. Each salient feature of the reactor was designed in relation to its use for therapy and diagnosis, or in the advancement of basic medical science. Operation on an intermittent basis is demanded by the nature of the research program. 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.

The MRR was operated 284 times during the year for a total of 281 Mw-hr. 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 analysis and processing of highly radioactive materials. It includes three hot cells in which chemical operations can be performed remotely while under observation by periscope, and a larger hot cell of the cave type for the physical examination of materials, especially metals of high activity.

Critical Assembly Laboratory

The Critical Assembly Laboratory provides specialized facilities for research in reactor physics and for reactor development studies. The laboratory consists of two critical assembly areas, each with an operating console and assembly room; a small, water-cooled, graphite-reflected neutron source reactor for exponential studies, contained in one of the assembly rooms; two additional assembly cells, one of which houses a pulsed Van de Graaff neutron source for diffusion experiments; and the Minimum Reflection Critical Experiment, a critical assembly located on a platform ≈ 20 ft above ground level in an unshielded silo building with thin steel walls.

High Intensity Radiation Development Laboratory

The High Intensity Radiation Development Laboratory (HIRDL) will be used to obtain engineering data on a variety of radiation sources in the million-curie range and to develop more efficient techniques for handling large-scale radiation sources. This information is essential for the design of future irradiation facilities needed for a wide range of applications of radiation energy. The main design features of the HIRDL are two unique cells, one an irradiation cell for the ex-

Figure 6. A high-sensitivity rare-gas mass spectrometer, used by the Chemistry Department in studies of the ages of meteorites and investigations of the bombardment of satellites in space by cosmic rays and particles from the sun. This instrument is capable of detecting as little as one-billionth of a cubic millimeter of gas.

Figure 7. In a laboratory at the Medical Research Center, a countercurrent distribution apparatus is used to separate medically interesting materials in biochemical studies.

Figure 8. Interior view of the High Intensity Radiation Development Laboratory, showing the two cells for handling and using radioactive sources in the million-curie range. An operator is using remote-control manipulators at the preparation cell, which is used to encapsulate Co^{60} strips in stainless steel and for irradiation or other types of remote-control experiments. To the right is the irradiation cell, where materials are exposed to the radiation sources for use in high-level irradiation studies and the evaluation of various geometric arrangements of sources.

Figure 9. The flying-spot digitizer system, used in the analysis of nuclear interactions photographed in bubble chambers. At the left is the digitizer, including the light-spot generator consisting of a light source and fixed and rotating crossed slits, optical focusing system, precision measuring stage, and high-speed film advance, all mounted on a heavy vibration-free stand. Light signals are received by a photomultiplier tube behind the film and, together with other control and phasing signals, are passed to the electronic circuitry, some of which is shown at the right. Here signals are passed to and received from the IBM 7090 computer.

perimental work with radiation sources, and the other a work preparation cell in which various types of sources will be prepared.

During the past year the installation and testing of the operational and safety equipment and the testing of the shielding of both cells using a 20,000-curie Co^{60} source were accomplished. The encapsulation procedure for 600,000 curies of Co^{60} currently on hand was begun. The total level of radiation expected to be employed in this laboratory is ≈ 2 million curies.

80-in. Hydrogen Bubble Chamber

The 80-in. liquid hydrogen bubble chamber was operated successfully for the first time on June 2, 1963. Approximately 100 stereo pairs of photographs showing beam tracks from an 8-Bev/ c π^-

beam from the AGS were obtained with the magnetic field on. Minor difficulties that developed during the initial operation of the chamber were corrected, and numerous improvements were made. The bubble chamber is expected to be ready for sustained operation in the very near future.

This chamber, with an effective volume of 900 liters, is the largest bubble chamber in the world. The chamber is positioned inside a vacuum chamber; a magnet capable of producing magnetic fields as high as 20,000 gauss and a 280-ton steel yoke complete 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 upon an undercarriage and can be translated, rotated, and elevated as required by the experimental program.

Figure 10. Inside the containment vessel of the High Flux Beam Research Reactor, showing partial construction of the reactor's biological shield (center) at the experimental floor level. Three of the nine experimental stations in the shield can be seen through the temporary structure of steel columns.

Figure 11. In the Medical Research Center, a subject is seated in the whole-body counter for the standard measurement of very low concentrations of internally deposited gamma-emitting isotopes. When the door is closed, the heavy shielding around the subject effectively blocks off outside sources of radiation, such as cosmic rays, which would otherwise affect the detection system. To the right of the door is the scintillation counter system.

MAJOR RESEARCH FACILITIES UNDER DESIGN AND CONSTRUCTION

High Flux Beam Research Reactor

Construction continued throughout the year on the High Flux Beam Research Reactor (HFBR). This reactor is designed to meet the need for higher neutron fluxes that has arisen as experimental techniques have improved. The HFBR will be cooled, moderated, and reflected by heavy water; it will be fueled with 28 ETR-type flat-plate fuel elements of enriched uranium comprising a compact, high-power-density core which will provide a maximum total flux of 1 to 2×10^{15} neutrons/cm²-sec. There will be 9 horizontal beam tubes in the reflector, 2 of them arranged to bring out double beams.

The HFBR will be housed in a three-story, circular, domed, gas-tight building. The bottom floor will house the operating machinery for the reactor; the second, or ground, floor will be reserved for beam experiments and laboratories; and the

top floor will accommodate the control room, irradiation experiments, and fuel handling facilities.

The architect-engineer work is being done by the Lummus Company under contract to the Atomic Energy Commission. The reactor is being constructed on Rutherford Hill, southeast of the BGRR's cooling tower. The containment dome and the basic concrete structure inside the dome are complete. At the end of the year the over-all project was 83% finished, with completion scheduled for April 1964.

GENERAL CONSTRUCTION PROGRAM

As previously mentioned, the work on the opening in the AGS tunnel to allow beams to be conducted to the North Experimental Area was completed in August 1962, and work on the Southwest Experimental Area at the AGS was begun in March 1963.

Construction was begun in September 1962 and completed in June 1963 of an addition to the Cos-

Figure 12.

motron which provides an area of 13,500 square feet for laboratories, offices, and machine shops.

On September 28, 1962, ground was officially broken for the new Instrumentation and Health Physics Building. This structure, when completed in the summer of 1964, will replace 4 temporary wooden World War II buildings in 2 locations. It will provide 47,000 square feet of space for laboratories, offices, and shops.

Ground was broken on February 19, 1963, for the new Chemistry Building which will also replace several temporary wooden structures dating from World War II. This three-story cross-shaped building, with a floor space of 138,000 square feet, is expected to be complete in the summer of 1965.

Construction is scheduled to begin during the first quarter of fiscal 1964 on the Physics and Mathematics addition to the Physics Building, the Controlled Environment Laboratory, and the water treatment plant. Construction of a steam plant addition, a low background counting facility for the Medical Research Center, and a tandem Van de Graaff accelerator facility is also scheduled to begin in fiscal 1964, contingent on congressional approval.

The *BNL Master Plan*, which discusses the Laboratory's present and future buildings and site plans, was reissued during the year, and detailed planning is currently under way for many of the laboratories and facilities required to meet Brookhaven's needs. These include the Administrative Services Center, the Lecture Hall-Cafeteria, the Central Shops Building, the AGS North Experimental Building, and the Nuclear Engineering Building, Phase II. Brookhaven will request a continuation of this building program for future years

so that its function as a research center can be efficiently and economically fulfilled.

PERSONNEL

The total number of employees at Brookhaven National Laboratory on June 30, 1963, excluding temporary appointees, Research Collaborators, and guests, was 2910. This represents a net increase over fiscal 1962 of 317, or 11.5%. During fiscal 1963 the regular salaried scientific staff (Ph.D. or equivalent) increased from 336 to 369, Research Associates from 76* to 80,* and salaried visitors from 27* to 31,* for a total increase in the salaried staff from 439 to 480. The nonsalaried scientific staff increased from 479 in 1962 to 516 in 1963 as of May 31 of these years. These visitors are not at Brookhaven on a full-time basis. About one-fourth to one-third of them are on site at any given time. About 550 (as compared to 503 the previous year) visiting scientists and students (salaried and nonsalaried) worked at the Laboratory during the year; this number does not include Research Associates. These individuals were affiliated with 213 different institutions. The total number of professional employees (B.S. or equivalent) increased during the year from 229 to 270.

Summer visitors continued to play a significant role in the Laboratory's program. Arrangements have been made for 340 visiting scientists and students to work at Brookhaven during the summer of 1963. Of this number, 156 are staff members from various educational and research institutions, and 184 are students.

*These figures include students. For further details, see Tables 1 and 2 in the section on Administration and Operations.

ADMINISTRATION

The organization of the Laboratory, as of July 1963, is given in Figure 1. On October 19, 1962, the Board of Trustees of AUI appointed Dr. I.I. Rabi as Chairman of the Board to succeed Dr. R.S. Halford of Columbia University and appointed Dr. G.F. Tape as President. Dr. Rabi had served as President since April 1961, and Dr. Tape as Vice President since January 18, 1962.

On March 22, 1963, the White House announced the appointment of Dr. Tape to the U.S. Atomic Energy Commission to replace Dr. L.J. Haworth, whose appointment as Director of the National Science Foundation was announced at the same time. On July 10, 1963, Dr. Tape resigned as President of AUI to assume his duties as an AEC Commissioner. Pending the selection of a permanent successor to Dr. Tape, Mr. Edward Reynolds was appointed President to serve until the annual meeting of the Board of Trustees in October. Mr. Reynolds, formerly Administrative Vice President of Harvard University, has been a

member of AUI's Board of Trustees since the corporation was organized in 1946. He was also its first President, serving from 1946 to 1948, and again for a brief period in 1961. He was a Vice President from 1961 to 1962.

Effective July 1, 1963, the Applied Mathematics Division became the Applied Mathematics Department. Dr. John W. Calkin was appointed Chairman of the new Department, to serve for a period of five years.

In December 1962 Dr. F.T. Miles, Deputy Chairman of the Nuclear Engineering Department, was granted leave of absence to accept a two-year appointment as Director of the Division of Reactors in the Department of Technical Operations of the International Atomic Energy Agency in Vienna, Austria.

FINANCE

AEC-supported research at the Laboratory continued to be financed by the AEC Divisions of Reactor Development, Research (Physical Sciences),

Figure 13.

Table 1

Organizational Expenditures - Fiscal 1961, 1962, 1963

(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	1963	8,637,495	335,333	198,836	3,686,095	94,830	634,176	—	13,586,765	36.7	425.5	584.5	1,010.0
	1962	6,703,649	229,532	163,881	2,399,307	250,803	402,092	(1,000)	10,148,264	34.2	375.0	438.0	813.0
	1961	5,831,438	191,771	159,766	2,196,171	110,902	342,521	—	8,832,569	34.4	339.5	372.0	711.5
Biology, Medicine & Biophysics Research	1963	2,753,044	112,478	76,131	721,110	125	—	(1,128)	3,661,760	9.9	148.5	212.0	360.5
	1962	2,493,351	86,324	81,635	603,116	770	—	(5,303)	3,259,893	11.0	140.5	194.5	335.0
	1961	2,301,162	76,928	90,853	554,921	3,642	—	(6,125)	3,021,381	11.8	135.0	183.0	318.0
Nuclear Engineering Research	1963	2,420,259	72,127	91,592	769,155	437,859	—	—	3,790,992	10.2	118.0	141.5	259.5
	1962	2,208,169	38,870	85,757	592,567	113,116	—	—	3,038,479	10.2	113.0	129.0	242.0
	1961	1,865,931	44,166	74,706	443,491	144,350	—	—	2,572,644	10.0	104.5	111.5	216.0
Isotope Development	1963	345,204	6,570	8,356	135,446	103,935	—	—	599,511	1.6	19.5	18.0	37.5
	1962	193,727	6,897	10,165	67,888	47,119	—	—	325,796	1.1	13.5	10.5	24.0
	1961	136,682	6,075	7,795	60,949	(2,198)	—	—	209,303	0.8	11.0	5.5	16.5
Training & Education	1963	48,485	2,752	31,139	5,582	7,029	—	—	94,987	0.3	3.5	1.5	5.0
	1962	47,838	3,419	26,789	30,185	2,093	—	(6,800)	103,524	0.4	3.5	0.5	4.0
	1961	29,635	3,643	21,167	15,291	5,664	—	(2,000)	73,400	0.3	3.5	2.5	6.0
Radiation Protection	1963	523,807	2,201	4,412	179,110	11	—	(491)	709,050	1.9	12.5	53.0	65.5
	1962	475,329	2,258	5,677	85,619	—	—	—	568,883	1.9	3.0	47.0	50.0
	1961	435,473	4,083	3,617	75,080	—	—	(1,115)	517,138	2.0	11.5	46.5	58.0
Supporting Scientific & Technical Services	1963	4,456,791	17,931	30,827	738,555	758,812	255,073	(134,749)	6,123,240	16.5	63.0	422.5	485.5
	1962	3,607,195	22,184	26,812	1,116,269	19,470	281,880	(129,824)	4,943,986	16.7	67.0	365.5	432.5
	1961	3,172,192	14,664	22,724	622,241	4,665	321,217	(167,786)	3,989,917	15.5	53.0	326.5	379.5
Security & Plant Protection	1963	584,084	—	619	18,661	—	—	1,932	605,296	1.6	—	75.5	75.5
	1962	580,958	552	876	9,841	—	—	2,331	594,558	2.0	—	75.0	75.0
	1961	596,392	833	502	11,620	—	—	1,946	611,293	2.4	—	77.0	77.0
Miscellaneous (including Lighting, T & T, Heating Fuels, Special Maintenance, etc.)	1963	—	—	2,246	266,568	(11,457)	421,009	937,806	1,616,172	4.4	—	—	—
	1962	—	—	908	183,800	(8,827)	363,404	838,735	1,378,020	4.6	—	—	—
	1961	—	—	(6,640)	172,465	—	311,453	697,911	1,175,189	4.6	—	—	—
General and Administrative	1963	4,357,676	55,716	89,366	870,938	21,757	—	97,690	5,493,143	14.9	37.0	576.5	613.5
	1962	4,053,265	51,371	151,104	572,470	15,200	—	(27,123)	4,816,287	16.2	—	563.5	563.5
	1961	3,805,697	35,614	126,328	505,433	(15,234)	—	(191,927)	4,265,911	16.6	—	539.5	539.5
Laboratory Total	1963	24,126,845	605,108	533,524	7,391,220	1,412,901	1,310,258	901,060	36,280,916	98.0	827.5	2,085.0	2,912.5
	1962	20,363,481	441,407	553,604	5,661,062	439,744	1,047,376	671,016	29,177,690	98.3	715.5	1,823.5	2,539.0
	1961	18,174,602	377,777	500,818	4,657,662	251,791	975,191	330,904	25,268,745	98.4	658.0	1,664.0	2,322.0
AUI Administration	1963	—	—	—	—	—	—	475,000	475,000	1.3	—	—	—
	1962	—	—	—	—	—	—	230,700	230,700	0.8	—	—	—
	1961	—	—	—	—	—	—	209,700	209,700	0.8	—	—	—
Total AUI and BNL	1963	24,126,845	605,108	533,524	7,391,220	1,412,901	1,310,258	1,376,060	36,755,916	99.3	827.5	2,085.0	2,912.5
	1962	20,363,481	441,407	553,604	5,661,062	439,744	1,047,376	901,716	29,408,390	99.1	715.5	1,823.5	2,539.0
	1961	18,174,602	377,777	500,818	4,657,662	251,791	975,191	540,604	25,478,445	99.3	658.0	1,664.0	2,322.0
Work for Others, Direct Costs Only	1963	63,409	36	11,501	152,217	20,922	—	—	248,085	0.7	8.5	5.0	13.5
	1962	75,079	1,806	4,015	111,789	61,570	—	—	254,259	0.9	7.5	7.5	15.0
	1961	75,896	1,910	3,388	45,537	62,590	—	—	189,321	0.7	9.0	5.5	14.5
Grand Total	1963	24,190,254	605,144	545,025	7,543,437	1,433,823	1,310,258	1,376,060	37,004,001*	100.0	836.0	2,090.0	2,926.0
	1962	20,438,560	443,213	557,619	5,772,851	501,314	1,047,376	901,716	29,662,649**	100.0	723.0	1,831.0	2,554.0
	1961	18,250,498	379,687	504,206	4,703,199	314,381	975,191	540,604	25,667,766†	100.0	667.0	1,669.5	2,336.5

* \$925,374 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.

** \$712,038 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.

† \$433,401 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.

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 Figure 13. Details of the operating expenditures of the Laboratory on a broad operational basis are given in Table 1.

The Laboratory's research costs, operations plus expenditures for capital equipment, increased by

nearly \$10,600,000, with high energy research accounting for >35% of the increase. The Laboratory's research costs represented 99.93% of the AEC cost ceilings.

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.

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

	FY 1963		FY 1962		FY 1961	
	\$	%	\$	%	\$	%
Scientific & hospital	10,021,696	95.2	6,604,023	93.6	5,220,768	92.0
Automotive & heavy mobile	195,927	1.9	154,852	2.2	198,411	3.5
Office machines & furniture	125,626	1.2	87,252	1.2	94,738	1.7
Shop equipment	134,232	1.3	159,313	2.3	136,201	2.4
Miscellaneous	39,843	0.4	46,661	0.7	24,462	0.4
Expenditures, Total	10,517,324	100.0	7,052,101	100.0	5,674,580	100.0
Proceeds from sales	(63,770)		(12,665)		(22,036)	
Expenditures, Net	10,453,554		7,039,436		5,652,544	

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

	FY 1963			FY 1962			FY 1961		
	Man-years			Man-years			Man-years		
	Costs, \$	Sci.	Others	Costs, \$	Sci.	Others	Costs, \$	Sci.	Others
<u>Alternating Gradient Synchrotron</u>									
Direct									
Salaries, wages, insurance	—	—	—	—	—	—	192,317	4.5	20.0
Materials, construction, etc.	245,413			1,226,016			2,486,877		
Subtotal direct	245,413			1,226,016			2,679,194		
Charges from organizational units	29,894			22,231			65,834		
Total	275,307			1,248,247			2,745,028		
<u>Other, Including High Flux Beam Research Reactor and 80-in. Bubble Chamber</u>									
Direct									
Salaries, wages, insurance	557,471	21.0	29.0	776,466	32.5	49.5	454,041	24.0	28.0
Materials, construction, etc.	14,178,652			10,079,560			7,174,253		
Subtotal direct	14,736,123			10,856,026			7,628,294		
Charges from organizational units	635,402			476,206			230,004		
Total	15,371,525			11,332,232			7,858,298		

Table 4
Inventory at Close of Fiscal Year

Type of inventory	Fiscal year		
	1963	1962	1961
General stores*	\$ 781,849	\$ 704,424	\$ 524,004
Precious metals and radium	137,745	96,683	84,648
Stable isotopes	32,899	38,793	37,644
Heavy water	674,252	683,039	672,330
Total	\$1,626,745	\$1,522,939	\$1,318,626

*The number of months investment was 3.0 in 1963, 3.5 in 1962, and 3.0 in 1961.

BROOKHAVEN NATIONAL LABORATORY
COMPARATIVE BALANCE SHEET

	June 30, 1963	June 30, 1962
<u>Assets*</u>		
Cash	\$ 1,433,405	\$ 435,663
Accounts receivable	271,039	187,917
Advances and prepaid expenses	146,902	113,667
Deposits	88,605	76,008
Property, plant, and equipment (less reserves of \$44,470,532 at June 30, 1963, and \$39,176,059 at June 30, 1962)	87,794,537	83,524,884
Construction in progress	26,192,785	17,851,202
Research materials and supplies	6,987,689	6,142,313
Total assets	<u>\$122,914,962</u>	<u>\$108,331,654</u>
<u>Liabilities</u>		
Accounts payable	\$ 4,358,184	\$ 4,301,914
Accrued vacations**	2,009,541	
Accrued payroll	205,571	177,688
Atomic Energy Commission	116,341,666	103,852,052
Total liabilities	<u>\$122,914,962</u>	<u>\$108,331,654</u>

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

**In accordance with a request from the Atomic Energy Commission, the Laboratory recorded the liability for accrued earned vacations at June 30, 1963. The amount of \$1,706,387 for accrued earned vacations at June 30, 1962, was treated as a contingent liability in accordance with the Atomic Energy Commission's reporting requirements in effect at that time.

CONFERENCES

Ten formal conferences were held at the Laboratory during the fiscal year. Among these were the High Energy Linear Accelerator Conference, August 20-24; the ninth Conference on Reaction Mecha-

nisms, September 5-8; the Rapid Data Processing Conference, September 20-21; the Symposium on Chemistry in Medicine, March 28-29; the High Temperature Fuels Committee Meeting, May 15-17; and the sixteenth Brookhaven Biology Symposium, titled "Meristems and Differentiation," June 3-5.

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, and the Graphite 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, atomic and molecular 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 national character of Brookhaven National Laboratory is in no way better illustrated than by the list of universities and laboratories participating in the particle physics program. About two thirds of the work at the Alternating Gradient Synchrotron (AGS) and the Cosmotron is done by groups from these organizations. During fiscal 1963 more than 240 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:

Argonne National Laboratory
Brandeis University
Brown University
California Institute of Technology
Carnegie Institute of Technology
City University of New York
Duke University
Iowa State University
Naval Research Laboratory
New York University
Northwestern University
Ohio University
Rutgers University
Syracuse University
University of California at Berkeley
University of California at La Jolla
University of Chicago
University of Illinois
University of Indiana
University of Kentucky
University of Maryland
University of Miami
University of Michigan
University of Washington
University of Wisconsin

Guest scientists also included representatives of the following foreign laboratories: Cambridge University, England; Centre d'Études Nucléaires de Saclay, France; CERN, Switzerland; École Polytechnique, France; Institut Interuniversitaire des Sciences Nucléaires, Belgium; Osaka City University, Japan; Panjab University, India; University of Padua, Italy; University of Rome, Italy; and Woodstock College, England.

Research at the Cosmotron

The study of resonances (excited states which can decay rapidly by strong interaction into other

particles) continued to dominate the research done at the Cosmotron in the past year. Physicists are seeking to understand the mechanism of production of these states and to determine their basic properties – mass, spin, isospin, parity, lifetime, and decay modes.

Further analysis of the experimental work done by the Cambridge Bubble Chamber Group with their bubble chamber filled with propane, methyl iodide, and methane has brought additional interesting results to light. Use of this type of dense liquid in a bubble chamber allows the observation of gamma rays by their conversion into electron-positron pairs. The reaction studied was $\pi^- + p \rightarrow \eta^0 + n$. The photographs were searched for evidence that the η had decayed into two gamma rays. The experimental technique consists of scanning for all interactions in which π^- mesons show no prongs on stopping but are associated with electron-positron pairs. The mere detection of this decay mode establishes the fact that the η has even spin, since the gamma has spin 1. A kinematic analysis indicates that the spin assignment should be zero rather than 2. Assuming spin zero, the failure to observe a two-pion decay mode implies odd parity.

A group from Yale University using the Brookhaven 20-in. hydrogen bubble chamber produced η mesons from the interaction of positive π mesons with protons. Their results, in addition to confirming those of the Cambridge Bubble Chamber Group, favor spin zero, odd parity, and even G parity (i.e., 0^{++}) and definitely exclude the simple isospin-conserving assignments 0^{--} , 1^{+-} , or 1^{--} . (In last year's annual report it was pointed out that a Brookhaven group had tentatively arrived at this assignment based on preliminary data.) They further observed at most only a small amount of the decay mode $\pi^+ + \pi^- + \gamma$ in their data. The fact that isospin is not conserved in the decay into three pions means that electromagnetic interaction should be involved in this decay. It thus seems rather surprising that the $\pi^+ + \pi^- + \gamma$ decay mode is so infrequent. In agreement with previous results of others, they conclude that the η mass value is ≈ 550 Mev with a half-width of < 5 Mev.

Another experiment to study the production and decay of the η meson was performed by a group from the University of Pennsylvania. Using the BNL-Columbia 30-in. bubble chamber filled with deuterium in a positive pion beam, they took

75,000 photographs. The results have not yet been analyzed.

A Brookhaven group, in collaboration with one from the Carnegie Institute of Technology, investigated the production of pion resonances (at proton energies from 1.5 to 2.5 Bev) from the reaction $p + p \rightarrow d + X$, in which X could be a π , ζ , ρ , or other meson with isotopic spin of unity. The deuteron was identified by time-of-flight techniques, and its formation in the final state meant that large momentum transfers had taken place in the interaction. Particle X was not detected directly, but its existence was inferred from the direction and momentum of the deuteron. The experiment revealed, as expected, copious production of π mesons, but somewhat surprising was the observation that production of π mesons at zero degrees increased with increasing incident proton energy. An analysis of this result suggests that even at the large momentum transfers involved here (≈ 1 Bev/ c) the interaction is consistent with one-pion exchange (OPE), the model in which the nucleon supplies a pion in a virtual state from which the incident pion scatters). Only a comparatively small production of ρ mesons was observed; this is consistent with experiments using incident π mesons in which it was found that ρ mesons occur predominantly in low momentum transfers. A prominent peak in the mass spectrum of particle X was found at 950 Mev. Pion resonances of about this energy have been tentatively reported by other experimenters, but verification that this peak indicates a resonance awaits further work. No evidence for the ζ was found at any energy.

Confirmation of these results may be obtained from a comparison experiment, $p + d \rightarrow \text{He}^3 + X$, which is planned for the Cosmotron. This experiment will extend the study of production processes at high momentum transfers to the production of resonances with isotopic spins of 0, 1, and 2.

A rigorous test of OPE has been suggested by Trieman and Yang, who point out that since the pion has no spin, its exchange can affect only the kinematics of a reaction, and, as a result, certain features of the scattering should show an uncorrelated angular distribution. A Brookhaven group has applied this test to data obtained previously at the Cosmotron. They conclude that the scattering angle asymmetry parameter of the pions forming the ρ^0 produced in the reaction $\pi^- + p \rightarrow \rho^0 + n$ has values that deviate significantly from the val-

ues it should have if the ρ^0 is produced by the mechanism of OPE. There was considerable production of the isobar (an excited state of the nucleon which decays into a pion and nucleon), and this may be the cause of the deviation. In addition, another peak was indicated at 790 Mev in the effective mass distribution which agreed with the theoretically predicted peak expected if the ω meson known to decay only into three pions was stimulated by electromagnetic mixing with the ρ to decay into two pions, as suggested by this group in last year's report. The existence of this peak has been confirmed by work at the AGS (see below, under the heading "Research at the Alternating Gradient Synchrotron").

Some time ago it was established that in single-pion production in π - p collisions there is a strong contribution from large impact parameter (peripheral) collisions, i.e., collisions with small momentum transfer to the nucleon. This effect is manifested in the characteristic backward peaking of the scattering of the nucleon in the center-of-mass system. Observations have shown an excess of these recoil nucleons over the number to be expected from statistical or isobar theory. The data thus suggest strongly that π - π interactions are important, especially when the incident pion has an energy >1 Bev. Assuming the OPE model, it is essentially possible to study the π - π interaction in the pure form, since the emission of the virtual (very short-lived) pion by the nucleon is reasonably well understood, and in any case the details of this emission are not too critical for low momentum transfers to the nucleon. This is the situation that exists in the case of peripheral collisions. An experiment to study the π - π interaction has just been completed at the Cosmotron. 1.6-Bev/ c negative pions were incident on a liquid hydrogen target, and the reaction producing two pions and a nucleon was studied. The experiment is designed to investigate the ρ (dipion) resonance well above and below the broad peak at ≈ 750 Mev. Possible additional dipion resonances will be sought, with the particular objective of establishing a strongly suspected splitting of the ρ mass peak by a two-pion decay of the ω meson. If the ω meson (three-pion resonance) decays into two pions, it must do so by violating isotopic spin conservation. By restricting the observations to pions that decay at 90° in the center-of-mass system, the experimenters have chosen a kinematic region of

interaction that is free from interference from isobar effects and, in addition, limited to very low momentum transfer. More than 10,000 events were accumulated, which will permit conclusions to be drawn with very good statistical accuracy. Work by a Brookhaven group at the AGS has already indicated the existence of the dipion decay mode of the ω (see below).

A similar approach may be used to evaluate $\pi + \pi \rightarrow K\bar{K}$ cross sections. An experiment by a University of Wisconsin group produced K pairs in peripheral π - p collisions which were observed in the BNL 14-in. hydrogen bubble chamber. The three possible reactions are

$$\pi^- + p \rightarrow K^0 + \bar{K}^0 + n,$$

$$\pi^- + p \rightarrow K^- + K^0 + p,$$

$$\pi^- + p \rightarrow K^+ + K^- + n.$$

High energy π^- experiments at CERN have shown that K mesons produced in pairs tend to peak forward in the center-of-mass system, which indicates that a peripheral collision may be involved. Analysis of the rather limited data showed results consistent with the OPE model. Based on this model, rough cross sections were established of ≈ 2 mb for the low energy production of K pairs with zero isotopic spin ($I=0$) and zero angular momentum ($L=0$), and of ≈ 0.6 mb for K pairs with $I=1$, $L=1$. Using these same photographs, the group also studied the reaction $\pi^- + p \rightarrow Y + K + \pi$. The products of this reaction contain a member of each class of the strongly interacting unstable particles. This type of associated production can yield very useful information on the interactions of such particles. The associated production of the K^* and the Λ was not observed, but the results suggest that the associated production of the K^* and the Σ^- does take place, which would account for the observed high rate of production of Σ^- compared to that of Σ^+ . The well-known Υ_1^* was observed with a width greater than that previously reported. The two Υ_0^* resonances at 1410 and 1520 Mev were observed when the bombarding pion momentum was 2.1 Bev/ c , but not when the momentum was lower by 200 Mev/ c . Some indication of two new resonances in the Σ - π system at 1430 Mev and 1550 Mev appeared in the data. The latter may be the Υ_2^* or Z^* resonance predicted in the global symmetry scheme.

A Brookhaven group has continued its study of nucleon charge exchange events. Detailed measurements were completed of the differential charge exchange cross section at 2 and 3 Bev (nominal incident kinetic energy). The observed angular distributions, when transformed to a momentum transfer scale, are the same, within experimental error, at the two incident energies. The distribution is peaked in the forward direction and is extremely narrow, falling to half maximum at a momentum transfer of 150 Mev/ c . The differential cross section at 0° at 2.04 Bev is 26 ± 5 mb/sr and is some 15% greater at 2.85 Bev. The corresponding total cross sections were found to be 0.65 ± 0.15 and 0.43 ± 0.16 mb at 2.04 and 2.85 Bev, respectively. Two important conclusions can be drawn from these results. First, the peaking of the cross section at 0° indicates that one-pion exchange is not the dominant process in the elastic nucleon-nucleon interaction at these energies. This must somehow be reconciled with the recent theoretical success of OPE models in explaining p - p inelastic scattering in this same energy region. Second, the narrow angular distribution indicates that the nucleon interaction has a tail that extends out to a distance of ≈ 2 fermis, whereas previous experimental data (on p - p and e - p scattering) have led to the belief that the proton is an object ≈ 1 fermi in size. It is not too surprising that this tail has not been seen in other measurements, because it represents only $\approx 1\%$ of the total nucleon-nucleon interaction. The reason that the nucleon charge exchange process seems to be an ideal way of observing the weak tail in the nucleon-nucleon interaction is related to the fact that, in contrast to direct scattering, diffraction scattering is not observed in the charge exchange process.

In the area of strange-particle (hyperon and kaon) physics, an interesting result has come to light in recent further analysis of an experiment performed some time ago at the Cosmotron by a Brookhaven-Yale University group using the BNL 14-in. bubble chamber to investigate the interaction of K_2^0 mesons with liquid hydrogen.

The fundamental interactions or forces now known are commonly divided into four classes: strong nuclear interactions, electromagnetic interactions, weak or beta-decay interactions, and gravitational interactions. These are conveniently differentiated on the basis of their different magnitudes and symmetry properties. The assumption

that a unique, well-defined, largely separate description exists for each of the four classes is attractive. Rather less attention has been paid to fundamental connections between these classes of forces, and almost no consideration has been given to the possibility of the existence of forces unrelated to the four known classes, or at least as little related to them as they are to each other.

It is not difficult to conceive of interactions that might exist without being observed or recognized. The effect of the existence of such a class of interaction need not be observed directly. Consider, for example, the importance of electromagnetic forces in elementary particle interactions. Even if $e^2/\hbar c$ were equal to 10^{-30} instead of $1/137$ and electromagnetic forces were, as a practical matter, unobservable experimentally, isotopic spin would still have meaning and importance; e.g., reactions such as $d + d \rightarrow \alpha + \pi$, which do not conserve isotopic spin, would still be forbidden.

The results of this experiment permitted investigation of some possible interactions of this nature, in particular, weak long-range interactions between protons and K mesons which differentiate between K^0 and $\bar{K}^0$. The possibility of such investigation was suggested by M.L. Good of the University of Wisconsin, who pointed out that coherent effects from macroscopic volumes of material may have important observable consequences on the constitution of neutral K -meson beams.

The analysis showed that a beam of 1.0-Bev/ c K_2^0 mesons passing through liquid hydrogen in a bubble chamber generated K_1^0 mesons with the momentum and direction of the original beam. The intensity of K_1^0 production was far greater than that anticipated from conventional mechanisms, which suggests that the K_1^0 mesons are produced by coherent regeneration resulting from a new weak long-range interaction between protons and K mesons.

A University of Pennsylvania group is studying K^0 decays for a different purpose. Assuming zero isospin for the leptons, it follows that certain changes of isospin are possible for strangeness-nonconserving weak interactions. One of the simplest assumptions is the $\Delta I = \frac{1}{2}$ rule which predicts exactly, from the rate at which the K^+ decays into a pion plus leptons, the absolute rate at which the K^0 decays into a pion plus leptons. By observing in a spark chamber the Λ hyperon from the strong interaction $\pi^- + p \rightarrow \Lambda + \bar{K}^0$, a beam of

K_2^0 mesons, known in momentum and intensity, is produced. The rate at which these K_2^0 mesons decay in a spark chamber in a magnetic field allows an absolute measurement of the amplitude for the decay into leptons. A comparison with currently available K^+ data provides a direct test of the $\Delta I = \frac{1}{2}$ rule in K leptonic decays.

An improved experiment for measuring the magnetic moment of the Λ hyperon is being set up in collaboration with a group from MIT. The basic technique is the same: Polarized Λ hyperons from the reaction $\pi^+ + n \rightarrow \Lambda + K^+$ are precessed in a pulsed, high-field magnet. The Λ is detected when it decays in a thin-plate spark chamber. Since the pion from the decay $\Lambda \rightarrow \pi^- + p$ is emitted preferentially in the direction of the Λ spin, the angle that the pion makes with the normal to the production plane is a measure of the precession angle. The K^+ is observed in a thin-plate spark chamber and then stopped in a large, water-filled Cerenkov counter where its decay products may be detected, which gives a cleaner sample of Λ 's. A second method of improving the sample will be to degrade the protons so that they are removed from the incident beam. The pulsed magnet has been redesigned and built to give a peak field of 200 kgauss over a 7-cm path.

A group from the University of California at La Jolla has completed a counter experiment to measure the excitation function and angular distribution for the production of the Υ^* hyperon. The data are being analyzed.

In addition to research in particle physics, 5% of the Cosmotron's experimental time is devoted to a research program carried out by the Chemistry Department, and 3% to experiments designed by the Medical Department. Considerable effort is also expended in the testing of instrumentation and equipment for use in high energy physics.

Research at the Alternating Gradient Synchrotron

Although the AGS has been operating on the basis of 21 shifts per week since January, it cannot provide sufficient beam time to meet the constantly growing demand for its unique facilities. The importance of the work produced at this accelerator is apparent from the results reported below.

The total cross section for the interaction of protons with protons is one of the most fundamental measurements that can be made in any new energy range that becomes available in parti-

cle physics. Of equal importance is the information provided by measurements yielding the elastic cross sections and the differential cross sections for the p - p interaction. The measurement of cross sections for the interaction of other particles with protons provides the next stage in the basic study of strong interactions. In this area a Brookhaven counter group has produced results of great current interest.

It was generally believed until about two years ago that at high enough energy (≥ 10 BeV) the size or effective radius of the proton approached a constant and the effective density of nucleon matter within the proton was also approximately constant. Then a new theory, the Regge pole theory, which has had widespread theoretical influence, predicted instead that at high enough incident particle energies (≥ 10 BeV) the effective size or radius of the proton grew logarithmically with incident energy, but the density of nuclear matter simultaneously decreased in such a manner that the total cross section for an interaction remained the same. This appeared to be a necessary result of the total cross section data. Earlier total cross section and some p - p elastic scattering experiments (of more limited accuracy) had indicated consistency with this prediction for p - p elastic scattering.

Perhaps the best way of measuring the effective radius of the proton for various incident elementary particles is to measure the elastic diffraction scattering, whose width shrinks inversely with the radius of the scattering object. If the vacuum (Pomeranchuk) pole dominates sufficiently, the Regge pole theory predicts a logarithmic shrinkage of the elastic (diffraction) scattering curve ($d\sigma/dt$), or equivalently a logarithmic increase of the effective radius, with increasing energy.

Scintillation-counter hodoscopes, consisting of crossed slab elements in coincidence to define small rectangular areas, detected the position of the forward-scattered particle and the position and direction of the recoil proton from the target. This information was used to select elastic scattering events by kinematic criteria. The pulse information in the counters was automatically recorded on tape and automatically transmitted over telephone lines to the Brookhaven Merlin computer. The data were processed continuously and automatically by the on-line computer. The computer also displayed curves and gave periodic data

Figure 1. The counter hodoscope system used in the elastic scattering experiment at the AGS. The forward scattered particle detecting hodoscope, hidden by the plywood panel, is mounted on a movable platform. The 5×5-ft recoil particle hodoscope composed of 96 slab counters 2½ in. wide ×30 in. long is shown at the upper center. The hydrogen target can be seen in right background.

printouts. This novel system greatly increased the statistical and systematic accuracy of the data. It also increased the efficiency of use of the AGS over that in previous elastic scattering experiments. Immediate examination of end results is possible while the experiment is still in progress.

The experimental results clearly demonstrated the Regge-pole-predicted shrinkage of the diffraction pattern for p - p scattering with increasing energy. However, the π^- - p and the π^+ - p data both clearly demonstrated no shrinkage of the Regge type within experimental error. Thus π^- - p and π^+ - p elastic scattering interactions imply a constant radius independent of energy, as the older optical model would have predicted. Therefore the assumption of dominance of the strong interactions by a single Regge vacuum pole in this energy region (7 to 20 BeV/ c) was contradicted, since in that case the π - p as well as the p - p data should have shown Regge-type shrinkage. The K^+ - p data also are consistent with no Regge-type shrinkage within experimental error. The more sophisticated analyses (three-pole model) involving two vacuum

poles P and P' and the vector mesons ω and ρ , which were previously able to explain total cross section data, have also been found to be inconsistent with these data. It seems necessary to conclude that Regge pole theory will not, as originally hoped, serve as a simple and definite prescription for this incident momentum range. It is of course possible that this range is not high enough for the asymptotic theorems of the Regge pole approach to hold. Nonetheless the striking difference in behavior of the π - p and p - p systems is an interesting physical fact from any theoretical point of view. The data imply that the effective radius or size of the π - p and p - p interactions is approximately the same, but that the K^+ - p interaction radius is somewhat smaller and the $\bar{p}$ - p and K^- - p interaction radii are somewhat larger.

Another Brookhaven counter group has measured the total cross sections for interactions of positive and negative pions with protons in the energy range from 1.5 to 6 BeV. Momentum-analyzed pions were identified by a differential Cerenkov counter in coincidence with a scintillation counter

telescope. The pions were allowed to impinge upon a 48-in.-long liquid hydrogen target, and those not interacting in the target were detected with four scintillation counters. An iron absorber was placed behind the four transmission counters, followed by a single scintillation counter, used in anticoincidence with the pion telescope to reject muons not resolved by the Cerenkov counter or arising from pion decay in flight. The total cross section in this energy range had previously been determined only at widely spaced points, particularly in the case of the π^-p interaction. The new data were taken in smaller energy steps and with a statistical accuracy of $\approx 1\%$. The improved resolution of these measurements resulted in the discovery of two new pion-nucleon resonances, one in each of the two isotopic spin states: a resonance with effective mass 2.19 Bev with a full width at half maximum of 200 Mev and isotopic spin $\frac{1}{2}$; and a resonance with effective mass 2.36 Bev with a full width at half maximum of 200 Mev and isotopic spin $\frac{3}{2}$. It is impossible at present to assign particular spin states to these two new resonances. However, the position and slope of the Regge trajectories on which they are expected to lie would indicate that the expected spin values are higher than $\frac{1}{2}$.

By interpreting these peaks as resonances due to the formation of excited states of the nucleon, the number of known excited states is raised to seven. Inspection of the quantum numbers of the nucleon and its well-known excited states suggests a possible selection rule, which states that $J-L=I-1$, where J is the spin of the excited state, L is its orbital angular momentum, and I is its isotopic spin. It is possible to predict the J , L , and I quantum numbers for other excited states of the nucleon. None of the predicted assignments are in contradiction with currently accepted assignments. The scheme, furthermore, predicts the angular momentum and spin states for the two newly measured resonances.

The eight states of the nucleon can be grouped into two pairs of four states each, in which mass differences between the states are equal, within experimental error, to one of the three systems of η - π , π - π , or ρ . It is not possible at present to explain the significance of this agreement. Furthermore it appears that this scheme of pion-nucleon interactions may be extended to the strange-particle and hyperon excited states. This classification

would provide links (in the form of η , ρ , K , and K^* mesons) between the excited states of the strange particles and the nucleon or other mesons and hyperons.

Although some of the predictions of the Regge pole theory have been found not to hold, as mentioned above, as a general approach to elementary particle theory it still has a strong theoretical appeal. If this approach, particularly as outlined by Chew and Frautschi, is correct, then in a sense the existence of some unifying principle for all the elementary particles will be indicated. One of the specific predictions of the Regge pole approach is the existence of a spin 2 particle having the quantum numbers of the vacuum (apart from the angular momentum), i.e., isospin, strangeness, and baryon number = 0, and with a mass of the order of 1.0 to 1.4 Bev. Such a particle could decay into two π mesons and should be observed as a π - π resonance with isotopic spin $I=0$. Experimental evidence for the existence of a particle with isotopic spin, G parity, and mass similar to those of the particle called for in the Regge pole theory has been found by a team from the University of Pennsylvania and Brookhaven.

By using the BNL 20-in. hydrogen bubble chamber and the 3-Bev/ c separated π^- beam, π^- interactions with protons were observed for two-prong reactions; in particular, the reactions

$$\pi^- + p \rightarrow \pi^- + \pi^0 + p, \quad (1)$$

$$\pi^- + p \rightarrow \pi^- + \pi^+ + n, \quad (2)$$

have been studied. The invariant-mass distributions for the π - π system in reactions (1) and (2) show a peak at ≈ 1250 Mev in the π^- - π^+ mass plot in addition to the ρ peak at 775 Mev. The 1250-Mev peak is not present in the π^- - π^0 data, and it therefore is identified as a $I=0$ resonance. This resonance, or particle, has been designated the f^0 meson. The full width at half maximum of the f^0 appears to be of the order of 100 Mev. This is considerably greater than the experimental resolution, which is estimated to be ≈ 20 Mev.

The conclusion that the f^0 exists is based on the difference between the π^- - π^0 and π^- - π^+ mass distributions. The π^- - π^0 mass distribution, for masses above the ρ peak, is completely consistent with a phase-space (statistical) distribution. The π^- - π^+ mass distribution, however, is quite inconsistent with such a distribution. The odds against a

phase-space distribution being consistent with the data are of the order of several thousand to one, when the number of events in mass intervals of 50 to 100 Mev, covering the range from 1000 to 1600 Mev, is compared with the relative numbers of events for a phase-space distribution. (These odds are calculated by a χ^2 method.)

The data have been examined for possible evidence of four-pion decay of the f^0 . There is no indication of any such events with a production cross section at all comparable with the cross section for two-pion decay of the f^0 .

Dalitz plots of the data were also made. This type of kinematic analysis clearly shows up departures from a phase-space distribution and thus makes apparent kinematic correlations which demonstrate the existence of resonances or particles. The principal conclusion to be drawn from these plots is that the f^0 peak is not an accidental result of any nucleon isobar production. There is little evidence of any isobar production at all. The data do not permit determination of the spin of the f^0 .

The mass of uncorrelated experimental data in particle physics is stimulating concentrated theoretical efforts to find systematizing concepts. A promising trend in these efforts is the search for symmetries (physical and mathematical). Familiar space-time symmetries are the concepts of conservation, i.e., conservation of energy and momentum, spin, number of particles (e.g., baryon number), and relative parity (right or left-handedness). A different type of symmetry which has had remarkable success is that embodied in the hypothesis of charge independence. Nuclear reactions are expected to be independent of the charge of the particles involved. A closely related symmetry concept is that of isotopic spin, which is based on the similar behavior of the proton and neutron in strong interactions. From this point of view the proton and neutron are a doublet, the nucleon. Electromagnetic interaction effects are small compared to the strong interaction effects. The electromagnetic interaction, however, can break the symmetry and remove the degeneracy of the nucleon, which reveals the neutron-proton doublet. The inability to distinguish between two different states of nature (the degeneracy) is removed when some force acts to reveal the underlying differences, and the result is the splitting into separately observable entities. These ideas bear a

close analogy to the well-established and well-understood theory of the energy levels of the nuclei. In particle physics there may be an overlying symmetry of strong interactions which is perturbed by some weaker interaction to give the mass differences of the baryons in analogy with the splitting of the isotopic-spin nucleon doublet. Thus the particles fall into groups of multiplets or supermultiplets. Certain algebras known for some time appear ready-made to provide the mathematical structure that leads to plausible correlation of the particle physics data. One of the most promising of these is the Lie algebra which employs the SU_3 group (unitary unimodular group in three dimensions). This algebra permits, amongst others, the so-called 8-fold way and 10-fold way of classifying the particle multiplets. To be successful, these schemes must fit all the known elementary particles and resonances. They may, and many of them do, predict additional resonances which are subject to experimental verification. Behind much of the work at the two accelerators is an effort to confirm or test these symmetry schemes.

The existence of a resonance in the $K\bar{K}$ system (called the ϕ meson) with a mass of 1020 Mev and a width ≥ 20 Mev was reported in last year's annual report. Since that time additional data have been accumulated that confirm the existence of this resonance and provide a conclusive determination of its mass, width, parity, spin, isotopic spin, and branching ratios. In particular it was found that mass (M) = 1019 ± 1 Mev, width (Γ) = 1_{-1}^{+2} Mev (with $\Gamma > 0$), parity (P) = -1 , spin (J) = 1 , isotopic spin (I) = 0 , and charge conjugation (C) = -1 . This resonance was observed by a joint Brookhaven-Syracuse group in a study of the K^-p interaction at 2.23 Bev/c in the reaction $K^- + p \rightarrow \Lambda + \phi (K^0 + \bar{K}^0)$ or $\Lambda + \phi (K^+ + K^-)$ using the BNL 20-in. bubble chamber. A total of 58 events was accumulated with the interesting result that the resonance decayed mainly into $K^+ + K^-$ and $K_1^0 + K_2^0$ states.

It should be noted that the ϕ meson, which has $J=1$, $P=-1$, and odd G parity (or $C=-1$), may be accommodated within a number of theories of elementary particles. In the unitary symmetry model of Gell-Mann the ϕ may be the predicted (singlet) partner of the vector meson octet (K^* , ρ , ω). Gell-Mann and Sakurai have pointed out that the pseudoscalar meson octet (π , K , η) and the baryon supermultiplets (N , Λ , Σ , Ξ) satisfy a gen-

eralized mass formula to a high accuracy. However, the same mass formula applied to the vector meson octet predicts an isosinglet mass of 930 Mev, which is different from the observed ω mass of 780 Mev. This discrepancy might be explained by the mixing of the ω and φ , since they have the same quantum numbers.

Further work on the properties of the Ξ^* previously discovered in this same experiment has established the following decay modes:

$$\begin{array}{l} \Xi^{0*} \rightarrow \Xi^- + \pi^+ \\ \quad \rightarrow \Xi^0 + \pi^0 \end{array} \quad \text{and} \quad \begin{array}{l} \Xi^{-*} \rightarrow \Xi^- + \pi^0 \\ \quad \rightarrow \Xi^0 + \pi^- \end{array}$$

From a study of the branching ratio of these decay modes, the isotopic spin of Ξ^* was determined to be $\frac{1}{2}$. The 10-fold way of the SU_3 symmetry scheme predicted the existence of the Ξ^* before it was discovered. The other particles involved in this scheme are the $N_{3,3}^*$, Υ_1^* , and Ω^- , the last being a hyperon with strangeness $= -3$ and mass of 1680 Mev which has not yet been observed. Continued analysis of the data in this same experiment has resulted in the determination of the spin of the Υ_1^* (1385 Mev). Previous evidence concerning the Υ_1^* was conflicting. The present experiment involving a study of the reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ was carried out at a much higher energy and thus was free from interference effects which might have obscured the conclusion. The data clearly indicate a spin $\geq \frac{3}{2}$. This result also fits very well into the SU_3 symmetry scheme and, combined with the findings above, has lent considerable further impetus to it.

Including those involved in the work just mentioned, $\approx 1,200,000$ photographs were taken in the BNL 20-in. liquid hydrogen bubble chamber during the year. The chamber was exposed to particles from a beam transport system which, by means of bending magnets and electrostatic separators, provides pure beams of antiprotons and positive and negative π and K mesons. Almost two-thirds of these exposures were made by non-Brookhaven groups. Much of their work and that of the Brookhaven groups still is being analyzed, but some of the available results are discussed below.

A combined Columbia University-Rutgers University group studied π^+p interactions. They found that a striking feature of the interaction is the dominance of the pionic resonance states.

About 40% of both the single and double pion events are accounted for by ρ production, while the η and ω account for $\approx 5\%$ and 50%, respectively, of all $\pi^+ + \pi^- + \pi^0$ production. The ρ and ω are produced predominantly in association with the $\frac{3}{2}, \frac{3}{2}$ pion-nucleon isobar. From an analysis of the angular distribution, it was found that the ρ^0 's produced showed a sharp forward peaking consistent with the OPE model previously found valid for charged ρ production. Correlations among the decay products and branching ratios of competing decay modes gave strong confirmation for the quantum numbers of the η meson previously mentioned in this report. The ratio of the decay of the ω into neutrals compared to its decay into $\pi^+ + \pi^- + \pi^0$ was found to be 0.10 ± 0.04 . A limit of 2% was set for the decay of the ω into two pions.

Production of nucleon isobars and multipion resonances by 3.5-Bev/c π^+ mesons was studied by a group from the University of California at La Jolla. The data indicate that $\approx 86\%$ of all ρ mesons are associated with the production of the $N_{3/2}^*$. Their results also appear to confirm the existence of the f^0 meson. In addition, the data show some evidence of a peak in the effective mass distribution of the $p\pi^+\pi^+$ triplet from the reaction $\pi^+ + p \rightarrow \pi^+ + p + \pi^+ + \pi^-$. If the existence of this peak can be confirmed, it should be easy to show that its isotopic spin is $\frac{5}{2}$. This $I = \frac{5}{2}$ resonance has been predicted by many theorists. Dalitz has pointed out that this resonance could be the start of a "25-fold family" within the SU_3 concept. Following the SU_3 theory, every member of this family must decay into three bodies, whereas for some members the SU_2 theory (which embodies the charge independence principle) allows a two-body decay. A very good test of the SU_3 theory is thus possible.

On the basis of isotopic spin conservation A. Messiah (Saclay) has predicted that there should be 50 times as many events in a $p\pi^+\pi^+$ peak as in a $p\pi^+\pi^-$ peak. The data are in good agreement with this prediction. Analysis of the data also shows the ω resonance, but the results with 3.5-Bev/c incident momentum indicate that only $\approx 46\%$ of the ω 's are produced in conjunction with the $N_{3/2}^*$. The events that do not show associated production with the $N_{3/2}^*$ were analyzed separately in accordance with the Yang-Trieman test, which indicates that the ω is produced by the OPE process.

Figure 2. The 14-ft-long spark chamber which permits observation of the recoil proton in the experiment designed to study muon collisions with protons now in progress at the AGS. A member of the Columbia-Rochester-Brookhaven experimental team is checking the operation of the triggering spark gaps, eight of which are visible in the photograph. The muon beam was collimated by means of a 12-in.-diam, 30-ft-long gun barrel salvaged from a U.S. Navy battleship. An average pulse of 3×10^{11} protons from the primary beam of the AGS yielded 6×10^6 muons peaked at a momentum of 2.5 Bev/c.

Figure 3. The track made by a recoil proton in the spark chamber illustrated above. Measurement of the recoil angle and the angle of the scattered muon observed in another spark chamber will permit analysis of the data for elastic μ - p events. This will provide information on the form factor (the shape of the charge distribution) of the proton. It will be particularly interesting to compare the results of this experiment with the form factor deduced from e - p scattering experiments.

In last year's report a Brookhaven group suggested that there might be a two-pion state of the ω meson. They have now confirmed its existence, but with rather meager statistics. A beam of incident pions of 1.7 Bev/c was chosen because isobar production, which could confuse the analysis, was known to be slight at this momentum. The analysis shows that the angular distribution is consistent with OPE, which confirms the suspicion that the deviation from OPE at the lower incident pion energy is correlated with isobar formation. Results of the effective mass distribution of the dipion final state show a peak in the distribution at 790 Mev close to the ω mass. Thus both ρ and ω intermediate states for the reaction are implied.

$$\begin{aligned}\pi^- + p &\rightarrow n + \rho^0 \\ &\quad \rightarrow \pi^- + \pi^+, \\ \pi^- + p &\rightarrow n + \omega \\ &\quad \rightarrow \pi^- + \pi^+.\end{aligned}$$

The ω resonance has the same spin and parity as the ρ but different isotopic spin. The ω can thus decay into two pions only by violating the conservation of isotopic spin through a symmetry-breaking electromagnetic interaction. It has been suggested that this may indeed take place, which would account for the two-pion decay of the ω . The width of the peak is consistent with the width of the ω resonance obtained from its decay into three pions. It is estimated that dipion decays occur at least 5% as often as tripion decays provided that the 790 peak does not contain some other as yet unknown resonance, a possibility that cannot be excluded.

Confirming evidence was found for the two new resonances in the $\pi^+-\pi^-$ system suggested by Brookhaven physicists last year. These resonances were observed in a study of the reactions $\pi^- + p \rightarrow \pi^- + p + \pi^- + \pi^+$ (+1 or more π^0 's) and $\pi^- + p \rightarrow \pi^- + \pi^+ + \pi^- + \pi^+ + N$ (+1 or more π^0 's) obtained in a 4.65-Bev/c π^- beam at the AGS. A comparison of the like ($\pi^-\pi^-$, $\pi^+\pi^+$) and unlike ($\pi^-\pi^+$) mass spectra showed a phase-space distribution for the former and the presence of the well-known ρ meson and the two new resonances for the latter. The values for the effective masses and widths of the resonances are $M=395 \pm 10$ Mev, $\Gamma=50 \pm 20$ Mev; and $M=520 \pm 20$ Mev, $\Gamma=70 \pm 30$ Mev. Most of these resonances come from events in which the nucleon is a neutron. The isotopic spin of these

two resonances can be either 0 or 1, and the spins are unknown.

In collaboration with groups at Yale University and the City University of New York, the production of anti-isobar-isobar pairs has been observed for the first time in $\bar{p}$ - p collisions at 3.25 Bev/c, in confirmation of an earlier prediction by Brookhaven theorists. A total of 400 events of the type $\bar{p} + p \rightarrow \pi^+ + \pi^- + p + \bar{p}$ (cross section, 3.3 ± 0.3 mb) have been identified to date. Approximately 90% of these events can be interpreted as pair production of the $I=\frac{3}{2}$, $J=\frac{3}{2}$ pion-nucleon isobar and anti-isobar (N_1^* and $\bar{N}_1^*$). The general features of the reaction are in agreement with the OPE model. Using these same photographs, some of these workers have found that $\approx 8\%$ of the annihilation cross section consists of production of K -meson pairs. Investigation of resonant states produced in these reactions resulted in evidence for $K_1^*-\bar{K}_1^*$ pairs and $\omega-K_1^*$ associated production. These were the first known examples of more than one meson resonance taking place in a single proton-antiproton reaction. The cross section for $p + \bar{p} \rightarrow K + \bar{K} + n\pi$ is 2.94 ± 0.11 mb, of which the state K^* (and/or $\bar{K}^*$)- K - $n\pi$ comprised 38%, and $\omega-K^*-K^0-\pi^\pm$, 3.4%. The state $K^*-\bar{K}^*-n\pi$ is seen roughly 40% as often as the $K^*-K-(n+1)\pi$ state.

Further evidence that these antiproton photographs have been a prolific source of information on strong interactions is the fact that they have been analyzed for information on hyperons. Measurements and analysis of $\bar{T} + \gamma$, $\bar{T} + \gamma + \pi$, and $\bar{T} + \gamma + 2\pi$ events has continued, with main emphasis on the three-body and four-body channels. A total of 66 $\bar{\Lambda}-\Lambda-\pi^+-\pi^-$ events have been identified. In these events the presence of the $\bar{T}_1^*$ resonance with mass 1385 Mev was demonstrated for the first time. Furthermore the charge states $\bar{T}_1^{*-}$ and $\bar{T}_1^{*+}$ are common, which indicates that the mechanism of interaction is more complicated than the usual one-particle exchange. In the three-body channels $\bar{\Lambda}-\bar{\Sigma}^+-\pi^-$, $\bar{\Lambda}-\bar{\Sigma}^--\pi^+$, $\bar{\Lambda}-\bar{\Sigma}^0-\pi^0$, and $\bar{\Lambda}-\bar{\Sigma}^0-\pi^+$ the same resonant state shows up clearly, and in addition the $\bar{\Sigma}-\pi$ and $\bar{\Sigma}^0-\pi$ combinations show $\bar{T}_0^*$ and $\bar{T}_0^{*0}$ resonances with masses 1405 and 1520 Mev. For the three-body channels a one-particle-exchange model seems to be roughly consistent with the observations, although the angular distribution of the $\bar{\Sigma}^-$ and $\bar{\Sigma}^0$ is much less strongly forward-backward peaked than that of the $\bar{\Sigma}^+$ and $\bar{\Sigma}^0$.

Researchers from the University of California at Berkeley have studied the interaction of K^+ mesons with protons. The production of the K^* resonance in the reaction $K + p \rightarrow K^* + N_{3,3}^*$ has permitted them to identify the K^* as a vector meson. From an examination of the angular distribution of the K^+ from the decay of the K^* ($K^* \rightarrow K^+ + \pi^-$), they conclude that the spin of the K^* is ≥ 1 . These findings, combined with the results of a previous experiment at Berkeley, allow the conclusion that the spin is indeed 1. From this conclusion it follows that the KK^* relative parity is even, if it is assumed, as has been suggested, that the $K\Lambda N$ parity is odd. This leads to odd parity for the K^* . A large proportion of the events resulted in the double-resonance state mentioned above. The data are also consistent with the concept that OPE is a dominant contributor to the production reaction.

In π^+p collisions at a momentum of 2.77 BeV/c an analysis of strange-particle production has shown that Σ^+K^+ , $\Sigma^+\pi^+K^0$, and $\Sigma^+K^+\pi^0$ final states are the most predominant production modes with a cross section of ≈ 0.17 mb each. The $\Sigma^+\pi^+K^0$ final state is $\approx 70\%$ in the Σ^+K^* resonant state. The 1385-Mev Υ_1^* is produced in $\Lambda K^0\pi^+\pi^+$ as well as $\Lambda K^+\pi^+$ final states, and a Υ_1^* decay angle distribution indicates that the spin of the Υ_1^* is $\frac{3}{2}$ or greater. Of 9 events of the type $K_1^0K_2^0\pi^+p$, 5 events were found to be in the double resonance of the form $\varphi + N_{3/2,3/2}^*$.

Much of the analysis of the photographs of the K_2^0 particle interactions obtained by a Brookhaven group last year has now been completed. A study of the decay mode $K_2^0 \rightarrow \pi^+ + e^- + \nu$ demonstrated that the e^+/e^- ratio was 1.00 ± 0.08 . Decays into positive and negative electrons should be equally frequent if the decay is invariant under charge conjugation (c) and parity inversion (p). The data are thus consistent with cp invariance. The measurements show that the interaction is principally, if not entirely, vector. The "tau decay" of the K_2^0 ($K_2^0 \rightarrow \pi^+ + \pi^- + \pi^0$) was also studied by measurements on four-pronged stars consisting of two charged pions and of two electrons from internal (Dalitz) pairs or external electron pairs. A branching ratio of decay by the τ mode of $12 \pm 2\%$ was found. Among the K_2^0p interactions, patterns consisting of three-pronged stars with an associated neutral V have been measured. Events were chosen which fitted kinematically either

$$K_2^0 + p \rightarrow \pi^+ + \pi^- + \pi^+ + \Lambda, \quad (1)$$

or

$$K_2^0 + p \rightarrow \pi^+ + p + \pi^- + K_1^0. \quad (2)$$

In almost all cases the final-state particles were identified by ionization and momentum. The interactions were found to proceed predominantly through the two-body reactions,

$$K_2^0 + p \rightarrow \pi^+ + \Upsilon^*,$$

$$K_2^0 + p \rightarrow N^* + K^*,$$

where N^* denotes the $\frac{3}{2}, \frac{3}{2}$ isobar at 1230 Mev, Υ^* the hyperon resonances at 1520 and 1680 Mev, and K^* the 880-Mev π^-K resonance. At least 80% of the events of reaction (1) for incident momenta up to 2.25 BeV/c are found in the Υ^* resonance. For incident momenta in excess of 2.25 BeV/c the data showed no evidence of the Υ^* resonance, which indicates that this resonance is excited principally by K_2^0 particles in the range below 2.25 BeV/c. Based on the initial measurements of the beam spectrum, analysis of the relative production cross sections shows that the 1680-Mev resonance rises slowly from threshold to a broad flat region extending from 1.5 to 2 BeV/c and falls to zero at 2.3 BeV/c, whereas the 1520-Mev resonance remains relatively flat after its initial rise from threshold. The excitation function for the production of the K^* and N^* resonances after it has risen from threshold to a maximum at 2 BeV/c essentially follows the incident K_2^0 beam spectrum.

Approximately 600,000 pictures have been obtained with the BNL-Columbia 30-in. liquid hydrogen bubble chamber in a new separated beam designed by a Columbia University group. This beam complex makes available antiprotons and K and π mesons in the momentum range from stopped particles to ≈ 1 BeV/c. A third of these pictures were of stopping antiprotons, and the remainder showed stopping K^- mesons. Analysis of these pictures has only just started, and additional data are to be taken.

The first particle tracks were photographed in the 80-in. liquid hydrogen bubble chamber on June 2, 1963. Before this could take place, every component had to be tested individually on completion. The first major component consisted of the 450-ton magnet, which when powered to 4 Mw produced a magnetic field of 20,400 gauss. The field has been mapped by making measurements

of its three components at numerous points. At the same time the expansion system, consisting of a 36-in.-diam piston weighing 250 lb, a cylinder, and several large pilot-operated valves, was tested for performance and endurance. Next the nitrogen and hydrogen refrigerators were tested and found to be operating satisfactorily and of adequate capacity. The chamber body and vacuum chamber were leak-tested. Numerous strength and leak tests were performed on the inflatable window seal by making use of a test fixture. The 6½-in.-thick large glass window was inspected for flatness (within a few light wavelengths) and was given an antireflection coating. An extensive test program also was carried out involving light sources, opti-

cal condenser lenses, "coat-hanger" reflectors, and cameras, the latter including data boxes to be photographed with every bubble-chamber picture to provide information needed for data analysis. Gradually all the components were assembled into one unit, all pneumatic, electric, and safety controls were connected, and the system became ready for final testing. Following the first successful observation of tracks, the chamber was shut down for several weeks to deal with the miscellaneous problems encountered during this first complete test. At the next cool-down certain engineering studies will be necessary to gain full control over the machine before it goes into productive operation.

Figure 4. A view of the 80-in. bubble chamber partially disassembled. A portion of the chamber is visible with the 12×25-in. beam window exposed. Just to the right is the safety chamber designed to contain the 1500 liters of liquid hydrogen in case of failure of the 6½-in.-thick glass window (not shown). Four camera ports and a central viewing port are accessible at the end plate of the safety chamber. The expansion mechanism (located on upper platform) actuates the piston, which has a special honeycomb design to reduce inertia. A wide neck extends from the top of the chamber to the piston housing. One magnet coil is visible behind the vacuum chamber, the other on the steel yoke to the right. The rails at the bottom provide a means of bringing the two portions of the yoke together around the bubble chamber. The whole assembly, which weighs 450 tons, can be rotated on the turntable shown under the left half of the yoke.

The design of an electrostatically separated beam for the 80-in. chamber is completed, and fabrication of the vacuum system and other components has been started. The most important aberrations of the beam transport magnets have been established as the six- and ten-pole moments of the bending magnets and the eight-pole moment and fringe-field focusing of the rectangular quadrupoles. Pole-face windings have been designed, tested, and found to correct the bending magnet aberrations. Both aberrations of the rectangular quadrupoles can be corrected by the addition of small octupole magnets which are now being designed. By correcting these aberrations and using sextupole magnets partially to offset the dependence of quadrupole focal lengths on momentum, it is expected that well-separated antiproton beams up to 8.5 Bev/ c and $K^\pm$ -meson beams between 2.5 and 5.5 Bev/ c can be obtained.

The first ten magnets of the separated beam have been installed in the new AGS conjunction section. These were used for a high-resolution π^- beam for the first exposure in the 80-in. chamber. The next exposures will be a test run for evaluation of picture quality in the chamber and will provide photographs for a systematic study of π^-p interactions from 4 to 10 Bev/ c with particular emphasis upon the peripheral interactions.

In the high-field magnet program, some effort has been devoted to the construction of small solenoids using Nb-Zr alloys as the superconducting windings. A field of 22 kgauss was generated by one solenoid of $\frac{3}{4}$ -in. i.d. with only $\frac{3}{8}$ of the winding in the superconducting state. In addition, numerous tests have been made on short straight samples of various wires and ribbons to determine some of their superconducting properties and to improve techniques for making low-resistance and superconducting joints.

One promising conductor consists of a ribbon 0.090 in. wide and 0.002 in. thick on which is deposited a surface layer of Nb_3Sn < 0.0005 in. thick. The ribbon is then copper-clad. Samples of this ribbon have been tested at helium temperatures and have been found to carry currents > 600 amp at zero magnetic field and as high as 45 amp at 93.5 kgauss. Lengths of this material have been obtained and are being wound in a solenoid.

The fully automatic measuring system using the Hough-Powell Flying Spot Digitizer (FSD) has reached a state of satisfactory refinement and

reliability in its mechanical, optical, and electronic aspects, including computer control of the FSD. The computer programs which are an integral part of the system have required more attention than had been anticipated. At present the HAZE program, which controls the FSD and deals directly with the massive flow of coordinates, can handle an indefinite number of pictures at an average rate nearly equal to the predicted rate of 1 frame/6 sec. The detection and precision measurement of the reference fiducial marks on the film is now carried out by the unaided 7094 computer with high reliability. (This is the first wholly satisfactory example of "pattern recognition" by a computer for bubble-chamber physics.) First results have been obtained for tracks measured in the "abnormal mode." (When one or more tracks of an event occur nearly perpendicular to the edge of the film and therefore nearly parallel to the normal scan direction, the computer calls for an abnormal or 90° scan in which the flying spot direction is parallel to the edge of the film rather than perpendicular.) The track-center circuit has been improved in resolution so that even partly merged bubbles are individually and correctly digitized.

A residual computing difficulty which has so far prevented production measurement is the filtering of true track coordinates from the collection of all coordinates occurring in a road. (As described in last year's report, the FSD system uses human guidance of the 7094 computer in the form of rough measurements at the scan table of the tracks of interest. These rough measurements are punched in IBM cards which are then made up into a "scan tape" read by the 7094. The computer calculates narrow bands called roads embracing the tracks for which measurements are desired.) The noise in the roads arises from crossing tracks and electron spirals, and in the case of beam tracks from a second parallel track in the road. The present filtering program, FILTER II, selects true track coordinates with fair reliability if the number of beam tracks incident on the chamber is not too high (say, 10 to 15). A manual control on FILTER II, carried out at the 7094 console, will be used to obtain production measurement at a rate equivalent to that of perhaps 5 to 10 conventional measuring machines and so permit testing and the development of smooth operation of the entire system. A FILTER III program is under development.

The 70-mm FSD for measuring 80-in. bubble-chamber film is in the assembly stage. The optical performance has been tested and found to be satisfactory. The electronic circuitry is largely a duplicate of that for the 35-mm FSD. The computer programs will also be nearly identical.

The conventional scanning and measuring equipment is also being used actively. The BNL scanning and measuring machines for 35-mm film are being converted to accept 400-ft rolls. Three rough digitizers to provide roads for Hough-Powell FSD machines are in operation, and another five will be built for five new scanning machines under construction. A second Hermes (Itek) measuring machine has been purchased to be used for measurements on 80-in. bubble-chamber pictures. This and the existing Hermes will be used primarily for measuring Hough-Powell rejects and for experiments involving low event statistics.

A Brookhaven group is constructing a system for the automatic processing of spark-chamber photographs. Sparks on the film are located by a flying-spot scanner which digitizes their positions. The flying spot is generated by an optical-mechanical device consisting of a disk containing 16 microscope objectives rotating in front of an illuminated, stationary pinhole. This pinhole is demagnified by the objectives to produce on the film an intense flying spot of light six microns in diameter. The film is clamped on a vacuum platen mounted on a precision stage; the stage moves the film in a continuous motion across the flying spot, and the scanning raster is generated. Fluctuations in the light intensity transmitted by the film indicate the presence of a spark and are sensed by a photomultiplier tube. Spark coordinates are obtained by digitizing the rotation of the disk and the translation of the stage.

Fast transistorized electronic circuitry converts the pulses from the scanner into spark coordinates and records them on magnetic tape in the proper form for processing on a computer. This circuitry contains a system for finding the center of sparks and also a 256-word fast core memory buffer which greatly reduces the dead time of the scanner.

The information on the magnetic tape is fed into an IBM 7094 computer where it is processed by programs specifically written for this device and for the particular experiment being analyzed.

Once coordinates are transformed into real space, fiducial marks are located, individual sparks are reconstructed, and from these the tracks of the particles are found. With these, kinematical analysis is performed in the same manner as for data obtained by manual measuring of the photographs.

Construction has begun on a preselector that will enable a human to instruct the flying-spot scanner to measure only certain photographs which have been chosen by visual inspection.

In addition to carrying out research programs at the two accelerators, Brookhaven physicists devote a large portion of their effort to improving or adding to the high energy particle research facility. They design, construct, and operate bubble chambers, separated beams, Cerenkov counters, special magnets, new types of beam lenses, hodoscopes, and complicated scintillation counter arrays. They also participate in shielding and superaccelerator studies and in the general future planning essential to maintaining the research program at peak efficiency.

Two hours per week of AGS experimental time are devoted to a continuing program of research by the Chemistry Department.

The Theoretical Physics Group continues to devote much of its attention to particle physics. Part of this work is concerned with the analysis and interpretation of experimental data on new particles or resonances.

A peak at 1250 Mev has been observed experimentally in the mass distribution of $\pi^+\pi^-$ pairs in the reaction $\pi^- + p \rightarrow \pi^+ + \pi^- + n$. This so-called f^0 resonance peak should also appear in the $\pi^+ + p \rightarrow \pi^+ + \pi^- + \pi^+ + p$ reaction, but has not been observed so far. A calculation has been made comparing the f^0 production to be expected in the two reactions for a range of pion momenta. The results indicate that the small or negligible f^0 production in the four-prong reaction is not in serious contradiction with the existence of the f^0 .

The high energy behavior of scattering amplitudes is at present the object of intense interest. Investigations have been made by various authors based on partial summations of the perturbation theory series. An investigation has been made of the standard assumption that certain so-called dominant terms determine the high energy behavior. The result is that the sum of the next most dominant terms is more important than the sum

of the dominant terms. (The result corresponds to a second-order Regge pole.) Further terms are summed and combined with the previous ones to restore the simple Regge behavior. The singularity at threshold in the trajectory function obtained by summing the most dominant term is not present in the final result.

A simple formulation has been obtained of the crossing relations that connect two reactions such as $A+B \rightarrow C+D$ and $A+\bar{C} \rightarrow \bar{B}+D$. The formulation utilizes "helicity amplitudes" and is therefore applicable to particles of arbitrary spin.

Calculations of pion-nucleus scattering (for light nuclei) were made by using Glauber's modification of the impulse approximation, a modification that takes into account multiple-scattering effects. The results show encouraging agreement with the experimental data for pions around 80 Mev, with the expected values of the scattering parameters.

The electronic dipole polarizabilities α_d of the alkali atoms have been calculated by a method in which the inhomogeneous Schroedinger equation for the dipole perturbation of the valence electron wave function is solved directly. The theoretical results for α_d are in reasonably good agreement with the observed values from two recent experiments.

Values of the quadrupole antishielding factor γ_∞ have been calculated for the Mn^{+2} , Fe^{+3} , Ga^{+3} , and Ag^+ ions. Upon applying the value of γ_∞ for Fe^{+3} to measurements of the quadrupole hyperfine structure due to the 14.4-keV metastable state of iron-57 (Fe^{57m}), the quadrupole moment Q for this state is found to be $+0.28 \times 10^{-24} \text{ cm}^2$.

NUCLEAR STRUCTURE

Nuclear structure research is concerned with the general problem of connecting the properties of the experimentally observed excited states of nuclei with the properties of the excited states as given by various nuclear structure theories. Accurate experimental information is required about the energy, spin, parity, lifetime, and electromagnetic moments of these excited states in order to test the validity of these current theories. In general, this information is obtained in two types of investigations, those dealing with the characteristics of unstable (radioactive) nuclei, and those concerned with the characteristics of the instan-

taneous products of a nuclear reaction. Some energy levels can be observed both in radioactive decay and in nuclear reaction studies, while others can be observed only in nuclear reactions because of their very short lifetimes or high energies.

Fast coincidence measurements have been used to determine lifetimes of excited states in Sn^{117} , Te^{121} , Te^{123} , and Sb^{123} . These states exhibit *l*-forbidden *M1* transitions which are retarded by factors ranging from 30 to 140 relative to single-proton estimates and have lifetimes which are in the region of a few times 10^{-10} sec. Lifetimes of the first excited state in Sm^{149} [22 keV; $T_{1/2} = (7.6 \pm 0.5) \times 10^{-9}$ sec] and in Eu^{151} [22 keV; $T_{1/2} = (9.3 \pm 0.7) \times 10^{-9}$ sec] have also been measured by delayed coincidence techniques. The lifetimes of these states are of interest in connection with interpretation of Mössbauer absorption spectra as well as in nuclear structure studies.

Directional correlation measurements have been carried out on several gamma-gamma cascades in Er^{166} which are populated in the decay of the high-spin, long-lived isomer in Ho^{166} . In this decay, the members of the ground-state rotational band of Er^{166} are populated up to spin 8, while the gamma vibrational ($K=2$) band is populated to spin 7. Directional correlation measurements involving gamma-ray transitions between states of the gamma band and the ground-state band show that these transitions are remarkably pure quadrupole transitions, although a very small dipole component is detectable. Typical dipole to quadrupole intensity ratios in these transitions are of the order of one part in a few hundred.

In collaboration with the Chemistry Department, the study of the level scheme of Os^{186} has been completed. Detailed analysis showed a strong downward shift in the levels of odd angular momentum in the $K=2$ band. While certain models of nuclear structure predict an odd-even shift, the particular form of angular-momentum dependence found experimentally for the shift in Os^{186} is so far unexplained. The only other extended $K=2$ band ($I=2, 3, 4, 5, 6, 7$) known, that in Er^{166} , a nucleus in the middle of the strongly deformed region, does not show any measurable odd-even shift.

An examination of isomeric states in even-*A* iridium nuclei indicates that very high as well as low spins occur. The coupling scheme between the odd neutron and odd proton, which can be de-

Figure 5. Decay scheme of Sb^{122m} .

rived from these data, may lead to interesting theoretical conclusions. A systematic search for new even-mass iridium isomers is being continued.

The decay of the 18.7-min isomer Re^{188m} has been studied, and the multipole order of the two known transitions of 63 and 105 keV has been determined to be $M1$. A third transition of 92 keV, populating the first excited state of 63 keV, has been found. It was further established that two competing low energy transitions, populating the states at 155 and 168 keV, are responsible for the isomeric lifetime. For the study of these low energy transitions the conversion electrons are accelerated by means of an electric field before they enter the lens of a Gerholm spectrometer.

The study of the production of Re^{189} (whose discovery was reported last year) and its decay to Os^{189} has continued. A detailed analysis of beta-gamma coincidence data taken with a two-dimensional pulse-height analyzer has allowed a determination of the absolute intensities (per Re^{189} decay) of the more prominent electromagnetic transitions and beta-ray groups. A detailed analysis of the level scheme of Os^{189} has been carried out.

In the past year work on the isomeric decay of Sb^{122m} has been completed. The decay scheme is shown in Figure 5. All three transitions shown are retarded relative to the Weisskopf estimates for single-proton transitions: The 61-keV $E1$ transition is retarded by a factor of $\approx 10^6$, the 77-keV $E2$ transition by a factor of ≈ 420 , and the 26-keV transition (responsible for the 4.2-min half-life and believed to be an $E3$ transition) by a factor of 46. These retardations have been discussed in terms of current nuclear theory. The most probable configurations for the three lower levels are indicated in Figure 5.

Mössbauer-effect studies concerned with the recoil-free emission and resonant absorption of

nuclear gamma rays emitted by nuclei of atoms bound in solids have continued. A study has been made of the disposition of iron atoms as impurity atoms in a beryllium sample by using the Mössbauer effect with the 14.4-keV gamma ray of Fe^{57} . The beryllium used in these experiments contained 0.1% iron by weight. Samples that should contain iron in solid solution exhibited a particular absorption pattern. Aging of the sample at 600°C produced a marked change in the absorption pattern. The result is interpreted as an indication of the precipitation of iron out of solution, probably as an intermetallic compound with beryllium or some other impurity.

The Mössbauer effect has also been observed in other nuclear transitions. For example, the 22-keV transition in Sm^{149} , with a source of Eu^{149} in a rare-earth oxide environment, exhibits the effect. Most recently the effect has been observed on the 89-keV transition in Ru^{99} . The source in this instance was Rh^{99} in a metallic ruthenium environment, while the absorber was metallic ruthenium. Measurements carried out at $\approx 85^\circ\text{K}$ exhibited a single line absorption with a line-width which, if unbroadened, would correspond to a lifetime of $\approx 8 \times 10^{-9}$ sec. A direct, delayed coincidence measurement of the same lifetime gave a value of 20×10^{-9} sec. The observed effect in absorption amounted to $\approx 3.5\%$.

Sources and absorbers have been prepared consisting of a light impurity in a heavy host (Fe^{57} in palladium). At 300°K the probability of recoil-free gamma-ray absorption is found to be $\approx 85\%$, which is appreciably greater than the probability of $\approx 55\%$ found for recoil-free gamma-ray emission. This difference is thought to result from localized lattice heating in the source following the neutrino emission which precedes the 14-keV Mössbauer gamma ray in Fe^{57} .

Preliminary experiments have demonstrated the existence of the Mössbauer resonance in suitably chosen liquid sources. Studies of the resonance width and position as a function of the molecular weight of the host and of the fluid viscosity are expected to yield information relating to diffusion during the lifetime of the excited state (10^{-7} sec) and to the recoil process.

A cryogenics laboratory is being set up which will be equipped for studies in the range from room temperature down to 0.35°K (to be reached with a He^3 cryostat) in magnetic fields (produced

by a superconducting solenoid) of up to 55 koe. This apparatus will initially be used in Mössbauer-effect studies relating to the behavior of paramagnetic impurity atoms in nonmagnetic hosts.

The investigation of the gamma rays emitted following thermal neutron capture in various elements has continued under the auspices of Brookhaven National Laboratory and the Aeronautical Systems Division of the United States Air Force. In this experiment a small sample of the material being studied is placed in a thermal neutron beam outside the reactor, and coincidences are measured between high energy capture gamma rays detected by a three-crystal pair spectrometer and lower energy gamma rays detected by a single scintillator. As the high energy gamma rays populate individual levels in the product nucleus, the coincident spectra display the patterns of de-excitation of these individual levels, selected from what is ordinarily a highly complex spectrum of capture gamma rays. In this way new information is obtained about the spins and parities of the energy levels and the pattern of the electromagnetic transitions observed.

Current interest in the interpretation of the low-lying energy levels of odd neutron nuclei at the beginning of the $2p_{3/2}$ neutron shell has prompted coincidence studies of the gamma rays following neutron capture by Fe^{54} . The results obtained, together with existing results of (d, p) reaction studies, have led to the construction of a level scheme for Fe^{55} incorporating a number of energy levels and a large number of electromagnetic transitions.

Coincidence studies of the capture gamma rays of dysprosium, coupled with precision measurements of the capture gamma rays carried out at MIT, have permitted the assignment of a number of gamma rays to individual isotopes of dysprosium and have led to the establishment of a number of features of the level schemes of these nuclei.

Work has been resumed on the study of double beta decay in Ca^{48} . A crystal of CaFe_2 weighing ≈ 19 g, in which the Ca is enriched to $>95\%$ Ca^{48} , is used as a scintillation detector for events originating within it. If neutrinoless double beta decay of Ca^{48} can occur, it will appear as a peak at a position equivalent to the total energy (4.26 Mev) available for this event. Such a peak has not been observed in preliminary runs made to date. A lower limit of 10^{18} yr for the lifetime of this type

of double beta decay can be deduced from these data. Several improvements are now in progress which should increase the sensitivity by 1 to 2 orders of magnitude.

A recent report from another laboratory indicated that the nucleus H^5 might be stable against particle emission, and that its beta decay may, in fact, have been observed ($T_{1/2} \approx 0.1$ sec, $E_{\text{max}} \approx 20$ Mev) when lithium was bombarded with 320-Mev bremsstrahlung. The activity was attributed to the reaction $\text{Li}^7(\gamma, 2p)$. To verify this report, an attempt was made in collaboration with the Chemistry Department to search for the H^5 activity from the reaction $\text{Li}^7(p, 3p)$ by bombarding lithium with 2-Bev protons from the BNL Cosmotron. No activity with the reported half-life and with beta rays of more than 15 Mev was found, while the bombardment of boron under the same conditions led to the production of Li^9 from the reaction $\text{B}^{11}(p, 3p)$. The upper limit for the production cross section for a 0.1-sec, 20-Mev activity produced by 2-Bev proton bombardment of lithium is $< 1/1000$ th of the cross section for production of Li^9 from the bombardment of boron. In the bremsstrahlung bombardments, the cross section ratio of " H^5 " to Li^9 was found to be ≈ 1 in 20.

A six-gap Orange beta-ray spectrometer of the Copenhagen design has been placed in operation. A useful feature of this instrument is its high beta-gamma coincidence capability. In this mode of operation, electrons are counted with a transmission of $\approx 10\%$ at a resolution of 1 to 2%, while 10 to 20% of the gamma rays are subtended by a 3-in. NaI crystal. This spectrometer is the first of its design in the United States.

A new method for determining the multipolarity of electromagnetic transitions above 2 Mev occurring in nuclear reactions has been developed by the Van de Graaff accelerator group. The technique makes use of the intermediate-image magnetic pair spectrometer modified with a special charge-selecting spiral baffle system. The baffle allows only those positron-electron internal pairs to be detected that have been emitted from the source on opposite sides of the spectrometer axis. Under these conditions there is considerable sensitivity to the type and multipole order of a transition, yet the good energy resolution of the spectrometer is preserved. Measurements consist of determining the intensity of an internal pair coincidence line both in the normal spectrometer

operation and with the spiral baffle installed, which gives a reduction ratio $R = \gamma_{\text{baffle in}} / \gamma_{\text{baffle out}}$. Theoretical calculations of R were carried out for the various types of transitions as a function of energy. By making slight adjustments to two parameters these ratio curves were fitted to the experimental ratios obtained for 14 known transitions as illustrated in Figure 6. It is evident from this figure that the various curves are spaced widely enough apart to allow clear multipole assignments to be made in most cases. As an example of the method, Figure 7 shows the baffle-out and baffle-in measurements on some pair lines occurring in the $\text{C}^{13} + d$ reaction. For the 6.58-Mev pair line the reduction ratio R is 0.28. Comparison of this result with the calibration curves of Figure 6 clearly establishes that the 6.58-Mev transition is $E0$ (electric monopole) and thus that the 6.58-Mev second excited state of C^{14} has a spin and parity of $0+$.

In the beta decay of B^{12} the 3.2-Mev gamma radiation from the 7.66-Mev "helium-burning" level of C^{12} was observed directly, and the result was used to determine a B^{12} beta-ray branching value of $(1.7 \pm 0.5)\%$ to the 7.66-Mev state.

Particle-gamma coincidence experiments, using solid-state detectors, were carried out in nine nuclear reaction investigations of various light ele-

ments. Studies of the alpha-particle spectra accompanying the beta decays of Li^8 , B^8 , B^{12} , and N^{12} were also made with this type of detector.

A program of experiments involving measurement of the correlations in energy and angle of coincident charged particles, using semiconductor E and dE/dX particle detectors and multidimensional pulse-height analysis techniques, is being carried out in collaboration with members of the Chemistry Department. The objective is to elucidate the nuclear reaction mechanisms leading to the production of three or more product particles and to understand the nature and effects of the final-state interactions of these particles. A study of the reaction $\text{O}^{16}(\alpha, 2\alpha)\text{C}^{12}$ (ground state) has been completed, furthering the understanding of the nature and extent of the interference between direct and compound nucleus mechanisms in nuclear reactions. Studies of the reaction $d(d, 2p)2n$ are being carried out. The final interaction due to a tendency for "dineutron" formation has been observed. This experiment is being refined to obtain a quantitative comparison of the n - n and p - n

Figure 6. Plot of the intensity reduction ratio for positron-electron pairs $R = \gamma_{\text{baffle in}} / \gamma_{\text{baffle out}}$ for various multipole orders as a function of transition energy.

Figure 7. Baffle-out and baffle-in measurements on some positron-electron pair lines occurring in the $\text{C}^{13} + d$ reaction. The reduction ratio determined for the 6.58-Mev line from curves (a) and (b) establishes that the transition is $E0$ (electric monopole).

scattering lengths. Such a comparison will provide the most direct test of the hypothesis of the charge independence of the nuclear force. The reaction $d(p,2p)n$ is being investigated to determine the magnitude and nature of specific three-body aspects of this system, which has been selected because the two-body interactions involved are known. A search for inelastic p - p scattering at 10 Mev has been completed. Such a process would be due to non-dipole bremsstrahlung; for a 1-Mev energy loss it has been found to have $\approx 2 \times 10^{-8}$ of the elastic scattering cross section.

A measurement of the electron-neutrino angular correlation coefficient in the beta decay of He^6 has been completed. The correlation coefficient, obtained from the measurement of the energy spectra of recoil ions in coincidence with beta particles of selected energy, was determined to be (-0.319 ± 0.028) . A measurement was also made of the He^6 beta spectrum with a thin-lens magnetic spectrometer. The spectrum yielded an end-point energy of 3.508 ± 0.015 Mev.

The study of the harmonic spherical nuclei has continued with the object of explaining the known deviations from harmonicity. The specific approach is based on the random-phase-approximation. For this purpose a study of corrections to the random-phase-approximation is in progress.

In connection with analyses of the nuclear penetration matrix elements in internal conversion, the theory of directional correlations involving internal conversion electrons has been re-examined. An error in the standard formulas used was noted and corrected. High energy limits for the conversion process were studied in order to check the results of the formalism. A review of the effects of this revision of the theory on analyses of directional correlation experiments in the published literature is still in progress.

Recently a "staggering" of the levels of a $K = \frac{3}{2}$ band in Tb^{159} was observed at another laboratory. This effect has been successfully interpreted by the application of higher-order Coriolis corrections to the energies of the levels.

NEUTRON PHYSICS

Studies of the interactions between neutrons and atomic nuclei continue to yield information important to the better understanding of the prop-

erties of matter. In a continuing program of research in neutron physics at the Brookhaven Graphite Research Reactor, investigations have been made of the scattering of very slow or "cold" neutrons by liquids and solids.

A study of the low-frequency motions of hydrogen in KH_2PO_4 has been completed. When cold neutrons are scattered from polycrystalline samples of potassium dihydrogen phosphate, a broad band of lattice frequencies is observed. By the substitution of deuterium for hydrogen, it is possible to distinguish between the motions in which the hydrogen moves with the unit cell and the motions of the hydrogen with respect to the unit cell. In this way, a band of low-frequency hydrogen vibrations was identified, centered around a transition energy of 0.023 eV ($\approx 180 \text{ cm}^{-1}$). This was at first puzzling, because from neutron diffraction measurements it had been concluded that the motion of hydrogen atoms at 77, 132, and 293°K is practically independent of temperature and is essentially all zero-point motion. The band can be interpreted as resulting from a correlated motion of the proton with respect to the oxygen atoms. The simplest correlation would be with the O-O stretching motions which have been theoretically estimated to be in the vicinity of 200 cm^{-1} . The motion of the hydrogen atom is viewed as consisting of a large zero-point motion resulting from the proton's being confined in a spatially fixed potential generated by the neighboring atoms. As the neighboring oxygen atoms stretch, this potential moves in space and gives rise to a correlated motion of the proton relative to the oxygen atoms. Because the zero-point motion is large, the correlation has meaning only with respect to some average position of the proton.

Construction of the vertically shafted rotor for the new cold-neutron facility at the High Flux Beam Research Reactor (HFBR), shown in Figure 8, is complete. This rotor is one of three 1-m-diam shutters which will be driven at 15,000 rpm by synchronous motors. In order for the system to yield optimum neutron intensity and resolution the relative phase angle between rotors must be constant within $\pm 0.1^\circ$. Preliminary tests indicate that this stringent phase stability is achievable.

At the joint Brookhaven-Chalk River fast-neutron chopper project, the program of measurements of total cross sections in the 10 to 100 keV region for Y, Nb, Mo, Ag, Rh, Cd, and In has

been completed. From these measurements the p -wave strength functions in the region of mass number $A = 100$ were obtained. This work showed that the strength of the spin orbit coupling (exhibited as a broadening of the strength function when plotted as a function of atomic weight) was, within experimental error, the same as that measured in the Mev region. A splitting of the p -wave strength function curve into two distinct peaks, previously reported elsewhere, was not observed.

Measurements of the parameters of the 1200-ev resonance in Fe^{56} have been completed. This resonance is so very weak that it is not seen in transmission measurements carried out with the chopper apparatus, even when the maximum resolution conditions with the 88-m flight path are obtained. By observing the capture gamma rays emitted by the target placed at the 20-m station, the resonance is readily observed, even though the resolution of the gamma-ray apparatus is poorer than that of the transmission apparatus. The spectra of the gamma rays resulting from neutron capture in the resonance have been investigated; from the presence of a strong ground-state transition the capturing state is assigned as $\frac{1}{2}+$. It had been conjectured earlier that this very weak level was a p -wave resonance; however, these results definitely show it to be an s -wave resonance. On the basis of capture areas, self-indication measurements, and gamma-ray spectrum studies both at the resonance energy and at thermal energy, the resonance parameters for this level were obtained.

Figure 8. The vertically shafted rotor for the new cold-neutron facility at the HFBR.

Studies of the elastic scattering of polarized neutrons from Fe, Co, Si, and Al, utilizing the neutrons produced by the $T(p,n)\text{He}^3$ reaction from the 3-Mev protons accelerated in the 18-in. cyclotron, have been completed. The differential scattering cross section and angular distribution of the polarization were obtained for scattering angles between 30° and 120° . The left-right ratios were similar for Fe, Co, and Si, but were inverted for Al. The observed polarizations were fitted with an optical model program which included a Hauser-Feshbach calculation. To obtain good agreement with the data it was necessary to include the compound-elastic contribution in the calculation.

In a cooperative program with Columbia University, studies have continued of the emission of long-range alpha particles in the thermal neutron fission of U^{235} . The relative probability of such a process has been measured for incident neutron energies of 0.003, 0.0253, 0.08, and 0.3 ev, as well as for two reactor beams having cadmium ratios of 30 to 1 and 200 to 1. These measurements show that the binary to ternary fission ratio in U^{235} is a constant, to a precision of 3%, in the energy region between 0.003 and 0.3 ev as well as for the two reactor beams considered. The total kinetic energy distribution of the fission fragments associated with the emission of long-range alpha particles in the thermal neutron fission of U^{235} has been investigated. From these observed distributions, the mean total kinetic energy of the fission fragments in ternary fission was determined to be less than that for binary fission by 12.7 ± 0.5 Mev. A study was also undertaken of the dependence of the mean energy of the long-range alpha particles upon the total kinetic energy of the corresponding fission fragments. The results obtained show that the mean energy of the long-range alpha particles decreases with increasing total kinetic energy of the fission fragments. This dependence has a maximum variation of ≈ 2 Mev about the mean energy of 16.1 ± 0.5 Mev of the long-range alpha-particle distribution.

A precise value of the half-life of U^{235} for alpha emission has been determined from an analysis of the alpha spectrum of natural uranium. The alpha spectrum was measured with solid-state detectors, and the half-life was determined from comparison of the intensity of the resolved portion of the U^{235} alpha spectrum with the intensities of the U^{238} and U^{234} groups. The half-life of U^{235} ob-

tained from those measurements is $(6.92 \pm 0.09) \times 10^8$ yr.

Measurements using polarized monoenergetic neutrons and polarized nuclei have continued. In the experiment, the transmission of the polarized target is studied as a function of neutron energy. The data yield the angular momentum of the compound nucleus formed by resonance absorption of the neutron or the spin dependence of the thermal neutron cross section. Also, by varying the sample temperature (and hence the nuclear polarization) it is possible to make accurate measurements of the hyperfine interaction constant of the nucleus in bulk ferromagnetic media.

The neutron transmission measurements on polarized holmium nuclei were extended to a holmium single-crystal sample. In the case of the single crystal it was expected that complete magnetic saturation would be obtained, which had not been possible with the polycrystalline holmium metal sample used earlier. The nuclear polarization was measured as a function of temperature between 4° and 0.05° K. The experimental data, corrected for spectrometer resolution, Doppler broadening, and second-order contamination of the neutron beam, were fitted to a spin $\frac{1}{2}$ Brillouin function by

$$f_N = CB_I(A/2kT),$$

where f_N is the nuclear polarization, B_I the Brillouin function, and C a constant. The best-fitting value for the coupling constant is $A/k = 0.595 \pm 0.010^\circ$ K, which corresponds to a magnetic field at the holmium nucleus of 8.57×10^6 oe. This value is somewhat higher than that derived from the polycrystalline sample data ($A/k = 0.58^\circ$ K) and is in excellent agreement with results of specific heat measurements and theory. The constant C was determined to be 0.92. This value deviates from the expected value of unity, and efforts are being made to explain the discrepancy. Depolarization measurements on the holmium single crystals are being made to determine whether the sample is actually magnetically saturated at the field used (10 kgauss). In addition, a study of the neutron beam polarization is being made to determine any possible loss of polarization of the beam before it passes through the sample. In view of these pending questions on beam polarization and sample magnetization, the quoted value for A/k must be considered preliminary. However, any possible

correction that may be made will increase the value and bring it in even closer agreement with theory and specific heat data.

By using the same single-crystal target the previous spin assignments, $I + \frac{1}{2} = 4$ for the neutron resonances at 3.92 and 12.8 eV, could be confirmed. In addition, spin $I - \frac{1}{2} = 3$ could be assigned for the next two higher resonances at 18.2 and 21.3 eV. Although these two resonances could not be resolved with the polarization spectrometer, a large transmission effect of 3% throughout the energy region of the resonances was observed, from which it is concluded that both resonances have the same spin. The sign of the transmission effect leads to the given assignment $I - \frac{1}{2} = 3$.

Among other isotopes studied was Tb^{159} (target nucleus). The spins of the neutron resonances at 3.35, 4.99, and 11.14 eV were found to be $I + \frac{1}{2} = 2$, $I - \frac{1}{2} = 1$, and $I + \frac{1}{2} = 2$ respectively. The hyperfine interaction constant for Tb^{159} in ferromagnetic terbium metal will be derived from the data when analysis is completed.

Transmission effect measurements at thermal energies may be used to obtain the fraction of the neutron cross section due to each spin state. Such measurements have been performed on Co^{59} , in a target of polycrystalline cobalt metal, and on Ho^{165} , in a single-crystal metal target. It was first necessary to extend the theoretical expressions for the total cross section and the transmission effect to the case of scattering by nuclei contained in a magnetic lattice. The theory shows that the magnetic electrons give a temperature-independent term in the transmission effect, in contrast to the strong temperature dependence of the nuclear terms. This allows the two contributions to be separated by making measurements as a function of temperature. In addition, the effects of nuclear scattering and absorption may be separated by making measurements as a function of neutron energy. For cobalt, $(78.3 \pm 1.0)\%$ of the thermal capture is into $(I + \frac{1}{2})$ states and $(87 \pm 1)\%$ of the thermal scattering is due to $(I - \frac{1}{2})$ states. This establishes the contribution of a bound level to the thermal cross section. Preliminary data on Ho^{165} show that $(59.4 \pm 3.4)\%$ of the thermal absorption is into $(I - \frac{1}{2})$ levels, which establishes the contribution of one or more strong bound levels. The thermal scattering appears to favor $(I - \frac{1}{2})$ states slightly.

A study of Doppler broadening and crystal binding effects on the 4.14-eV neutron resonance

in W^{182} is being performed at the BNL crystal spectrometer. To date, very accurate measurements of the level shape have been completed with a pure tungsten metal target at temperatures of 4° and 825°K. Intercomparison of the metal data reveals a shift in the energy of the resonance, with the highest value appearing at the elevated temperature. At 296°K the solid sample and a heavy water solution of sodium tungstate were run simultaneously, and differences in the measured cross sections have been observed. The half-width of the level as observed with the solution is less than that observed with the metal. Determination of the level shape for the metal sample at 78°K is now in progress, and in the near future measurements will be extended to WO_2 -Cu and WO_3 -Cu samples.

ATOMIC AND MOLECULAR PHYSICS

The atomic beam magnetic resonance technique is being utilized to study hyperfine structures of various radioactive nuclei. The apparatus at Brookhaven is designed for work of extremely high precision. By utilizing this capability, it is possible to measure nuclear magnetic moments with sufficient precision to permit the determination of nuclear hyperfine structure anomalies. At present, the study is directed toward Lu^{176m} (3 hr). By comparing this atom in the $^2D_{3/2}$ and $^2D_{5/2}$ electronic states with stable Lu^{175} in the same states, it may be possible to observe both a magnetic and an electric quadrupole anomaly. To date the hyperfine interaction constants have been determined to an accuracy of <1 part in 10^6 for the $D_{3/2}$ state and ≈ 2 in 10^6 for the $D_{5/2}$ state.

A new atomic beam machine is under construction. This equipment has been designed to combine high precision, greater sensitivity, and greater flexibility.

SOLID STATE PHYSICS

Several theoretical advances have been made during the year. Theoretical calculations with high-speed computing machines continue to give important results about the nature of lattice defects. These calculations have been extended to a bcc crystal lattice simulating α -iron. Most of the work during the year has been concerned with

directional effects in the atomic displacement processes at low (20 to 60 ev) and intermediate (up to 1000 ev) knock-on energies. The anisotropy of the lattice has a strong influence on the dynamics of displacement in different directions, especially at the low energies. The threshold energy for creating a stable Frenkel pair (a vacancy and a $\langle 110 \rangle$ -oriented split interstitial) has been found to be highly dependent on the initial direction of the knock-on. There are large differences between the three main crystallographic directions, $\langle 100 \rangle$, $\langle 110 \rangle$, and $\langle 111 \rangle$, which should lead to observable differences in the damage rates for oriented single crystals irradiated with low energy (300 to 400-kev) electrons. For a polycrystalline sample the "effective" threshold energy (the energy at which there is 50% probability of displacement) should be taken as 40 ev, whereas the lowest threshold in $\langle 100 \rangle$, the direction of easiest displacement, is as low as 18 ev. Directional effects on the number of displacements made by an intermediate-energy knock-on have also been studied.

A clear and concise theory of the amplitude of vibration of "isotopic" impurities in three-dimensional lattices has been developed. From these amplitudes of vibration Debye-Waller factors may be deduced as well as other quantities useful in the interpretation of the Mössbauer effect, nuclear resonance scattering, and inelastic neutron scattering experiments. The frequency distribution in three-dimensional random binary alloys has also been obtained. The theory follows an extension of the method developed by J.S. Langer at Carnegie Institute of Technology for the one-dimensional lattice. Results show reasonable agreement with experiment on the Pd-Ni alloys.

A number of theoretical studies have been started within the field of magnetism. The theory of the scattering of polarized beams by simple ferro- and antiferromagnetic materials was given a number of years ago by Halpern and Johnson. In the last few years, however, many magnetic substances much more complicated in structure than simple ferromagnets have been discovered. In order to study these a complete treatment of the scattering of polarized beams for arbitrary magnetic structures is necessary and has been developed recently. A number of terms omitted by Halpern and Johnson have been evaluated. These terms vanish for simple substances but give rise to

several interesting effects in more complicated substances. The experimental determination of these effects can now yield, via the theory, a number of quantities of interest for these complex magnetic substances. Development of the theory of scattering of polarized neutrons by polarized nuclei is nearing completion. Progress is being made on the theory of magnetic scattering of neutrons by Ti^{+3} ions. The theory is expected to account for the experimentally observed form factor which increases with increasing $\sin\theta/\lambda$.

Crystal Imperfections

A major experimental research activity in solid state physics is the study of defects in crystals. While the main emphasis is on radiation effects in solids, other departures from perfect periodicity, e.g., order-disorder phenomena, are under active investigation.

The effect of lattice vacancies on the diffusion of an interstitial solute has been studied in the iron-carbon system. Both internal friction and electrical resistivity measurements indicated that carbon atoms were trapped by irradiation-produced vacancies and their precipitation was thereby delayed. Microcalorimetry measurements showed that the binding energy of the carbon atom to the vacancy is 0.4 ev. Similar measurements showed that the intermediate carbide precipitate, which occurs in unirradiated iron-carbon, corresponds to a carbon binding energy of 0.27 ev. The prediction, based upon these relative energies, that the precipitation process in the irradiated material should not go through the intermediate carbide phase, but should go directly into the cementite phase, was confirmed by electron microscope observations.

The role of strain in the color center formation process is being studied in the alkali halides. Crystals are first colored with gamma rays until a linearly increasing portion of the coloration curve is reached. Next they are subjected to a strain, and finally the irradiations are resumed. Application of strain results in a discontinuity in the coloring curve, apparently caused by vacancies, or other defects, formed from dislocations during straining. In NaCl the "jump" in the F -center coloring is proportional to the total strain, but appears to be independent of strain rate. The total number of vacancies is in reasonable agreement with the theoretical predictions. When the irradi-

ations are resumed after straining, there is also an increase in the slope of the coloring curves. This change in slope increases with strain and is very nearly proportional to the strain. The fact that the slope is changed strongly supports the idea that dislocations are essential to the defect formation process. Gamma-ray and reactor irradiations also influence the macroscopic stress-strain curves. The yield point is increased, and the easy glide region is greatly extended. Motion picture photoelastic measurements, made during straining, indicate that the strain pattern in gamma-ray-irradiated crystals differs greatly from that in unirradiated crystals. Apparently the dislocation dynamics is modified by the irradiations.

A consistent picture is beginning to emerge from the continuing work on irradiated diamond. The early stages ($< 2 \times 10^{20}$ nvt) of fast-neutron damage in diamond are characteristic of a crystal containing point defects. There is a lattice expansion in agreement with the reduction in density, and the x-ray reflections are sharp but attenuated by a true "Huang" factor, arising from the lattice distortions. By combining density and x-ray intensity measurements the concentration of interstitial-vacancy (Frenkel) pairs vs exposure can be deduced. Density vs neutron exposure is independent of exposure rate and shows an initial tendency to saturate. This is indicative of radiation annealing. A model fitting these data requires that ≈ 100 atoms be displaced per primary knock-on. Of the Frenkel pairs, $2\frac{1}{2}\%$ are inherently stable, while $\approx 97\%$ of them can enter into radiation-induced annealing reactions.

The ESR spectrometer has been employed to detect paramagnetic centers in NaBrO_3 that are formed by uv irradiation. Samples are irradiated in the cavity, and ESR measurements are made without interrupting the irradiations. At room temperature a prominent asymmetric ESR absorption is observed. It consists of two or more unresolved lines in the vicinity of $g = 2$. This absorption decreases to $\approx \frac{1}{2}$ in a week at room temperature. During irradiation the surface is decomposed, apparently with the formation of sodium metal, and considerable gas is evolved.

Recent experiments have shown that reactor irradiation causes large changes in the photoconductivity of TiO_2 . In the wavelength range 4000 to 14,000 Å, a continuum is produced with photoconductivity peaks superposed on it at 4065,

4900, 5350, 7000, 7750, and 8800 Å. In addition, pronounced changes occur in the photoresponse as a function of light intensity. To distinguish the effects of ionization from those caused by neutron irradiation, a series of gamma-ray irradiations has been performed. These produced a small, structureless increase in optical absorption, but minor changes in the photoresponse.

The scattering of neutrons from a crystal of β -CuZn at temperatures exceeding the critical ordering temperature, T_c , has been compared with the short-range-order scattering predicted by several theories. An accurate determination of the short-range-order parameters was not possible because of the number of parameters required to describe adequately the long-range nature of the order. The theories considered (Zernicke, Cowley, and Elliott and Marshall) all lead to a linear difference equation in the short-range-order parameters involving only the reduced temperature, T/T_c . The corresponding solutions give scattering curves in good agreement with the measurements made at the various temperatures. These Ising model theories appear to give a surprisingly good description of the short-range correlations existing above the critical temperature.

Structure of Solids

Another major research activity is the use of neutron and x-ray diffraction in structural and extrastructural studies of crystals. These studies have largely been confined to magnetism and vibrational characteristics. The work in these areas has been greatly strengthened by experiments involving the Mössbauer effect.

It is becoming increasingly apparent that the Mössbauer technique can serve as a valuable complement to the neutron diffraction investigations on magnetic alloys. A particular example of this is to be found in the work on the iron-rhodium series, carried out in collaboration with the Westinghouse Research Laboratory. Magnetic measurements on the iron-rhodium system show that the magnetic moment per atom increases with the addition of rhodium to iron. At the 50% composition there is a low-temperature transition at which the bulk magnetism disappears by means of a ferromagnetic to antiferromagnetic transition. Hyperfine field measurements using the Mössbauer effect of the iron atoms show the presence of two distinct fields in the compositions beyond

25% rhodium. They also show a small drop in the hyperfine field in the 50-50 composition at the magnetic transition. From the neutron measurements it has been established that the iron moment in the 50-50 alloy is $3.2 \mu_B$ and the moment on the rhodium is $0.9 \mu_B$. These two atomic species are arranged in the CsCl structure. No significant change in the net moment per iron atom is observed when it becomes antiferromagnetic. Less accurate observations suggest that in the not fully ordered compositions the iron atoms residing on the normally rhodium sites have essentially the same moment as in pure iron. From these two sets of results it is concluded that the hyperfine fields are clearly not proportional to the net iron moment; indeed the hyperfine field is larger for the iron having the lower moment. There is additional evidence for this behavior from the Mössbauer work on the iron-palladium system. In this case, although the neutron measurements show that the magnetic moment per iron atom has increased by some 30%, the observed hyperfine fields are essentially the same as in pure iron. The antiferromagnetic to ferromagnetic transition is not accompanied by any change in the electronic structure of the iron atoms. These effects can be explained by a change in the net number of unpaired conduction electrons. Precise measurements of the neutron magnetic scattering from these alloys may confirm this mechanism.

The behavior of the electric hyperfine splitting of Fe^{57} in extremely dilute alloys of iron in hcp metals is also being studied with the Mössbauer technique. The size of the quadrupole coupling constant is found to vary from metal to metal, as do the "isomeric" shifts. The data taken to date indicate that the conduction electrons which screen the iron impurity contribute significantly to the electric field gradient at the Fe^{57} nucleus.

Measurements by neutron diffraction of the distribution of covalent spin density in MnF_2 have been extended and improved. The improved data yield density maps showing the spatial features of the covalent spin. These results indicate that there is a change in the sign of the covalent spin density in proceeding outward from the Mn^{+2} toward the F^- atom. One difficulty with the present technique is that from these measurements only the projection of the spin density is obtained. The possibility of improving the situation by analyzing the final

polarization of the reflected beam is being investigated.

The behavior of the antiferromagnetic domain population in $\alpha\text{-Fe}_2\text{O}_3$ as a function of an applied field has been examined with the use of polarized neutrons. The mechanism by which the single-crystal specimens achieve saturation magnetization has been established, based on a correlation of the neutron data with the field dependence of the magnetization. According to this work the antiferromagnetic domains may be divided into two classes: a trigonal type, in which the magnetic spins turn by 120° from domain to domain; and the 180° domains, which act as subdivisions within each of the trigonal domains. At low magnetic fields the distribution of the trigonal domains remains unaltered, but, within each of these domains, the walls between the 180° domains are swept out. This sweeping out is accompanied by a rapid increase in the net magnetization of the specimen. Taken together, the magnetic and neutron diffraction measurements indicate that the parasitic ferromagnetism in $\alpha\text{-Fe}_2\text{O}_3$ is an intrinsic effect, arising from a departure of the magnetic structure from a perfect antiferromagnetic arrangement. Such a model has been proposed by I. Dzyaloshinski, and the above may be taken as a general confirmation of his suggestions.

The inelastic neutron scattering experiments being carried out to determine the role of impurities on the vibrational frequency distributions are continuing. Measurements taken on the nickel-palladium series across the entire range of compo-

sitions indicate the presence of impurity vibrational bands in low nickel alloys. For larger nickel concentrations the disordered-lattice frequency distribution can be predicted from the pure-nickel frequency distribution by very simple theoretical arguments. The vibrational frequency distributions have been deduced from the analysis of the inelastic neutron scattering data taken on first-row transition metals of bcc, fcc, and hcp structure. The prominent peaks shown in the experimental data correspond to the major critical points in the distribution curves. These are found to be not very different for the two cubic structures, but to change drastically in going over to the hcp metals.

Cold neutrons are being used to study the low-frequency motions in several of the simpler polymers. The data show the presence of low-frequency acoustic modes in agreement with the theory. These modes had not been observed heretofore by infrared or Raman techniques. Additional low-frequency modes not predicted by the theory are also evident. By studying the neutron spectra from a variety of polyethylene and paraffin samples, prepared in different ways, and as a function of temperature, it can be concluded that the molecular motions in short chains in the liquid and solid phases do not vary greatly. As the number of carbon atoms is increased, the nearly free rotation of the chain links is progressively replaced by a twisting motion and a deformation of the carbon backbone. Similar measurements for polypropylene are now being analyzed.

High Energy Accelerators

The Accelerator Department has continued its activities in the operation, maintenance, improvement, and exploitation of the 3-Bev Cosmotron and the 33-Bev Alternating Gradient Synchrotron (AGS); the development and operation of community property apparatus such as beam separators and magnets; and advanced accelerator development. The Atomic Energy Commission has recently requested that the Laboratory undertake studies of storage rings for the AGS and of accelerators in the 600 to 1000-Bev energy range. Both studies are expected to produce proposals for the construction of such facilities.

The following sections summarize the current status of activities in the Department.

ALTERNATING GRADIENT SYNCHROTRON

Operations

The AGS has moved ahead rapidly to establish itself as one of the major facilities for research in high energy physics.

During the first part of this fiscal year, operation of the machine continued on the previous schedule of three 8-hr shifts/day, 5 days/week. On February 15, 1963, the schedule was expanded to three 8-hr shifts/day, 7 days/week. A typical 2-week repeating cycle is as follows: 1st week, 2 shifts for planned maintenance, 2 shifts for accelerator studies, and 17 shifts for experiments in high energy physics; 2nd week, 1 "floating" or unscheduled shift for maintenance, 2 shifts for accelerator studies, and 18 shifts for work in high energy physics.

During the latter part of the year the experimental program at the AGS was based on the simultaneous flipping of targets at three separate locations around the ring. The technique permitted up to six experiments to use each machine pulse.

The synchrotron continues to run routinely at intensities of 2 to 3×10^{11} protons/pulse. During the year 4463 hr of operating time were available and were utilized as follows: 67%, high energy physics experiments; 8%, AGS studies; 16%, machine downtime; 6%, machine start-up and shutdown procedures; and 3%, scheduled maintenance.

Machine components and systems that have proved to be operationally unreliable on a long-term basis are being redesigned and replaced as time and personnel become available. Improvements made to the linear accelerator have resulted in a significant reduction in outages directly attributed to the injector. The AGS rf system has performed very well. A source of difficulty has been extensive radiation damage in a 2-week period to some of the semiconductors located in areas with high beam spills. A concrete block-house has greatly extended the useful transistor life. In the nine months since this shielding was installed no failure of elements or system degradation has been noted. Control systems for machine operation, access control, and safety continue to be expanded to keep pace with the growth of the AGS complex. The main magnet power supply has been pulsed $>13,200,000$ times since its installation. The synchrotron vacuum system reliably operates in the 10^{-7} torr region using standard Evapor-Ion pumps. A second generation of pumps has been developed and has been in limited use on the AGS. These units are based on the continuous sublimation of titanium and have some distinct advantages over the older evaporation pumps. Several of the rectangular-type beam separators have been in use on the AGS, and designs have been completed for shorter assemblies required for specialized beams. Modeling and testing of components for an rf beam-type separator are proceeding. The problems arising from the high iron content of the primary water-cooling system still exist but are under reasonable control with chemical treatment and periodic system flushing. The complexity and multiplicity of the experiments making use of the AGS have required a great deal of detailed advanced planning. In addition to the physics involved, the logistics of available magnets, power supplies, beam separators, power, water, and floor space are important considerations in setting up a working schedule.

Breaching of the main magnet enclosure to provide a beam channel to the North Experimental Area (80-in. bubble chamber) was completed on August 30. The first elements of the separated beam to this area have been erected, and prelimi-

nary tests of the optics are under way. With the expanding interest in neutrino physics, the Department has designed and is constructing a 45,000-sq-ft experimental area on the southwest periphery of the ring to accommodate the planned experiments. The primary proton beam will be extracted from the AGS and delivered to this area through a 1-ft hole in the magnet enclosure.

On July 1, 1962, personnel associated with the AGS numbered 214. By July 1, 1963, the total had reached 269. Further growth is planned to provide adequate manpower for the new experimental areas and allow full exploitation of the synchrotron.

Theory

A theoretical study has been made of the possibility of accelerating deuterons (or other nuclei with $Z/A = 1/2$) in the AGS. It has been found that deuterons can be accelerated in the present linac to 25 Mev by using the mode in which the particles spend two rf periods in each drift tube instead of a single period as in normal linac operation. These 25-Mev deuterons could then be accelerated in the AGS to ≈ 32 Bev, provided that the radio-frequency system is modified to permit a jump from 24th-harmonic to 12th-harmonic acceleration shortly after injection. The 32-Bev deuterons could then, by use of the stripping reaction, provide a high-quality beam of 16-Bev neutrons.

Experimental work to test these possibilities is in too early a stage for any results to be reported.

Experimental Programs

In October 1962, the full experimental program was reinstated at the AGS with almost continuous simultaneous targeting at three locations. At the first of these, separated beam No. 1 (described in last year's annual report) from the *F*-10 target provides separated antiprotons, K mesons, and pions of medium momenta for the study of interactions in the BNL 20-in. bubble chamber. At the *F*-20 target, separated beam No. 2 provides particles up to ≈ 950 Mev/ c for use with the 30-in. bubble chamber. A series of counter and spark-chamber experiments has been carried out in the *G*-9 and *G*-10 target areas, with 3 or 4 groups making simultaneous use of secondary beams emerging at various angles.

Somewhat more than 700,000 photographs have been taken of interactions in the 20-in. hydrogen bubble chamber resulting from particles obtained from separated beam No. 1. These have

included $\approx 200,000$ with antiprotons at 3.5 and 3.7 Bev/ c for a joint group from Yale University, City College, and Brookhaven; somewhat over 200,000 with K^- mesons at 2.3 Bev/ c for a Syracuse University-Brookhaven group; $\approx 50,000$ with K^- mesons at 2.0 Bev/ c for a joint group from Yale University, New York University, and Brookhaven; $\approx 112,000$ with π^+ mesons at 3.2 Bev/ c for a University of Wisconsin group; $\approx 110,000$ with π^+ mesons at 1260, 1350, 1660, and 1800 Mev for a joint group from Yale and Duke Universities; and $\approx 40,000$ with π^+ mesons at 3.5 Bev/ c for a group from the University of California at La Jolla. Parasitic exposures of stacks of emulsions were also made in the K^- -meson beam for groups from Tufts University and the University of Washington, and emulsions were exposed in the π^+ -meson beam at 1800 Mev for a group from the University of Tennessee.

The 20-in. bubble chamber subsequently was modified to use deuterium, and exposures are under way with antiprotons at 2.0 and 2.8 Bev/ c for a joint group from Brookhaven and Carnegie Institute of Technology. A considerable program, comprising a total of $> 550,000$ photographs for several groups, has been approved for interaction studies in deuterium.

Separated beam No. 2 is situated on the inside of the AGS ring in the *F*-20 target area and has been designed to transmit K mesons and antiprotons in the range 600 to 1000 Mev/ c . A single stage of separation is provided by one of the AGS rectangular-type electromagnetic velocity spectrometers. During the early tune-up operation, considerable background was observed in this beam because of its close proximity to the synchrotron and the problems associated with the limitations on space. Additional shielding resulted in considerable improvement. A group from Columbia University has been using this beam to take photographs of stopped K^- mesons in the 30-in. hydrogen bubble chamber and has obtained $> 300,000$ pictures. About 2 or 3 stopped K^- mesons are observed with a reasonable amount of background for $\approx 5 \times 10^{10}$ protons on the target. This group has also taken $\approx 100,000$ photographs of stopped antiprotons in the 30-in. chamber. A program of almost two million photographs in the 30-in. chamber has been approved for use with this beam.

During the fall, the prime users of the *G*-10 target area were a Brookhaven counter group studying the differential elastic scattering of protons and pions on hydrogen, using a system of wide-

array counter hodoscopes connected on line to the Merlin computer. Data for several values of momentum transfer were obtained for particle momenta from 10 to 19 BeV/ c . Some data were also obtained on $\bar{p}$ - p and K^+ - p scattering. Three groups working inside the AGS ring shared the same target with this group. At 30° , a group from MIT took $\approx 300,000$ spark-chamber photographs of both positive and negative pion interactions in hydrogen in the region of 860 Mev. Also at 30° , in a neutral beam, $\approx 85,000$ spark-chamber photographs were obtained by a group from the University of Illinois for a study of K_2^0 events. A Brookhaven counter group, at 15° , measured both total and differential cross sections of positive and negative pions in hydrogen in the range from ≈ 2 to ≈ 6 BeV/ c . The same group also studied scattering in hydrogen of both positive and negative K mesons in the same momentum range.

After a short shutdown in January, a high-purity μ -meson beam was established from the G-9 target area. A special 46-ft-long collimator was built by utilizing surplus gun barrels packed with lead to a uniform diameter of 12 in. which supported a pipe filled with uniform-density light concrete; the whole structure was encased in high-density concrete blocks. The performance of this beam was above expectations with $\approx 2.5 \times 10^6$ muons per 10^{11} protons on the target. Analysis showed that $\approx 75\%$ of the muons were above 2 BeV, where the spectrum peaked, with a gradual fall-off to ≈ 9 BeV. A joint group from the University of Rochester and Columbia University used this beam to investigate μ - p elastic scattering with values of momentum transfer of 500 to 850 Mev/ c . This group obtained $\approx 66,000$ spark-chamber pictures, of which $\approx 1/3$ were for calibration and test purposes and the rest for final data. Preliminary observation showed that these pictures should provide ≈ 6000 μ - p scattering events.

Parasitic exposures of emulsions were made in this μ -meson beam for a group from the University of Washington; exposures of maize seeds, tulip bulbs, and *Tradescantia* plants were made for the Brookhaven Biology Department, and special radiation studies were carried out by the Health Physics Division.

Also from the G-9 target, at a smaller emergent angle than that of the muon beam, a beam transport system was established to produce a high-intensity π^- -meson beam. This beam, too, proved to be better than anticipated: at 20 BeV, $\approx 1.5 \times 10^5$ pions were obtained per 10^{11} protons on the target,

and the beam at the end of the transport system was not much larger than 1 in. in diameter. A joint group from Princeton University and Brookhaven used this beam, with a pion momentum of ≈ 22 BeV, to measure the form factor of the π meson. This group obtained $\approx 400,000$ spark-chamber pictures, of which $\approx 1/10$ were of the desired scattering events. Emulsions were also exposed in this beam for groups from the University of Florida, the University of Chicago, and Washington University.

The G-9 target also provided beams for other experiments conducted concurrently with the two major experiments outlined above. A joint group from the University of Maryland and Brookhaven used a neutral beam at 30° on the inside of the ring to measure the lifetime of the K_2^0 meson and obtained $\approx 300,000$ spark-chamber pictures. A Brookhaven counter group, at 15° on the inside, measured total cross sections in both deuterium and hydrogen of positive and negative K mesons.

The Chemistry Department has continued to use the AGS on an average of ≈ 2 hr/week for its studies with irradiated targets.

To provide a test beam of pions for preliminary trials of the 80-in. bubble chamber, a beam transport system has been set up in the I-10 target area. Preliminary counter tests are in progress.

Linear Accelerator

Significant progress has been made during the year in improving the reliability of the linac as an injector for the AGS. Two factors are mainly responsible for this progress. First, by operating the linear accelerator continuously 21 shifts/week it was possible to eliminate the problem of obtaining sufficient rf level in the linac tank after deconditioning of the linac during the weekend shutdowns. Second, the cast polyethylene insulated grid coupling loops in the FTH rf amplifiers, previously responsible for a substantial part of linac downtime, were replaced by air insulated rigid loops connected to rigid air coaxial line. A further improvement in rf system reliability was obtained by replacing three parallel 4-in. air coaxial lines, used to couple rf power from the FTH tubes into the magic tee, by a single 8-in. rigid air coaxial line. Studies and experimentation have been continued to improve the over-all power output of the rf system in view of the higher rf power demands expected in the near future (because of beam loading).

During fiscal 1963 the PIG ion source has been used exclusively, and consequently the beam intensity has not changed from last year's values.

Improvements were made in the beam optical system following the ion source by installing a pulsed high-voltage supply. Linac output current now averages between 10 and 15 ma. Experiments are continuing with the duoplasmatron source on the low-voltage test set, and further understanding has been gained. Improved cathodes have been made, and some commercial units have been bought and tested. It is planned to reinstall the duoplasmatron on a trial basis in the near future. During the long shutdown of July-August 1962 it was found that several "O" rings between vertical drift-tube stem bellows and the linac tank wall had deteriorated sufficiently to cause vacuum leaks, and it was decided to replace these rings. Because of previous experience realignment tolerances on the drift tubes were relaxed somewhat, and alignment around a smooth curve to within ± 0.005 in. was considered acceptable. The ball tuner stem-to-vacuum seals were redesigned, and long bellows have now replaced the "O" ring sliding seals. Since completion of these modifications, no linac vacuum leaks have been detected from these sources. The preinjector vacuum system has been completely replaced, and independent servicing of each of the two Evapor-Ion pumps is now possible.

Continuous efforts are being made to improve the ancillary apparatus of the linac. A new timing system has been designed and will be installed in the near future. It is expected that the system will "lock in" the linac proton beam pulse more accurately with the AGS acceptance time, which will permit a shorter linac pulse and reduce beam loading effects. Shifts assigned to accelerator studies are being used regularly for linac experimental studies to provide further understanding of linac behavior and guidance in the development of linac instrumentation. Partly as a result of this work it was decided some time ago continuously to monitor linac output beam energy and energy spread by means of a pulsed momentum analyzer. The optical layout of this analyzer has been designed, and engineering design is nearing completion. Improvements are being made on the beam transport system between the Cockcroft-Walton generator and the linac.

Development and Engineering Programs

Power. Since the last annual report the main magnet power supply has performed extremely well, having pulsed $>5,000,000$ times. Total energy for the complex for fiscal 1963 is ≈ 35.5 kw-hr.

Eleven separate power feeders to distribute 11.5 Mw-a of power have been installed in the North Experimental Area. In line with plans to accommodate some of this expected increase in power consumption, fans were installed on four of the substations servicing the area. This procedure increases the rating of the equipment by 25%.

Thirty-one additional experimental power supplies (silicon-controlled rectifiers) have been procured. This new equipment brings the total available conversion capacity for experimental apparatus to ≈ 27 Mw.

Appropriate substations and power distribution systems have been designed for the Southwest Experimental Area. Installation is expected to commence shortly.

Performance tests have been satisfactorily completed on the main power supply for the 80-in. bubble chamber.

Mechanical - General. The third group of experimental magnets for beam transport systems is on hand. These include magnets for use in both the AGS and Cosmotron complexes. Deflecting magnets include seven 36-in.-long and six 72-in.-long units, each with 6×18 -in. apertures. Quadrupoles include ten 32-in.-long units of 8-in. diam and four 30-in.-long units of 12-in. diam.

Two special sextupole magnets have been built for the beam transport system to the 80-in. bubble chamber. These are 24-in.-long units of 12-in. diam. Eight pitching magnets for use with the external beam transport system have been designed and built. These units are 78 in. long with a 3×4 -in. aperture. Design field is 12 kgauss.

Three sets of "shuffling feet" have been designed and built. These are devices to move magnets weighing up to 35 tons in areas lacking crane facilities. They are capable of moving loads at the rate of 100 ft/min. A set has been successfully used to position bending magnets in the conjunction section.

Work is continuing on the fabrication and testing of the components for a fast-ejected external beam at the AGS. The major parts of the ferrite kicker and its associated delay line have been fabricated and successfully tested. The complete septum assembly, including the septum magnet, hydraulic ram system, power supply, and associated components, is now undergoing life tests under conditions simulating operation in the AGS. The magnet moves 3.6 in. in 0.2 sec with acceptable shock loads. The magnet and the condenser bank portion of the power supply for the ejector

section are complete. The magnet has been tested at full voltage by using this condenser bank. The remaining components of the system, including the hydraulic ram and condenser bank charging supply, have been designed and are being fabricated.

Portable buildings have been designed and built to house equipment placed beyond the confines of the existing research buildings. The buildings are 24 ft wide by 14 ft high and are 10 or 20 ft in length. Since it is necessary to relocate the equipment and its housing quickly, the structures are so designed that they can be picked up and moved completely assembled. Individual structures can be placed end-to-end to form a continuous building or used separately with detachable end walls.

Motor-driven flip target mechanisms introduced last year have been further refined to facilitate blade ejection, maintenance, and alignment in the AGS. A number of these mechanisms have completed $>2.5 \times 10^6$ cycles without failure or noticeable deterioration. Further refinements have been made in the air lock design in preparation for completely remote operation and automatic cycling. One prototype air lock equipped with remote controls has been set up and has successfully undergone preliminary tests. A programmed system designed to remove and exchange target blades remotely from such air locks is in an advanced stage of development. Its purpose is to reduce exposure of personnel to induced radioactivity, a problem which is becoming more severe with increased machine intensity, and to reduce operational downtime required for target blade changing.

A second rapid beam deflector has been installed at the *F*-20 straight section with provision for an air lock and target for chemistry experiments.

The design of ≈ 400 ft of vacuum system for a high-momentum separated beam to the 80-in. bubble chamber is complete. A large proportion of the necessary gear is on hand or is being fabricated, and installation is expected to begin toward the end of July.

Vacuum. The average pressure in the linac has improved to 5×10^{-7} torr after repair of some long-existing leaks. The ring continues to operate at an average pressure level of 5×10^{-7} torr. Titanium usage continues at a relatively low duty cycle; ion pumping is sufficient for the most part. When leaks occur in superperiods and operation does not permit immediate location and repair, titanium evaporation must be increased, with a

Figure 1. Ferrite kicker magnet for the external beam.

Figure 2. Septum magnet for the external beam.

Figure 3. Ejector magnet for the external beam.

concomitant increase in the need for repair and maintenance.

A new technique of providing a chemisorptive layer of titanium has been developed which eliminates any moving parts *in vacuo*. Instead of evaporating the titanium wire on a hot tantalum surface, the titanium is sublimed from a solid cylinder $\approx \frac{3}{4}$ in. in diameter by $1\frac{1}{2}$ in. long. This system provides a lower maximum pumping speed (≈ 1200 liters compared to 2000 liters at 10^{-5} torr for evaporation), but it is a much more stable device with a better ultimate pressure (10^{-8} vs 10^{-7} torr). Six of these pumps have been in operation on the main synchrotron vacuum chamber and show considerable promise.

The new injection system has been in operation successfully for >9 months. Pressures of 10^{-6} torr and below are consistently provided.

Controls. The installation of the permanent personnel safety and security system is now $\approx 60\%$ complete, and the gates and barriers are in place. These incorporate special features to minimize the possibility of entry into high radiation areas of the machine complex during operation. A system of emergency crash buttons throughout these areas is operational. Operation of any of these buttons immediately secures the machine as a radiation source.

The extension of control, communication, information, and explosive gas alarm systems to the East Experimental Area and Target Building is complete. Setup, operation and monitoring of these systems is handled completely from the area's control room.

Circuits to permit remote operation and automatic sequencing of both target insertion and retraction in the main vacuum chamber have been designed, and a prototype system has been built. These circuits incorporate position and vacuum interlocks and provide for automatic functioning of the associated vacuum equipment. A radial position-indicating technique (for the target) incorporating a precision potentiometer and a ratio digital voltmeter will be included.

Temperature sensors consisting in part of a low-melting-point metal slug restraining an appropriate electrical limit switch have been designed to be mounted one on each of the 960 coils of the main ring magnets. Details for high-voltage isolation transformers and relay summing circuits are complete, much of the hardware is on hand, and installation will begin presently.

DC Beam Separators. Electrostatic beam separators have been used in three beams this year.

Two cylindrical separators continue to be used in the beam to the 20-in. hydrogen bubble chamber at the AGS. One of the recently constructed rectangular separators is being used in a low energy K^- -meson beam for the 30-in. hydrogen bubble chamber. Another rectangular separator was used to produce a π^+ beam at the Cosmotron.

The voltages routinely held in the cylindrical separators range from 350 to 400 kv on a 2-in. interelectrode gap. The electrodes in the rectangular separators maintain 400 to 500 kv on a 4-in. gap. Much attention is being given to methods of achieving higher voltages and stable operation. Such methods include the use of partially resistive glass cathodes, elevated electrode temperatures, tank pressures of $\approx 10^{-3}$ torr, and new instrumentation.

Three rectangular beam separators have been joined together for a total electric field length of 50 ft. Two such triplets will be used as part of a beam transport system to the 80-in. bubble chamber. In order to provide low energy separated beams, three short separators, each 6.5 ft long, are being constructed. With the addition of these separators, the total length of electric field available for beam purification will be 165 ft.

RF Beam Separators. The design of the rf particle separator has been completed, and components are on order. A rf particle separator of the Panofsky type gives promise of producing useful separated beams with sufficient flux at momenta up to 19 Bev/ c for antiprotons and 13 Bev/ c for K mesons. A study indicated that a 2-deflector system with fixed drift length can achieve 10 different beams with 2-contaminant rejection. From the experience gained with a simple system it will be decided whether a more sophisticated separator is justifiable.

The construction of rf separators requires design of the beam optics, generation of the rf power, and development of a deflecting structure. A preliminary design of a high energy beam for the 80-in. bubble chamber was prepared using only currently existing beam transport elements. The low-level rf system will consist of a frequency synthesizer and a varactor multiplier chain ($\times 144$) to generate the standard S-band frequency of 2.856 Mc, followed by symmetrical CW-amplifier and pulsed-driver stages at the klystrons. All units are on order, but several items have not yet been delivered. Tests are being carried out to find a satisfactory solution for the stringent phase requirements. A 20-Mw klystron with modulator for high-power tests has been ordered.

An iris-loaded waveguide was chosen as deflecting structure. Theoretical and model work was done to investigate the hybrid character of the deflecting mode and to find the correct dimensions for a $\pi/2$ mode. A FORTRAN program for the IBM 7090 was written to compute the dispersion diagram, space harmonic content, and deflecting properties. It was found that a negative group velocity must be selected if nondegenerate field solutions are desired. A brazed test cavity and a 1-m prototype with waveguide couplers are on order.

Electronics. The rf system has required little in the way of extraordinary maintenance. In general the weekly maintenance periods have sufficed to keep the system fully operational. The most persistent difficulty has been the failure of transistors due to radiation damage. The circuit most affected was placed in a concrete cave, which significantly extended the useful lifetime of the equipment. Since October 1962 this transistor

bank has shown no degradation. The over-all rf system is being studied with the ultimate goal of reducing the straight sections required by the accelerating stations from 12 to 8 and thereby releasing 4 additional straight sections for experimental use.

Most of the timing system in the main control room has been converted to solid-state circuits with a resultant improvement in system reliability and appreciable reduction in space requirements.

Much of the linac electronic system has been redesigned or reworked. This includes a variety of control room equipment such as timing circuits and a low-level rf system. Specifications have been written for a portion of a new high-level rf system including a capacitor energy storage network, high-voltage power supply, and a hard-tube modulator.

All the electronic components required for the external beam either have been built or are on order and scheduled for early delivery.

Figure 4. A triplet beam separator being positioned in the Target Building.

Survey. During the shutdown of the AGS in July and August 1962 for the construction of the conjunction tunnel to the North Experimental Area, precise levels were run (1) immediately before removal of the shielding earth, (2) a day after the period of maximum excavation, and (3) during the last two weeks of the shutdown, for the realignment of the ring magnets. A gradual rise in elevations of the magnet foundations over 3 super-periods reached a maximum difference of 0.274 in. at the period of maximum excavation, settling back to 0.120 in. after completion of the construction. Leveling during March 1963, 6 months after completion of construction, showed a further rise of 0.042 in. near the conjunction tunnel to the North Experimental Area and a settling of 0.038 in. in the Target Building due to heavy shielding loads after the realignment of the magnets in September 1962. These changes closely approximate the predicted amounts. The excavations for the Southwest Experimental Area caused a rise of 0.069 in. at the time of maximum excavation on May 14, 1963.

A complete horizontal resurvey and radial realignment of the ring magnets was made during September 1962. One control monument at the conjunction section had shifted 0.145 in. outward with adjacent stations moving ≈ 0.060 in. The maximum radial shift of the magnets themselves from the 1960 to the 1962 alignment was 0.070 in., with a general readjustment in the undisturbed sections of the ring of ≈ 0.015 in. The maximum tilt of the magnets observed prior to realignment was 0.2 milliradians near the conjunction section.

The precise setting of the equipment for each experiment has called for many variations in survey techniques. New spark-chamber equipment was found to be capable of higher precision than anticipated, and appropriate survey techniques of comparable precision are being developed. Direct beam surveys from the ring through the north conjunction section checked with the roundabout exterior triangulation from the East Target Area within 0.125 in., possibly because of fortunately compensating errors.

Mechanical Services. The major water-cooling systems of the AGS have functioned throughout fiscal 1963 with few interruptions to the machine program. The well water continues to have a high iron content, and consequently the chemical treatment program must continue. The water processing is supplemented periodically with mechanical cleaning of the system.

As is the general case in the accelerator field, there are many cooling problems (both water and air), each requiring special handling. Systems have been designed and built for equipment ranging from chillers for transistor plates (rf system) to a water tower of 12-Mw capacity to increase the over-all experimental water capacity.

The activation of the Southwest Experimental Area has required relocation of overflow lines in this vicinity. The design and procurement of cooling and distribution apparatus for this area has been completed, and installation has started.

Advanced Accelerator Development

In the Advanced Accelerator Development Division studies are in progress on super high energy accelerators, storage rings for colliding beams, and radio-frequency beam separators. In April 1963 the super high energy accelerator and storage ring studies were authorized by the AEC. The former study is expected to continue for 4 or 5 years, and the storage ring study should result in construction proposals in ≈ 2 years.

The super high energy studies are directed toward a machine in the energy range between 600 and 1000 Bev. Component design is proceeding from the point reached during the 1961 study [BNL 772 (T-290), Aug. 1961, revised Dec. 1962]. Several proposals have been made for improved design of synchrotron magnets, and model work will be initiated during the coming year. Further analysis is in progress on methods for tuning accelerating cavities and on injection methods.

One of the more important parts of the storage ring study follows from the requirement that the pressure in the ring must be of the order of 10^{-10} torr. A study of super high vacuum techniques, including preparation of a high vacuum system, is under way. In addition, an intensive study is in progress on techniques for storing beams in order to reduce the rather large energy spread inherent in the radio-frequency stacking process now proposed.

During the summer of 1963 a study will be conducted in which about 30 visitors will collaborate with the Brookhaven staff on possible designs and experimental utilization of storage rings and super high energy accelerators.

COSMOTRON

The bulk of the experimental program at the Cosmotron was devoted to the exploration of new

resonance particles and to further study of the positive and neutral K mesons. An experiment was performed measuring the charge-exchange scattering cross section for neutrons on a hydrogen target. Further counter work upon proton isobars, although well executed, did not yield additional information. The Cosmotron continued to support the radiochemistry program of the Chemistry Department, and a similar program for the Medical Department was added. About two-thirds of the experimental beam time was assigned to non-Brookhaven research groups. The experiments designed to isolate rare events are complicated and time consuming, and in two cases the experimenters were forced to conclude that to continue beyond the testing stage would require unreasonable effort. An analysis of potential running time is shown in Figures 5 and 6.

The Cosmotron reliably delivers a circulating beam of $>2 \times 10^{11}$ protons/pulse at 3 Bev and continues to improve in stability. The maximum intensity achieved to date is 10^{12} protons/pulse. Routine delivery is now possible of monokinetic proton beams lasting for 200 msec from the 3 external beam ports. Although the proton bunching during this spill time will eventually be improved, it is sufficiently smooth to permit the isolation of rare events from background in counter-spark-chamber systems. Without this feature it would be impossible to perform more than half of the experiments in the current phase of the research program within tolerable time allotments. Regulation of the current in the motor driving the Cosmotron magnet power supply by means of solid-state switching has eliminated wasteful heating in the motor and has made possible a reduction in the

Figure 5. Use of the Cosmotron for experiments in high energy physics during fiscal 1963.

Figure 6. Cosmotron utilization during fiscal 1963.

pulsing period of the Cosmotron. When this improvement is supplemented by an augmented water-cooling system, it will be possible to increase the rate of delivery of protons by 40% over that attainable before work on these projects began.

Efforts to advance injection technology have been fruitful. Replacement of the corona spark gaps along the Van de Graaff acceleration tube by fixed resistors has greatly increased the life of belts operating in the pressure tank by removing the sources of ozone, and it is less frequently necessary to open the tank because of belt failure. A high-speed compressor has been installed to reduce the time required for transfer of the insulating gas to half of its previous value. Geometrical rearrangement and surface treatment of parts in the vicinity of the ion source has increased the proton injection current from 5 to 8 ma.

The many devices added to the operating console over several years have been consolidated into a unified system. Reworking of the final radio-frequency power unit has greatly improved its reliability and waveform. Jigs and fixtures have been designed and built which will enable quadrants of the vacuum chamber to be withdrawn from the magnet gap without removal of the main shielding. Six magnet-positioning tables were added to the experimental floor equipment. The middle external proton beam was bifurcated, which makes it possible to set up two major experiments in this beam.

To obtain information pertinent to storage ring design, preliminary experiments to sustain a proton beam in the Cosmotron vacuum chamber have been performed. Although it is too soon to make positive statements on the results, the obser-

vation of a 1-Bev beam surviving $>1\frac{1}{2}$ min is encouraging evidence of progress.

Construction of an addition (an office and machine-shop wing) to the Cosmotron complex was started and is virtually complete.

Between June and November 1962, 57,000 liters of liquid hydrogen were manufactured. In November the hydrogen liquefier ceased manufacture of liquid hydrogen and was placed on a stand-by basis. Two 1500-gal storage tanks were installed to receive liquid hydrogen delivered by tank truck from a commercial vendor. To date 200,000 liters have been purchased.

A deuterium-generating plant that electrolyzes heavy water has been received from the National Bureau of Standards and installed at the Cosmotron. It is capable of producing 24 cubic feet of deuterium gas per hour at standard temperature and pressure. Three and one-half tons of heavy water, with a tritium content $<10^{-13}$ that of deuterium, were obtained from the AEC installation at Savannah River and are on hand. Over 36,000 cubic feet of gas have been produced at the Laboratory, which at present is the sole source of this gas for use in high energy physics research in the nation.

Instrumentation

During the past ten years automatic systems for data recording and analysis have become increasingly important. The 1953 annual report described a multichannel analyzer using photographic techniques and a 100-channel time analyzer to measure neutron velocities. The data from these and other instruments were recorded by hand. Today the Laboratory has many multichannel analyzers, of commercial and BNL design, which are provided with displays and printers. Data from many experiments are punched on paper tape for analysis and tabulation by computers.

Members of the Instrumentation Division are working with other groups in the Laboratory on automatic systems for reading the coordinates of bubble-chamber and spark-chamber tracks on photographic film. A member of the Division completed a Ph.D. thesis on automatic pattern recognition at Brookhaven this year. Automation not only accelerates the gathering of information but also makes possible many otherwise impossible experiments.

Members of the Division worked closely with L.C.L. Yuan (Physics Department) and his group on a study of elastic scattering by hydrogen of high-energy particles. Scintillation detectors arranged in flat arrays signaled the path of the recoil particles. A set of fast (0.025- μ sec) electronic gates was built to sample all the detectors when an event occurred. The track coordinates so determined were stored in a magnetic core memory. Up to 32 events could be stored in the memory during each 0.1-sec period of particle production by the Alternating Gradient Synchrotron (AGS). Between accelerator pulses the data in the memory were recorded on magnetic tape and simultaneously transmitted over telephone wires to the Merlin computer in another building. The particle trajectories were calculated as fast as the data entered the computer. They were sorted according to angle and momentum, compiled, and displayed on cathode ray tubes at the computer and at the AGS. The entire system performed in a highly reliable manner throughout the several months of the experiment and resulted in highly efficient use of expensive accelerator time.

In an attempt to achieve higher spatial resolution in experiments of this type, wire spark chambers are being investigated. Several hundred wires are strung in parallel to form one plane surface of a spark chamber. Several single-plane spark chambers may be set up to form a hodoscope. The wire spark chambers have a spatial resolution of 1 mm and an efficiency of $>95\%$. Current from a spark will flip a magnetic core. Properties of the system are being investigated, and circuits will be developed to read information from the cores into a buffer memory and computer, as for the system described above.

Some years ago Brookhaven developed a 4096-channel analyzer for multidimensional pulse-height analysis. There are cases in which many more channels would be desirable except for the prohibitive cost of an adequate memory. The most recent approach to this problem is to record the data on magnetic tape as it arrives and simultaneously to monitor the experiment with a small, fast, digital computer. After the data are recorded, the tapes may be scanned with a computer to bring out the fine detail in regions of interest. Members of the Instrumentation Division have worked with J. V. Kane (Bell Telephone Laboratories) on the design of such a system and are now working on a similar system for use with the Physics Department's fast-neutron chopper.

A number of more conventional data recording systems were built this year. Several printout systems were built for use with neutron crystal spectrometers. Equipment was assembled that permits data from scalers and other external devices to be transferred to a commercial (RIDL) pulse-height analyzer and printed or punched out along with the contents of the analyzer memory. Systems are under construction for recording environmental factors in an irradiated forest and the oxygen, CO_2 , and C^{14} content of an individual's breath.

Work has continued on semiconductor radiation detectors, with emphasis on lithium drifting, and a number of these detectors have been fabricated for special applications. As described in last year's annual report, it is possible to compensate acceptors in silicon by drifting lithium atoms through

the material at high temperature with an electric field and to produce thick detectors (>1 cm thick). At times, however, this process does not operate satisfactorily because of properties of the silicon that are not well understood as yet. In cooperation with the Crystal Division of the Dow Corning Corporation, an investigation of this effect is nearing completion. Special crystal samples of known histories and a wide variety of lifetimes, impurity concentrations, and dislocation densities have been drifted. Rather surprisingly, carrier lifetime has been found to be quite unimportant; the dominant factor seems to be the dislocation density.

The response of thick lithium-drifted devices to minimum ionizing particles has also been investigated at the Brookhaven AGS, and they have been shown to behave just as predicted by the Landau theory, i.e., they do not exhibit any anomalous effects.

Field effect transistors have recently become available in experimental quantities. They have characteristics similar to those of vacuum tubes (very low input current and high voltage gain). They are attractive because of their high input impedance and low intrinsic noise. At low voltages they behave like a variable resistor that is voltage controlled. Samples were obtained from several manufacturers and their performance was studied. They have been used with conventional transistors in a low noise preamplifier for use with radiation detectors. In this application field effect transistors compare favorably with the best available tubes and are substantially better than bipolar (conventional) transistors. They can be operated at liquid nitrogen temperature, which is useful in some experiments. Two field effect transistors have been used in a balanced circuit as controlled variable resistors to form a multiplier. The multiplier has a response time of $\approx 0.5 \mu\text{sec}$ and a useful range of $\approx 100:1$, which makes it especially suitable for forming the product of radiation detector pulses. A field effect transistor was used at the input to the amplifier of a resistance bridge designed for measuring temperatures near absolute zero. The amplifier noise is low enough so that sensitivity is limited only by the noise of the input bridge resistors. A pair of field effect transistors was used at the input of an amplifier for measuring photomultiplier currents. This amplifier has a response from zero to 300 kc.

Of the many instruments designed and built in fiscal 1963, the following deserve mention.

A monitor was built to show the location and shape of beams of high-energy particles. The sensing elements are 32 lithium-drifted detectors ($2 \times 2 \times 2$ mm) mounted on a light aluminum cross in a vacuum. The assembly is cooled by Peltier junctions to stabilize the lithium. Outside the vacuum are an amplifier, discriminator, and analogue count accumulator for each of the detectors. A circuit scans the accumulators in sequence and transfers the counts to the memory of a 256-channel analyzer. The instrument can accept from 0 to 4000 counts per detector per accelerator pulse with digital accuracy. The vertical and horizontal intensity distribution may be displayed by the analyzer. Successive pulses may be stored in different locations in the analyzer for ease of comparison.

A device has been built to scan microscope slides automatically in a systematic pattern. The scan pattern is comparable in size to a single blood cell. A small platform is suspended on flat springs to allow it to move in the x and y directions in the horizontal plane. In each direction the position is determined by the length of a wire filament, which in turn is controlled by heating. Since both length and resistance are linearly related to temperature over a substantial range, it was possible to build a servo circuit to force the length to track a programmed voltage waveform. The control is very smooth and positive in the range 0 to 100 microns (0 to 0.004 in).

A circuit to integrate the current in an accelerator beam was built with use of modern techniques to achieve high stability and resolution in the current range 10^{-6} to 10^{-10} amp.

A method of producing quick changes of temperature in small liquid samples was desirable to allow determination of the rates of certain chemical reactions. The method devised consists of discharging a capacitor through the liquid and observing the time-dependent change in spectral transmission. An energy storage capacitor, spark gap, and sample holder are placed in series and enclosed in a conducting cylinder which completes the electrical circuit and contains most of the transient electrical signal. The capacitor may be charged to 100 kv from an external power supply. A light beam passes via a monochromator through the case and the sample to a photomultiplier. The output from the photomultiplier is connected to a low noise amplifier, described above, and to an oscilloscope. Electrical pickup from the dis-

charge is small enough that very small changes in the transmitted light can be readily measured.

A light, photocell, and controls were arranged in such a way that the density of a bacterial culture can be maintained constant by adding culture medium as the bacteria grow. A new version of the 100-Mc scaler was put into production. The scaler is more reliable and potentially faster than the previous design, and the circuit divides by 10 instead of 8. To measure antenna patterns and performance, a field intensity meter was constructed which senses the magnetic rather than the electrostatic component of the field. It is an absorption meter with a tuned circuit, the inductor being wound on a ferrite rod. A display was built for the Merlin computer using a magnetic-deflection cathode ray tube and transistor amplifiers. It takes less than 10 μ sec to deflect the spot fully. A superregenerative, parametric, free precession, proton resonance magnetometer employing varicap diodes was constructed, and its exceptionally low noise properties were demonstrated. This system may have applications in searching for weak resonance lines.

METEOROLOGY

The Meteorology Group has broadened its program somewhat during the past year. Two members have been added to the professional staff, and the addition of a scientist in July 1963 will strengthen the supervision of the program.

The research program is developing along two major lines. One is a continuation of the diffusion-deposition studies, which are now largely concerned with particulates and the processes resulting in their transfer from the atmosphere to the ground. The second major part of the program is directed toward fundamental problems in low-level turbulence, and a significant portion of the research is now devoted to this work.

Turbulence Studies

Systematic examination of various terms in the equations governing the production, transfer, and dissipation of energy in the turbulent flow has been expanded in the past year, and several interesting conclusions have resulted. The dissipation of energy, associated essentially with the smaller eddies, has been found to follow the Kolmogoroff similarity hypothesis only for the com-

ponent in the direction of the mean wind. In the cross-wind and vertical directions, the dissipation apparently obeys different laws.

It has also been determined that the logarithmic and logarithmic-linear laws describing the change in wind speed with height near the surface appear to fit the observed data up to 150 ft above ground, but in unstable cases the theory becomes unsuitable at greater heights.

Somewhat surprising is the fact that the wind profile immediately above the typical forest on the Laboratory site almost invariably follows the logarithmic pattern as long as the thermal stratification is at all unstable. This suggests that the structure in the first 50 ft above the top of the forest generally has the properties of a neutral atmosphere. In common with other investigators, the Group has been unable to advance any theory that satisfactorily predicts the profile under stable conditions.

The study of the wind structure in the vicinity of natural obstructions has been considerably extended. Detailed investigations of the wind profile above the forest have proved rewarding. It has been possible to determine the effective displacement of the ground level provided by the thick forest cover, and to show that this varies systematically and reasonably with the change in the deciduous vegetation from season to season.

Plans have been completed to include in this investigation the influence of a change in roughness on the wind flow as a function of distance and meteorological conditions. To accomplish this, the tower system has been augmented by four 50-ft masts mounted on trailers. They can be moved readily to various positions in relation to the main fixed tower assembly.

Suitable instrumentation is gradually being developed to implement these studies. The sensitive three-cup anemometers described in the 1962 annual report have been standardized and produced in sufficient quantity to be used on all the towers. These instruments can now be matched to better than 1%, and assembly procedures are such that they can be interchanged without correction.

One particularly challenging problem remains, and that is the measurement of horizontal wind flow within the forest. The anemometers developed are suitable as far as sensitivity is concerned, but it appears to be impossible to situate a single instrument within a forest in such a way that it is not seriously affected by individual branches and

Figure 1. Plot of normalized Cu^{64} deposition, $\text{sec}/\text{m}^2 \times 10^{-4}$.

leaves. Anemometers have been observed, for example, to rotate in reverse. Development of more suitable instrumentation for this type of work will continue to be an important objective.

In both turbulence and deposition research, data handling is a most important consideration. Supplementing the paper-tape recording system that has been a mainstay of Group activity for some years, a new data collection unit consisting of a series of simple scalars and data storage units coupled to an IBM 526 punch-card machine constitutes an inexpensive and versatile addition to the equipment. The cost of this assembly is $\approx \frac{1}{5}$

to $\frac{1}{10}$ that of the more sophisticated equipment, and the unit will be installed in a trailer so that it can be moved to various locations with a minimum of difficulty.

Particulate Studies

Investigation of the behavior of Cu^{64} spheres and various naturally occurring pollens continues to account for a large proportion of the Group's effort. During fiscal 1963, six additional field tests, including the first run ever made under temperature inversion conditions, were conducted on the copper deposition sampling grid. Additions to the

sampling data and refinement of the portable radiation counting devices gave much better definition of the three-dimensional distribution of the plume and deposition near the source. A typical deposition pattern is shown in Figure 1. Much of the winter season was devoted to transfer of all the deposition, diffusion, and meteorological data from the field tests to IBM punch cards and to the development of programs for the required analyses. Many of the latter have been completed, and reports on various aspects of the work are being prepared for publication.

One of the more interesting and disturbing results of the deposition studies is the suggestion that the collection efficiency of filter samplers may be sensitive to variations in atmospheric stability as well as horizontal wind speed. The former probably implies variations in vertical wind components, and therefore involves the angle of attack of the wind in relation to the sampling head. This problem fortunately can be investigated in the Meteorology Group's wind tunnel, and the study will be pursued vigorously, since the implications in relation to field sampling accomplished both here and elsewhere are important.

The pollen study, continuing as a cooperative venture with the New York State Museum and Science Service, has been expanded. Various configurations of ragweed and timothy pollen sources have been investigated, and airborne concentrations were measured at four heights above ground for the first time in fiscal 1963. Previous studies of particulate problems have so consistently indicated the need for a thorough picture of the vertical distribution of the material that the considerable effort involved in sampling at four heights is warranted. During the course of the season $\approx 18,000$ individual samples were obtained and counted.

Plans have been completed and equipment is now being installed to extend both the Cu^{64} and pollen studies into regions of heavy vegetation. There are strong reasons to believe that the effect of vegetation, such as a moderately dense forest, will be to remove particulates from the atmosphere very efficiently. It is most important in many practical considerations to define this effect.

Cloud Rise Studies

The Meteorology Group has had an opportunity to undertake a new project in diffusion, one in which it has long been interested. A cooperative

Figure 2. Rocket fuel plume ascending during nearly calm conditions. Meteorological and cloud dimension measurements are made at 410 ft on the 420-ft meteorological tower.

effort with the Atlantic Research Corporation, begun in June 1962 and extended into the summer, involved the burning of nontoxic solid rocket propellant in configurations producing a wide variation in both total heat release and release rates. The behavior of these extremely hot clouds was observed under all typical meteorological conditions, and full utilization of the tower and aircraft observational facilities available to the Group resulted in good definition of the rise rates and maximum heights reached. In one respect the

experiments were disappointing. The burning rates varied appreciably with time, and it was decided to attempt to verify the results in a new series to be conducted during fiscal 1964. Preliminary data certainly indicate that cloud behavior for modest releases at low level should be quite predictable, and one of the more encouraging results is that even very small heat releases rise considerably above ground level during inversions. Figure 2 shows the configuration of one of the clouds approximately one minute after release.

Chemistry

The following sections describe research in the Chemistry Department on various problems involving radiations, isotopes, nuclear properties and reactions, and related chemical and physical topics. The work reported has been done by members of the continuing staff, postdoctoral Research Associates, and visitors from other institutions.

HIGH ENERGY NUCLEAR REACTIONS

Simple Reactions

It is possible to obtain information about elementary particle interactions by the investigation of high energy interactions in which only one or two elementary particles are ejected from a complex nucleus. Recently two elementary particle interactions of the type $p + p \rightarrow n + p + \pi^+$, with the neutron remaining in the product nucleus, have been studied. These are the $\text{Cu}^{65}(p, p\pi^+)\text{Ni}^{65}$ and the $\text{Al}^{27}(p, p\pi^+)\text{Mg}^{27}$ reactions. The nature of the reactions limits the momentum transfer from the incoming proton to small values, since large values lead to products lighter than Ni^{65} or Mg^{27} . The experimental results have been compared with

calculations based on the "one-pion" exchange theory.

The experiments yielded excitation functions from 0.5 to 28 Bev (Figure 1). Recoil ranges were measured from thick targets; and an angular distribution of Ni^{65} recoils for a 2.9-Bev incident proton energy was determined. The theoretical calculation of Ericson, Selleri, and Van de Walle for $(p, p\pi^+)$ cross sections has been improved and extended to give recoil ranges. The shape of the calculated excitation function (Figure 1) is in good agreement with experiment; the broad peak at 1.2 Bev is a direct consequence of the pion-proton resonance (first isobar). At very high energies (>10 Bev) there is a 40% discrepancy between the observed and calculated cross sections which is not yet understood. The calculated recoil ranges agree well with experiment.

A new study of the $\text{Cu}^{65}(p, pn)\text{Cu}^{64}$ reaction has been initiated. The angular distribution of Cu^{64} nuclei, for 2.9-Bev incident protons, has a narrow peak about 85° from the incident beam direction. Differential range measurements will be made in an effort to obtain a detailed comparison between theory and experiment for (p, pn) reactions.

Studies of pion-induced reactions have been pursued with the 0.5 to 2.0-Bev π^- beams available at the Cosmotron. An excitation function has been determined for the $\text{C}^{12}(\pi^-, \pi^-n)\text{C}^{11}$ reaction by measuring the C^{11} activity induced in plastic scintillators and monitoring the incident pion flux with nuclear emulsions. The experimentally determined function reflects some of the structure of the elementary particle (π^-, n) excitation function. The following simple equation is in qualitative agreement with the measurements.

$$\sigma(\pi^-, \pi^-n) = \sigma(p, pn) \frac{\sigma_T(\pi^-, n)}{\sigma_T(p, n)},$$

where $\sigma(p, pn)$ is the well-known $\text{C}^{12}(p, pn)\text{C}^{11}$ cross section, and the σ_T 's are the indicated elementary-particle total cross sections.

Excitation functions have also been measured for the production of C^{11} and F^{18} from π^- -irradiated Al targets. These results are the same as those for the corresponding proton-induced reactions.

Figure 1. Excitation function for the reaction $\text{Cu}^{65}(p, p\pi^+)\text{Ni}^{65}$.

Cross Sections of Complex Reactions

A study of the interaction of 3 and 30-Bev protons with Ag, Pb, and U targets has been continued during the past year in an attempt to gain further insight into the systematics of cross sections for reactions induced by high energy protons. With Ag, formation cross sections have been measured for 50 nuclides at 2.9 Bev and for 30 nuclides at 30 Bev. With Pb and U, cross sections were measured for >60 nuclides at both energies. Although the results have not been completely analyzed, it is clear that most of the cross sections do not show a large energy dependence. The principal differences between the Pb and U data appear among neutron-excess products which are virtually absent in the Pb targets but are formed in substantial yields from U, evidently by relatively low energy fission processes.

A study has been started of the yields of light products (in the mass region 7 to 24) resulting from the interaction of 30-Bev protons with the series of targets Cu, Ag, Ta, Au, Pb, and U. In addition to the usual radiochemical techniques for the radionuclides, mass spectrometry is being used to measure the cross sections of the stable Ne isotopes. These measurements give total yields at masses 20 and 21. For mass 22 isobaric yield ratios are obtained by measuring Na^{22} as well as Ne^{22} to obtain the total yield of mass 22.

An experiment has been performed in an attempt to answer the interesting question: What is the influence of the neutron to proton ratio (N/Z) of the target nucleus on the dispersion of nuclear charge among the spallation products? The targets selected were Zr^{96} , Mo^{96} , and Ru^{96} ; the products measured were isotopes of Zn, Ga, As, and Se in the mass region 66 to 74, and the reactions were induced by 1.8-Bev protons. Graphs of cross section of a given mass number vs N/Z show a nearly Gaussian charge distribution for all three targets, but the peak of the distribution shifted from $N/Z=1.18$ for the Zr target to a value of 1.13 for the Ru target. In other words, a difference of 4 charge units in a target at mass 96 results in a difference of 0.8 units of charge in the spallation products around mass 70. These results are in qualitative agreement with cascade-evaporation calculations.

A new series of experiments has been started to measure the cross sections, from a series of targets, of delayed neutron-emitting products and of other short-lived species that emit β rays of unusually high energy. One experiment of this type, de-

signed to search for H^5 , was carried out in collaboration with members of the Physics Department, and the results are presented in the Physics section of this report.

Recoil Studies

Numerous recoil experiments are being performed to identify and elucidate the various processes involved in high energy nuclear reactions. The study of the recoil properties of Na^{24} produced in the irradiation of Bi with 2.9-Bev protons has been completed, and analysis of the resulting data is nearly complete. Energy spectra and angular distributions of Na^{24} were obtained at laboratory angles of 15° , 90° , and 165° . If the fragments are emitted *after* the "knock-on" phase of the reaction, the emission should be symmetric about 90° in the coordinate system of the excited nucleus, and the energy spectra at supplementary angles should be identical. Therefore the spectra at 15° and 165° were used to determine the transformation from the observed angular distribution in the moving system. Instead of symmetry about 90° , there was preferential emission in the forward direction. It was concluded that the hypothesis of a 2-step mechanism for the formation of this product leads to contradictions outside experimental error, and that fragment production occurs before the first step, or knock-on phase, of the reaction is completed.

Another set of experiments using thin targets is in progress to measure the range distribution at 90° to the beam of a series of products from an Ag target irradiated by 2.9-Bev protons. The mean ranges in formvar of Na^{24} , $\text{Sc}^{43,44}$, $\text{Cu}^{61,64}$ and Sr^{83} are 1.30, 0.73, 0.53, and 0.31 mg/cm², respectively. The widths at half maximum of the differential range curves are $\approx 120\%$ of the mean range for the first three products, and the maxima are near the mean values. However, for Sr^{83} the range curve is nearly flat until it reaches 0.36 mg/cm². It is hoped that analysis of the data and comparison with Monte Carlo calculations will show the relative contributions of a spallation-type mechanism and a 2-body breakup mechanism for the various products.

The recoil properties of Na^{24} and K^{42} formed from targets of Ti, Fe, and Cu irradiated with high energy protons are also being investigated. The mean ranges determined from thick-target range measurements are in agreement with the results of Monte Carlo evaporation calculations. However, a more sensitive test of the mechanism

should be possible by comparing calculated and experimental energy spectra of the emitted fragments. Accordingly, thin-target differential range measurements are being made of Na^{24} emitted from these targets.

Xenon Bubble Chamber and Nuclear Emulsion Studies

About 300 nuclear interactions initiated by 1.2-Bev/ c π^- mesons in a Xe bubble chamber have been analyzed. The resulting energy and angular distributions of protons with kinetic energy >20 Mev, the angular distribution of emitted π^+ and π^- mesons, and the frequency of occurrence of π^0 emission have been determined. A similar analysis is being carried out for interactions induced by 800-Mev/ c π^+ mesons. The results will provide a direct check on predictions of new Monte Carlo nucleonic cascade calculations (see below).

Low-sensitivity nuclear emulsions have been irradiated with a separated beam of 2.7-Bev anti-protons. The emulsions are being scanned in a manner similar to that used previously for the 2 and 3-Bev proton irradiations mentioned in the 1962 annual report. Only those stars originating in nuclei of Ag and Br are being analyzed. The following characteristics will be compared for the two types of irradiations: the number of alpha particles and light fragments per star, the energy spectrum and angular distribution of alpha particles, and the range spectrum and angular distribution of spallation residues with respect to the beam.

Theoretical Calculations

Further Monte Carlo calculations of intra-nuclear cascades have been made with the IBM 7090 computer. Interactions of nuclei with low energy pions have been programmed both with and without the assumption of isobar formation. However, emphasis has been on detailed investigations of the effects of the nuclear model and parameters used; these studies have been carried out with incident nucleon energies below 400 Mev with neglect of pion production. It has been found that the calculated cross sections for simple reactions such as (p, pn) and $(p, 2p)$ are, as previously conjectured, quite sensitive to the assumed nuclear density distribution, and that the interactions leading to these reaction products are strongly localized near the nuclear surface. A trapezoidal density distribution consistent with the Stanford

electron-scattering data gives better agreement with (p, pn) and $(p, 2p)$ cross section measurements than does a rectangular density distribution; but a further improvement is obtained when a step-function density distribution is used which approximately reproduces the Fermi distribution "tailing-off" used by Hofstadter. Comparisons have also been made between the new Monte Carlo cascade calculations, in conjunction with evaporation calculations, and radiochemically measured mass-yield curves; again the step-function model with inclusion of nucleon refraction and reflection effects appears to give satisfactory agreement.

LOW ENERGY NUCLEAR REACTIONS

In the interpretation of excitation functions it is necessary to take account of (1) the emission of γ rays in competition with particle emission, and (2) the distribution of the excited nuclei with respect to angular momentum. These remarks are based on a comparison of calculations with data in the literature. Although such comparisons are reasonably convincing, an experiment has been devised and carried out which provides a more stringent test of these factors. In collaboration with the Lawrence Radiation Laboratory, Livermore, Calif., measurements have been made of the cross section ratios $R_\alpha = \sigma(\alpha, 2n) / [\sigma(\alpha, n) + \sigma(\alpha, 2n)]$ for the reactions $\text{Pb}^{206}(\alpha, n)\text{Po}^{209}$ and $\text{Pb}^{206}(\alpha, 2n)\text{Po}^{208}$, and $R_p = \sigma(p, 2n) / [\sigma(p, n) + \sigma(p, 2n)]$ for the reactions $\text{Bi}^{209}(p, n)\text{Po}^{209}$ and $\text{Bi}^{209}(p, 2n)\text{Po}^{208}$. Both reaction systems involve the same "compound nucleus," Po^{210*} , but the distribution of the excited Po^{210*} nuclei with respect to angular momentum is expected to be different for each case. Both sets of measurements were carried out for energies up to $\epsilon = 2.3$ Mev, where ϵ is the energy in the center-of-mass system in excess of the $(\alpha, 2n)$ or $(p, 2n)$ threshold. The thresholds were determined internally for each system by extrapolation of the data with the aid of the IBM 7094 computer. If effects (1) and (2) are neglected, then independence of formation and decay of the "compound nucleus" demands that $R_\alpha(\epsilon)/R_p(\epsilon) = 1$. Experimentally, for $\epsilon = 0.22$ Mev, $R_\alpha/R_p \approx 3.5$, and this ratio falls monotonically with increasing energy so that at $\epsilon = 1.0$ Mev, $R_\alpha/R_p \approx 1.8$ and at $\epsilon = 2.2$ Mev, $R_\alpha/R_p \approx 1.1$. If the effects of γ -ray emission and angular momentum are taken into account, the experimental observations are exactly as expected, both in direction and approximate magnitude.

Detailed calculations show that these data can be explained with only the compound nucleus mechanism; more complicated or sophisticated mechanisms are not required.

Studies of nuclear reactions by particle-counting coincidence techniques have been carried out at the 60-in. cyclotron in collaboration with members of the Physics Department. A résumé of this work is given in the Physics section of this report.

NUCLEAR SPECTROSCOPY

Studies of conversion-electron lines of Te^{123m} , Te^{121m} , and Te^{121} have been made with the double-focusing β -ray spectrometer. The ratios of electric quadrupole to magnetic dipole radiations in the ground-state transitions of Te^{123m} and Te^{121m} were determined by measuring the relative intensities of the L -subshell electron lines. These ratios are of interest in connection with the particle-collective theoretical description of the excited nuclear states. Absolute values of K and L -conversion coefficients of the transitions were shown to be in good agreement with the values expected for transitions with no contributions from intranuclear matrix elements. In the case of the Te^{121} and Te^{121m} decay states of Sb^{121} , measurements on the K -lines and L -subshell lines, together with results of measurements on the gamma radiations made by members of the Physics Department, established the descriptions of the excited states of Sb^{121} which are thus populated. Measurements have also been made of electron lines arising from M -shell conversion of the $M4$ and $M1-E2$ transitions in Te^{121m} and Te^{123m} , and from $M4$ conversion in Ba^{137m} . In the $M4$ transitions of the Te isotopes, the M -subshell lines were resolved. The M -conversion coefficients deduced differ from the theoretical values of M.E. Rose by factors >2 . The discrepancies probably arise from the screening of M electrons by K and L electrons, an effect not included by Rose in his calculations. The screening effect has been analyzed in terms of a corrected effective nuclear charge. With fixed nuclear charge decrements for the s , p , and d M electrons, quantitative agreement is obtained between the calculated conversion coefficients and the observed values for the $M4$ and $M1$ transitions in Te^{121m} and Te^{123m} and for the $M4$ transition in Ba^{137m} .

In the course of experiments on Y^{83} it was observed that there are two isomers of Y^{85} , one with a half-life of 2.68 hr decaying to 70-min

Sr^{85m} , and one with a 5.0-hr half-life decaying to 64-day Sr^{85} . The shorter-lived isomer seems to lie about 40 keV above the longer-lived one, although the transition between the states has not been observed. The 2.68-hr Y^{85} isomer decays mainly by emission of 1.54-MeV positrons followed by a 503-keV γ -ray transition. The 5.0-hr Y^{85} isomer decays mainly by emission of 2.24-MeV positrons to the ground state of Sr^{85} . Many low-intensity transitions have been found, and partial decay schemes have been proposed for both isomers.

Anomalies in cross sections for the "independent" formation of La^{131} in high energy fission led to an investigation of its Ce^{131} precursor, which is reported to have a 30-min half-life. Ce^{131} produced by $(\alpha, 3n)$ reaction on enriched Ba^{130} was chemically isolated, and its half-life was measured by successive extractions of the well-characterized 59-min La^{131} daughter product. The Ce^{131} half-life was found to be 10 ± 1 min, with no indication of a 30-min period.

COSMOCHEMISTRY

Determination of Lead Isotope Ratios in Stone Meteorites by Alpha Activation Analysis

Determination of lead isotope ratios in meteorites can yield information on the age and chronology of formation of the various kinds of meteorites. Alpha activation analysis is now being used in the investigations of the Pb^{204} , Pb^{206} , and Pb^{208} contents of meteorites. An $(\alpha, 2n)$ reaction on the above-mentioned lead isotopes yields, respectively, Po^{206} , Po^{208} , and Po^{210} . Study of lead in meteorites by the conventional wet chemistry-mass spectrometric method is hampered by the small amount of lead present (commonly ≈ 0.1 ppm), which necessitates the use of large samples and involves the serious problem of contamination by terrestrial lead.

If terrestrial contamination is excluded, the differences observed in the isotopic composition of lead in meteorites are related to

- (1) the Pb/U and Pb/Th ratios in the meteorite,
- (2) the age of formation of the meteorite, and
- (3) the isotopic composition of the lead incorporated in the meteorite when it solidified.

This is termed primordial lead.

Table 1 summarizes the measurements of the $\text{Pb}^{208}/\text{Pb}^{204}$ and $\text{Pb}^{208}/\text{Pb}^{206}$ ratios and the Pb^{208} concentration made on various samples by alpha activation analysis. These data are generally con-

sistent with results obtained by other workers using conventional techniques, including neutron activation analysis. A complicating factor in this work is the polonium activity observed on the aluminum foils used to cover the sample during alpha bombardment. This activity comes from lead impurities in the foil. There is a possibility that some polonium has distilled out of the foil onto the sample and thus influenced the derived isotopic composition.

In view of the probable contamination in the meteorites with low lead contents, it is concluded that the present results are consistent with the assumption that the primordial lead in meteoritic material was of uniform isotopic composition.

Further Tests of the Spatial Intensity of Cosmic Radiation

The intensity of the low energy cosmic radiation exhibits a time variation that follows exactly the 11-yr cycle of solar activity. An increase in solar activity produces a decrease in the intensity of cosmic radiation in the energy range 0.2 to 3.0 Bev. The solar effect is attributed to modulation of the galactic cosmic radiation by the magnetic fields associated with the outward-streaming plasma from the sun, the so-called solar wind. This effect produces a variation in the cosmic-ray intensity within the solar system such that the intensity increases with distance from the sun. This spatial variation should be observable in the cosmic-ray-produced radioactive spallation products in meteorites, since these objects have highly eccentric orbits with apogees of 3 or 4 astronomical units and perigees within the earth's orbit. The

amount of a radioactive product with a short decay period is a measure of the intensity of cosmic radiation exposure to which the meteorite was subjected just before striking the earth, whereas the amount of a radioactive product with a long decay period determines the average cosmic-ray intensity over the meteorite's orbit. Thus, the ratio between the amounts of a short-lived product and a long-lived product gives a measure of the cosmic-ray intensity at one astronomical unit relative to that at several astronomical units from the sun.

On the other hand, the sun periodically emits large numbers of high energy particles accompanying prominent solar flares. If a meteorite should encounter such an intense particle flux shortly before striking the earth the activity of a short-lived radioactive product would be greatly increased relative to that of a long-lived radioactive product.

The two isotopes of argon, Ar^{37} (35-day half-life) and Ar^{39} (325-yr half-life), are ideally suited for these studies. The activity ratio $\text{Ar}^{37}/\text{Ar}^{39}$ in the meteorite is determined and compared with the relative production cross sections for these isotopes measured with high energy protons and alpha particles on meteoritic material.

For these observations it is necessary to analyze the meteorite shortly after the time of fall, preferably within a week. Useful, though less accurate, results have been obtained, however, as long as 70 days after fall. Six meteorites have been studied at Brookhaven over the last three years. Four were stone meteorites: Hamlet (Illinois, October 1959), Bruderheim (Canada, March 1960), Harleton (Texas, May 1961), and Ehole (Angola, August 1961). Two were iron: Aroos (USSR, November

Table 1

Lead Concentration and Isotopic Composition of Various Meteorites as Determined by Alpha Activation Analysis

Sample	Classification	Pb^{208} , ppm	$\text{Pb}^{208}/\text{Pb}^{206}$	$\text{Pb}^{208}/\text{Pb}^{204}$
Bruderheim	chondrite	0.10	1.88 ± 0.06	
Elenovka	chondrite	0.22	1.88 ± 0.07	37.3 ± 2.2
Norton County	achondrite	0.035	1.90 ± 0.06 1.57 ± 0.06	45 ± 7 48 ± 6
Murray	carbonaceous chondrite	2.0	2.74 ± 0.10 2.67 ± 0.08	27.6 ± 1.3
Troilite from Canyon Diablo			2.20 ± 0.07	38.0 ± 1.7

1959) and Bogou (Upper Volta, August 1962). With this number of observations extending over a period of diminishing solar activity, some comparisons of $\text{Ar}^{37}/\text{Ar}^{39}$ ratios can be made with solar activity. The observed $\text{Ar}^{37}/\text{Ar}^{39}$ ratios in the meteorite must be compared to the relative cross section ratio for these same isotopes produced inside a meteorite by the spectrum of cosmic-ray protons (87%) and alpha particles (13%). The production cross section ratio from iron has been found to be independent of energy from 0.2 to 3.0 Bev. As a consequence the ratio will be independent of the cosmic-ray energy spectrum and the position of the sample in the iron meteorites or the iron phase of stone meteorites. An evaluation of the cross section ratio for the stone meteorites is complicated because Ar^{37} is also produced by secondary particles on Ca^{40} . As a result the $\text{Ar}^{37}/\text{Ar}^{39}$ ratio will depend upon the cosmic-ray energy spectrum and the depth of the sample in the meteorite. Experiments were carried out simulating the natural exposure of the meteorite as closely as possible. In the case of the Harleton meteorite a comparison was made for the whole meteorite and the iron phase. Figure 2 summarizes the results for the six meteorites studied. The meteorites Hamlet and Ehole, which fell <3 months after an intense solar flare, show an $\text{Ar}^{37}/\text{Ar}^{39}$ ratio somewhat above the cross section ratio. For the other meteorites the observed ratio either agrees with the cross section ratio or is lower, as would be expected for a solar modulation of the galactic cosmic radiation. It should be noted, however, that in nearly all cases the observed effects are within the experimental uncertainties.

These results allow estimation of the long-time effect of solar flares on activities. The measurements could be improved considerably in accuracy if the meteorite sample could be obtained within a week of the time of fall. With this prospect, measurements will be continued at Brookhaven on all samples that become available.

Some additional studies were made on a sample of the Bogou meteorite, shown in Figure 3, that fell in 1962. These made possible estimates of the cosmic-ray exposure age and the spatial and time constancy of cosmic radiation. A mass spectrographic analysis was made for the helium, neon, and argon isotopes, and from the results it was deduced that the Bogou meteorite was exposed to cosmic radiation for 400 million years. In addition, several other activities were measured: Mn^{54} (278-day half-life), Sc^{46} (84-day half-life) and Cl^{36}

Figure 2. Measured $\text{Ar}^{37}/\text{Ar}^{39}$ ratios in six meteorites compared to high energy proton cross sections. The time of fall of the meteorites (vertical arrows) is shown in relation to the monthly average sunspot number (solid line) and to high-intensity solar flares (vertical lines starting at the abscissa).

SCALE
ONE INCH

SCALE
1/100 INCH

Figure 3. Bogou meteorite. Top: Exterior surface. Bottom: Polished surface showing Neumann lines, a twinning of the iron-nickel alloy produced by mechanical deformation, perhaps formed by the violent impact of an asteroidal collision.

(308,000-yr half-life). From these measurements the time constancy of cosmic radiation was tested, and the exposure age was checked by the Sc^{45} - Sc^{46} method.

CHEMICAL EFFECTS OF NUCLEAR REACTIONS

Recoil Reactions in Crystals

Studies of the Szilard-Chalmers reaction in potassium permanganate have continued. The aim was to obtain, by inference from analyses in which the neutron-irradiated crystals were dissolved at different pH values, information on the distribution of Mn^{56} -labeled chemical species present in the crystal. It was found that 60 to 70% of the recoil manganese appeared on dissolution as cationic, probably divalent, Mn^{56} , and not, as previously thought, in the chemical form MnO_2 . At pH values more alkaline than ≈ 2 , this cationic Mn^{56} was tightly adsorbed onto traces of MnO_2 which were inevitably present, and from which it can be reversibly removed. It was also found that a large portion of the pH sensitivity of the recoil species, first noticed by Libby in 1940, disappears on thermally annealing the irradiated crystals.

Studies of recoil reactions of Br^{82} in crystalline hexabromoethane have revealed a new and unexpected effect: the changes in yield of labeled C_2Br_6 upon moderate isothermal annealing (30 min at temperatures from 0° to 120°C) are dependent upon the doses of ionizing radiation previously absorbed by the crystals at dose levels of the order of 20 to 200 r. Although dose-dependent annealing in several other systems has been reported, the effective dose levels studied here are lower by 3 or 4 orders of magnitude.

A detailed study of the thermal annealing in "dose-free" (i.e., radiation exposure level of 3 r) crystals has shown the presence of at least two resolvable groups of first-order kinetic processes having activation energies of ≈ 0.77 and 0.94 eV. Only the second of these is affected by radiation doses at the low level mentioned above. This study in particular has served again to emphasize the close relationship between the hot-atom chemistry and radiation-damage physics of crystals.

Finally, the chemical reactions of recoil N^{13} (half-life, 10 min), generated by fast-neutron bombardment of crystals of sodium azide, have been studied. The system is remarkably simple: radioactive nitrogen and azide seem to account for $>95\%$ of the recoil activity. The irradiated crystals

were also examined for other nitrogen-containing labeled species such as nitrate, nitrite, ammonia, hydrazine, and hydroxylamine, but only traces, at most, were found. Annealing reactions were also investigated between -78° and 325°C , but only relatively small temperature effects were observed.

In a separate but related experiment fast-neutron-activated sodium azide was thermally decomposed at 325°C , and the specific activity of the evolved nitrogen gas was determined at each stage of the decomposition reaction. The specific activity decreased with time as gross decomposition began, after the induction period. However, this fall was not, as expected, monotonic, but showed several peaks. An effort is being made to correlate these data with the hot-atom studies on the one hand and with spin resonance investigations (made elsewhere) on the other.

Carbon-11 Recoil Studies

Emphasis on the use of C^{11} in studying the reactions of energetic carbon atoms is continuing. The nuclear reactions being used include $\text{C}^{12}(n,2n)\text{C}^{11}$, $\text{C}^{12}(p,pn)\text{C}^{11}$, $\text{O}^{16}(p,n\alpha)\text{C}^{11}$, and $\text{N}^{14}(p,\alpha)\text{C}^{11}$. The reasons for using these reactions are the low and, to some extent, variable range of radiation dose that can be given to the system; the ability to vary the temperature, phase, or pressure of the system under study; and the ease with which radiochemical assay can be carried out. The chemical systems studied were ammonia and hydrocarbons.

An unknown species appearing in runs carried out on ammonia at low doses has been tentatively identified as methylene imine ($\text{C}^{11}\text{H}_2=\text{NH}$). The variation in product yield as small amounts of oxygen are added to the ammonia used in the irradiation can be seen in Figure 4. Methylene imine is rapidly oxidized and appears as formaldehyde. Methane is eliminated at very low oxygen concentrations and is, therefore, probably a thermal product.

Experiments on ammonia (summarized in Table 2) in the liquid and solid phases show a striking increase in methylamine yield, probably because of stabilization of the excited intermediate. There is no appreciable temperature effect in the liquid. The yield in the solid phase was similar to that in the liquid phase at equivalent dose. At high dose in the solid phase radiolytic reduction takes place, as had previously been observed in the gas phase. However, the essentially complete reduction observed in the gas phase did not occur in the solid.

The $C^{12}(p,pn)C^{11}$ and the $C^{12}(n,2n)C^{11}$ reactions have been used in studies on hydrocarbons.

Evidence has been obtained to support the view that ethylene- C^{11} is formed primarily by insertion of methyne- C^{11} into the primary carbon-hydrogen bonds of alkanes.

*Vibrationally excited with excess kinetic energy; possibly also electronically excited. Arrows indicate electronic shifts.

Insertion into secondary or tertiary carbon-hydrogen bonds cannot give ethylene- C^{11} by simple bond scission. Hydrogen migration or hydrogen abstraction reactions are necessary in addition to bond scission. If little or no ethylene- C^{11} is formed by these more complex modes of decay then little or no ethylene should be formed from compounds with no primary hydrogens such as the alicyclic hydrocarbons. This is found to be the case. A number of absolute yields of ethylene- C^{11} from different hydrocarbons are plotted against the ratio of primary hydrogens to the total number of hydrogens in the molecule in Figure 5. The expected linear relationship between ethylene- C^{11} yield and hydrogen ratio in the compound undergoing reaction is found for the compounds studied.

Phase-effect studies on methane, ethane, propane, butane, and pentane show that the yield of ethylene- C^{11} decreases in going from the gas to the liquid to the solid. The decrease in acetylene- C^{11} is generally larger than the decrease for ethylene- C^{11} . It is suggested that de-excitation of the "primary" complex must play an important role in determining product distributions. A tentative scheme of reaction is outlined below.

[†]Excess kinetic energy.

*Excess vibrational and kinetic energy; possibly electronically excited.

Figure 4. Low dose irradiation of $NH_3 + O_2$ mixtures.

Figure 5. Reactions of C^{11} with hydrocarbons in gas phase, 4.5% O_2 present.

Table 2

Distribution of C^{11} Activity in Ammonia

Target	Dose, ev/molecule	% C^{11} activity		
		CH_4	CH_3NH_2	Unidentified
Liquid (-47°)	3×10^{-3}	8.2	71.9	19.9
Liquid (-72°)	3×10^{-3}	7.6	74.4	18.0
Solid (-196°)	3×10^{-3}	9.0	74.8	16.2
Solid (-196°)	0.75	50.4	32.2	17.4

CHEMICAL ISOTOPE EFFECTS

Calculation of Molecular Zero-Point Energies by an Expansion Method

It can be shown that the vibrational energy of a molecule in its ground vibrational state is given by a power series in a parameter x_k . This parameter is simply defined as the square of a "reduced" vibrational frequency $(\omega_k/\omega_0)^2$, and the choice of ω_0 is restricted by the convergence properties of the series. This series is not useful if the values of x_k are known, since this is equivalent to a knowledge of the individual vibrational frequencies of the molecule, from which the zero-point energy is immediately obtainable. Rather, the significance of this method depends upon the fact that the various terms in the expansion can be expressed as functions of atomic masses and molecular force constants, without explicit calculation of the individual frequencies.

Convergence properties of the zero-point energy series have been tested for dependence on the reduced frequency, and the errors produced by truncation of the series at various terms have been evaluated. Calculations of the zero-point energy by this method have been made for several molecules and their deuterated analogues, and the results have been compared with the results of exact calculations based on individual frequencies. With a suitable choice of ω_0 , the series truncated after terms in x_k^2 gives reasonable values for the zero-point energy and for differences in the zero-point energies of isotopic molecules.

Hydrogen Isotope Fractionation Between the Hydronium Ion and Water

A method that has been applied frequently as a mechanistic test in acid-catalyzed reactions is the determination of the reaction rate in mixtures of light and heavy water. The observed rate at a particular isotopic composition is a function of the rate constants found in pure light water and pure heavy water and is dependent on the relative concentrations of the various lyonium ion species (i.e., H_3O^+ , H_2DO^+ , HD_2O^+ , and D_3O^+). These concentrations can be calculated if the equilibrium constant K_w for the exchange reaction

is known. This constant has been determined by a method that gives indirectly an isotopic analysis of the water in equilibrium with the hydronium

ion. This involved determining the following quantities: D/H in the vapor in equilibrium with the acid solution, D/H of the liquid phase, the corresponding quantities for pure water, the concentration of acid, and its extent of dissociation. The experiments were carried out with water and aqueous solutions of perchloric acid of normal isotopic abundance, and the D/H ratios were measured by mass spectrometry with a precision of $\approx 0.1\%$.

From these data a value of 0.96 ± 0.01 was obtained for K_w , which may be contrasted with the value of $2/3$ which would be found if there were no isotopic fractionation. The result is in good agreement with the analogous constant for the equilibrium of an acid in almost pure heavy water:

The constant for this equilibrium was determined independently in this laboratory by nuclear magnetic resonance methods. It is also in agreement with previous estimates derived from electrochemical data obtained in light and heavy water, which were subject to some uncertainty because of contributions from differences in hydration energies of ions in the two solvents.

MASS SPECTROSCOPIC STUDIES OF ION-MOLECULE REACTIONS

The reactions of H_2^+ with helium and neon have been further studied as part of an investigation of the problem of energy transfer in elementary processes. In last year's report a summary of work on the H_2^+ -He reaction presented the result that only internal, vibrational energy in H_2^+ contributes to the energetic requirements of the reaction. The reaction of electron-impact-produced H_2^+ with neon, giving NeH^+ , is in quantitative agreement with the results for helium. Only 75% of the H_2^+ available in the mass spectrometer ion source reacts with neon, and this amount is independent of ion velocity over a wide range of ion kinetic energy. This result implies that neon reacts only with H_2^+ ions in the second or higher vibrational states, and gives 2.1 eV for the heat of dissociation of NeH^+ .

At higher gas pressures in the mass spectrometer ion source a reaction was discovered which begins with electron-impact-produced, metastable neon atoms. NeH^+ ions are eventually produced by a reaction which is second order in neon concen-

tration and first order in H_2 . The role of the metastable neon atoms was established by comparison of the ionization efficiency curves of NeH^+ produced in the third-order process with the neon metastable atom excitation function. The reaction scheme proceeds via a pre-ionized H_2 molecule, which produces H_2^+ molecule-ions in the fifth or sixth vibrational state (ν). This was established by using the H_2^+-He ion-molecule reaction as a probe for species above or below the fifth state. The H_2^+-Ne reactions, with broad distribution of vibrational energy produced by electron impact on H_2 and narrow distribution resulting from energy transfer on collision with excited neon atoms, differ at low ion kinetic energies. In the electron-impact reaction a fall-off in rate constant was observed at low ion energy, and a kinetic energy threshold of 0.18 eV was found. No kinetic energy threshold was observed for the third-order process giving NeH^+ . The conjecture put forth to explain these results is that a competitive de-excitation mechanism is operative for relatively low kinetic energy collisions. The de-excitation mechanism can take place with the loss of a few quanta, but there is insufficient time for transition from $\nu=5$ or 6 to $\nu=1$ or 0. The energy loss is probably radiative in nature. Conversion of vibrational energy in H_2^+ to translational energy in either H_2^+ or Ne or both is highly probable from either experimental observation or theory. Radiative lifetimes would require an NeH_2^+ complex that survives for the order of 10^{-8} sec or longer for the emission of a quantum of radiation.

CHEMICAL EFFECTS OF RADIATION

The Perhydroxy Radical, HO_2

The disappearance of HO_2 radicals produced in oxygen-saturated water by an electron beam has been followed in a flow system by using tetranitromethane scavenging to determine the concentration of HO_2 remaining after a time t . The radicals are destroyed by the reaction $2HO_2 \rightarrow H_2O_2 + O_2$. The change in HO_2 concentration obeyed second-order kinetics at all acid concentrations, $-d(HO_2)/dt = 2k(HO_2)^2$. The rate constant k is a function of the acid concentration, increasing from $2.4 \times 10^6 M^{-1} sec^{-1}$ at pH 2 to 1.5×10^7 above pH 5. The rate constant at pH 2 agrees well with that determined by electron spin resonance, reported last year. The change in rate with pH was ascribed to the acidic dissociation of the radical, and its pK was estimated to be 4.3 ± 0.3 .

Hydrogen Sesquioxide

If a ferrous sulfate solution is used as a reagent in place of tetranitromethane in the flow system mentioned above, a new intermediate, longer-lived than HO_2 , is observed which exhibits first-order decay at all acid concentrations studied. This intermediate is formed only in the presence of oxygen. It appears in H_2SO_4 , $HClO_4$, and HCl solutions, which means that it is composed of hydrogen and oxygen only, and is probably H_2O_3 , formed by the reaction $OH + HO_2$ in the electron beam. The reaction $H_2O_3 \rightarrow H_2O + O_2$ was found to be catalyzed by acid and base. The maximum lifetime for H_2O_3 occurs at pH 1.8 and is ≈ 2 sec at room temperature.

Absolute Rate Constants of Hydrogen Atom Reactions in Water

Hydrogen atoms are known to oxidize ferrous ion in the absence of oxygen:

This reaction contributes an important part of the ferrous oxidation yield in deaerated ferrous sulfate solutions. At high radiation intensity, hydrogen atoms will combine to give H_2 without oxidizing $Fe(II)$, which leads to an intensity dependence of the ferric ion yield. This intensity dependence has been studied, and the lifetime of the hydrogen atom under various conditions has been determined by pulsed-beam techniques. The rate constant for the above reaction was found to be $2 \times 10^7 M^{-1} sec^{-1}$, and the rate constant for combination of hydrogen atoms was found to be $1.6 \times 10^{10} M^{-1} sec^{-1}$.

The Yield of Ions in Irradiated Liquid Hexane

The number of ions formed by irradiation per unit of energy input has been a favorite object of study for gases, but no authoritative values have been determined for liquids. In the liquid state most of the ions are thought to disappear very rapidly by "initial recombination." Of special interest to chemists is the question of how many ions escape initial recombination and actually appear in the liquid in the absence of an applied electric field. To determine this number, the conductivity of irradiated hexane at very low fields was measured as a function of radiation intensity. The mobilities of the positive and negative ions were determined in a separate experiment. The recombination coefficient for the ions in hexane

was known theoretically and checked by measurements of the rate of decay of conductivity when the irradiation was interrupted. From these measurements, the yield was found to be close to 0.1 ion of either sign generated per 100 ev deposited in the hexane. The ion yield in gases is 20 to 30 times larger, so it is evident that only a few percent of the free electrons generated in the liquid by radiation escape immediate recombination with their parent positive ions.

The Photolysis of Nitromethane

The purpose of this study was to determine whether nitromethane is photolyzed to free radicals or undergoes an internal rearrangement to methyl nitrite. Both reactions have been proposed.

It has now been found by electron spin resonance spectroscopy that when nitromethane is photolyzed in a solid matrix at liquid nitrogen temperature it decomposes to form free radicals,

The electron paramagnetic resonance (EPR) spectrum observed upon photolysis of nitromethane at -196°C was a combination of the spectra of the methyl radical and nitrogen dioxide. When the sample was annealed at -80°C , the part of the spectrum due to the methyl radical disappeared, and only the NO_2 spectrum remained. Similar results were obtained when the nitromethane was photolyzed in solid matrices of water and of carbon tetrachloride at -196° .

An investigation of the photolysis of methyl nitrite is in progress. Preliminary results indicate that methyl nitrite is also decomposed to free radicals. The EPR spectra of the latter differ from those observed for the nitromethane system.

KINETIC STUDIES IN INORGANIC SYSTEMS

Free-Energy Relations in Electron Transfer Reactions

Studies have been continued of the relation between the free energies of activation and the standard free-energy changes of electron transfer reactions. The free energies of activation for the oxidation of a variety of substituted *tris*(1,10-phenanthroline) complexes of Fe(II) by Mn(III) and Ce(IV) have been found to be linearly related to their standard free-energy changes, provided that the latter are not too large.

The kinetics of the oxidation of $\text{Fe}(\text{CN})_6^{4-}$, $\text{Fephen}(\text{CN})_4^{2-}$, $\text{Fe}(\text{phen})_2(\text{CN})_2$, $\text{Fe}(\text{phen})_3^{2+}$, and

of the corresponding dipyridine complexes by Ce(IV) have been studied in $0.5\text{ }F\text{ H}_2\text{SO}_4$ at 25.0° . The reactions of $\text{Fephen}(\text{CN})_4^{2-}$ and $\text{Fedipy}(\text{CN})_4^{2-}$ proceed faster than those of the other Fe(II) complexes. If the free energies of activation for the various reactions are corrected for the differences in their standard free-energy changes, approximately linear relations between the corrected free energies of activation and the number of cyanide groups in the complexes are obtained. This result shows that an approximately constant change in free energy of activation is produced on replacing a pair of cyanide groups by a phenanthroline or dipyridine group. This effect is illustrated in Figure 6. These changes in free energies presumably reflect differences in the free energies of activation for the corresponding Fe(II)-Fe(III) electron exchange reactions.

The System Cr(II)-Ti(III)

The kinetics of the oxidation of Cr(II) by Ti(III) have been studied in chloride-perchlorate media. The results are consistent with the rate law

Figure 6. Plots of $\log k$ and $(\Delta G^\ddagger - \Delta G^\circ/2)$ versus the number of cyanide ligands in the iron(II) complex; the triangles represent ferrocyanide, and the open and closed circles represent the phenanthroline and dipyridine complexes respectively.

$$R = k_0(\text{Cr}^{2+})(\text{Ti}^{3+}) + k_1(\text{Cr}^{2+})(\text{TiOH}^{2+}) + \\ k_2(\text{Cr}^{2+})(\text{TiCl}^{2+}) + k_3(\text{Cr}^{2+})(\text{TiCl}_2^+) + \\ k_4(\text{Cr}^{2+})(\text{TiCl}_3) + k_5(\text{Cr}^{2+})(\text{TiCl}_4^-),$$

where $k_0 < 10^5$, $k_1 \approx 4.8 \times 10^6$, $k_2 \approx 7.8 \times 10^4$, $k_3 \approx 1.4 \times 10^5$, $k_4 \approx 4.2 \times 10^5$, and $k_5 \approx 1.6 \times 10^6 \text{ F}^{-1} \text{ sec}^{-1}$ at 25.0° . As mentioned in last year's report, the chromic product of the reaction is distributed among the forms dimeric Cr(III) , $\text{Cr}_{\text{aq}}^{3+}$, and CrCl^{2+} . The proportions vary with the chloride concentration in a manner reasonably consistent with the foregoing rate constants. The results do not establish whether the chlorothallium(III) complexes react with Cr(II) in a two-equivalent reaction or through successive one-equivalent steps.

The System $\text{Cr(II)}\text{-Fe(III)}$

The kinetics of the $\text{Cr(II)}\text{-Fe(III)}$ reaction in chloride-perchlorate media have been studied. Since the formation of FeCl^{2+} from Fe^{3+} and Cl^- proceeds relatively slowly, it proved possible to estimate the rate constants for the various chloride-catalyzed paths by adding chloride to only the chromous solution on the one hand, and to both the chromous and iron solutions on the other. The rate data satisfy the following expression:

$$R = k_1(\text{Cr}^{2+})(\text{Fe}^{3+}) + k_2(\text{Cr}^{2+})(\text{FeOH}^{2+}) + \\ k_3(\text{Cr}^{2+})(\text{FeCl}^{2+}) + k_4(\text{Cr}^{2+})(\text{Fe}^{3+})(\text{Cl}^-),$$

where R is the rate of the redox reaction. Preliminary estimates of the rate constants at 25.0° are $k_1 \approx 2 \times 10^3$, $k_2 \approx 3.3 \times 10^6$, and $k_3 \approx 2 \times 10^7 \text{ F}^{-1} \text{ sec}^{-1}$, and $k_4 \approx 2 \times 10^4 \text{ F}^{-2} \text{ sec}^{-1}$. It was found that CrCl^{2+} is produced in both chloride-catalyzed paths. The formation of CrCl^{2+} in the reaction of FeCl^{2+} with Cr^{2+} is evidence that this reaction proceeds via an inner-sphere activated complex in which the chloride is attached to both the iron and the chromium. If the hydration shells of the reactants are included, the reactants in this path may be formulated as $\text{Cr}(\text{H}_2\text{O})_6^{2+}$ and $(\text{H}_2\text{O})_5\text{-FeCl}^{2+}$. Similarly, the reactants in the second chloride-catalyzed path (which does not involve FeCl^{2+} as a reactant) may be either $(\text{H}_2\text{O})_5\text{CrCl}^+$ and $\text{Fe}(\text{H}_2\text{O})_6^{3+}$ or $\text{Cr}(\text{H}_2\text{O})_6^{2+}$ and $(\text{H}_2\text{O})_6\text{Fe}^{3+}\text{Cl}^-$. It is not possible to distinguish between the two pairs of reactants on the basis of the evidence available at present.

The Formation of FeN_3^{2+}

The formation of FeN_3^{2+} in perchlorate media containing iron(III) and hydrazoic acid proceeds

via two paths, one acid independent and the other linearly dependent on the acidity. The rate constant for the formation of FeN_3^{2+} via the acid-independent path, formulated in terms of the reactants FeOH^{2+} and HN_3 , is $6.8 \times 10^3 \text{ F}^{-1} \text{ sec}^{-1}$, while the rate constant for its formation from the reactants in the acid-dependent path involving the reaction of Fe^{3+} with NH_3 is $4.0 \text{ F}^{-1} \text{ sec}^{-1}$ at 25.0° . The difference in the rate constants may be related to the difference in the rates of water exchange of $(\text{H}_2\text{O})_5\text{FeOH}^{2+}$ and $\text{Fe}(\text{H}_2\text{O})_6^{3+}$.

REACTION KINETICS AND MECHANISMS IN ORGANIC SYSTEMS

Secondary Isotope Effects

Organic compounds having deuterium substituted for hydrogen in the position alpha to a leaving group ($\text{R}_1\text{R}_2\text{CDX} \rightarrow \text{R}_1\text{R}_2\text{CD} + \text{X}$, radical or ionic reaction) undergo the indicated reaction at a rate $\approx 12\%$ slower than that of the natural compound. This has been attributed in great part to the decrease in one of the C-H (or C-D) bending frequencies in going from the starting state to a tricoordinated transition state. If, however, the reaction is a bimolecular substitution ($\text{Y} + \text{R}_1\text{R}_2\text{CDX} \rightarrow \text{R}_1\text{R}_2\text{CDY} + \text{X}$), in which the transition state is believed to be a pentacoordinated carbon species, the deuterated compound is reported to react at a faster rate, and the magnitude of the effect varies with the nature of the leaving group. In an attempt to gain more information about this effect and the transition state in bimolecular substitution, the secondary deuterium effect was determined for the radioiodide exchange of methyl- d_3 iodide in methanol, $\text{CD}_3\text{I} + \text{I}^* \rightarrow \text{CD}_3\text{I}^* + \text{I}^-$. In this reaction, in which there is a symmetrical, pentacoordinated transition state, the hydrogen compound reacts at a rate 6% faster, differing from the reactions reported previously. The temperature-independent factor (the effective mass along the reaction coordinate) is calculated to be 9% in favor of the natural compound. Therefore the zero-point vibrational effect is $k_{\text{H}}/k_{\text{D}} = 0.97$, which indicates that any decrease in C-H frequencies as an X moves away from carbon is slightly overcompensated by the increase of these frequencies as another X approaches the back side of carbon.

The isotope effects, reported previously, in the decomposition of the *exo* Diels-Alder adduct from 2-methylfuran and maleic anhydride are $k_{\text{I}}/k_{\text{II}} = 1.16$ and $k_{\text{I}}/k_{\text{III}} = 1.08$.

- I. $R_1=R_2=R_3=H$, $R_4=CH_3$
 II. $R_1=R_2=D$, $R_3=H$, $R_4=CH_3$
 III. $R_1=R_2=H$, $R_3=D$, $R_4=CH_3$
 IV. $R_1=R_2=R_3=H$, $R_4=CD_3$
 V. $R_1=D$, $R_2=R_3=H$, $R_4=CH_3$
 VI. $R_1=H$, $R_2=D$, $R_3=H$, $R_4=CH_3$

Although these effects are low, it was concluded that bonds *a* and *b* rupture simultaneously. Since then, k_I/k_{IV} , a β -deuterium effect, has been found to be 1.03, which indicates essentially no need for hyperconjugative stabilization at the transition state and is consistent with concerted process. By following the reaction with proton magnetic resonance, k_V/k_{VI} was found to be equal to 1.00. Therefore $k_I/k_{III}=k_I/k_V=k_I/k_{VI}=1.08$, a strong indication that bonds *a* and *b* break simultaneously. From the principle of microscopic reversibility, the formation of this Diels-Alder adduct must involve forming of bonds *a* and *b* simultaneously.

Studies on a similar adduct (from 2-methylfuran and maleimide but of the *endo* configuration) are in progress to determine whether the two configurations involve similar reorientation to reach the transition states. The observed effect ($k_{VII}/k_{VIII}=1.16$ in this case)

- VII. $R_1=R_2=H$
 VIII. $R_1=R_2=D$

indicates that there is probably the same amount of bond breaking in the *endo* imide adduct as there is in the *exo* anhydride adduct at the transition state.

Photolysis of C_3O_2 - C_2H_4 Mixtures

In experiments on the photolysis of C_3O_2 - $2-C^{14}-C_2H_4$ mixtures, 20 to 30% of the product was found to be methylacetylene, the rest being allene. The methylacetylene does not arise from a photochemically induced rearrangement of allene. The distribution of activity in methylacetylene is essentially what would be predicted from a mechanism involving carbene insertion into both the carbon-hydrogen bond and the carbon-carbon double bond. Almost no activity is found in the end positions in allene. The use of a Corning 7-54 3-mm filter during photolysis reduced the percent activity in the end position in allene and also reduced the percent activity in the methyl group in methylacetylene. These distributions follow.

CH_2	$\equiv$	C	$\equiv$	CH_2
3.0%		94.0%		3.0%
CH_3	$\equiv$	C	$\equiv$	CH
8.3%		37.1%		54.7%

Taking into account the yields of allene and methylacetylene and also the distributions found in these compounds, it would seem that the insertion ratio (double bond to single bond) is about the same as that found for the reaction of singlet methylene in the gas phase.

FREE RADICAL HYDROXYLATION OF AROMATIC COMPOUNDS

The HO_2 radical generated from hydrogen peroxide by ceric sulfate has been utilized for the hydroxylation of double bonds of aromatic compounds. This study deals specifically with the effect of substituent groups R (CH_3 , Cl, Br, OH, H) on the rate of hydroxylation of *p*-benzohydroquinones. For *p*-benzohydroquinones substituted in the 2-position the following mechanism has been found.

For step (4) the following detailed mechanism is offered.

Experimental conditions have been developed which permit the above reaction to be carried out at -60°C . Preliminary investigations with other compounds indicate that this technique may have several applications in organic chemistry.

BIOCHEMISTRY

Rates of Reaction of Enzymes With Methanol-Water Solutions

Methanol added to aqueous solutions of enzymes is known to retard the rates of enzymatic reactions. When an aqueous solution of lactic acid dehydrogenase was injected into 30% methanol-water at 0°C there was at first little inhibition of enzymatic activity, but on longer contact with this solvent the enzyme lost activity. The rate of this alcoholation was measured as a function of temperature and methanol content. As a consequence, it is possible to obtain considerable enzymatic activity in solvents at low temperatures; greater activity was available at 0°C with a solution prepared at this temperature than at room temperature where the rate of alcoholation and inhibition is extremely rapid.

Fluorescence spectra indicated that the reaction of lactic acid dehydrogenase with 30% methanol at 0°C scarcely disturbs the shape and size of the enzyme even after substantial inhibition of the enzymatic activity has occurred. In solvents 42% or higher in methanol at room temperature, resonance energy transfer between the aromatic amino acid residues of the enzyme suffers interruption which progresses with time. New bands with structure of the "autonomous" fluorescing amino acid residues make their appearance and

grow in intensity. Profound alteration in the molecular configuration of the enzyme has occurred, to be identified with the uncoiling process. These changes are especially in evidence when the fluorescence is excited at 2000 Å where the polypeptide backbone of the enzyme also absorbs radiation.

In addition to lactic acid dehydrogenase, α -chymotrypsin undergoes similar behavior but at higher methanol concentrations. The generality of these phenomena among enzymes remains to be established.

The measurement of the properties of α -chymotrypsin was facilitated by a fluorometric assay of considerable sensitivity recently developed for such experiments.

Chemistry of Planaria and Their Behavior While Learning

Relationships have been observed between the behavior of planaria in learning and their spontaneous endogenous chemistry. P^{32} incorporation within ribonucleic acid (RNA) and within deoxyribonucleic acid (DNA) was different in trained planaria from that in controls receiving the same number and kind of stimuli but randomly applied. The largest differences in the ratios of these incorporations occurred in the middle stages of the training period rather than at the end. The endogenous chemical changes appeared to be well advanced before appreciable changes in behavior could be observed. A covariance appeared in the rates of synthesis of P^{32} -RNA and of P^{32} -DNA.

COMPOSITIONAL INVESTIGATION OF ARCHAEOLOGICAL MATERIALS

The study of the compositions of ancient glasses is being rounded off at ≈ 400 specimens. The data are now being subjected to a statistical analysis which is revealing additional correlations with origins and raw materials. For example, it has been found that much of the ancient Egyptian glass is characterized by a significantly low calcium concentration. Moreover, the relatively high concentrations of cobalt in glasses colored by this element are accompanied by correspondingly high concentrations of both manganese and zinc. The relative concentrations of these three elements in cobalt-blue glasses from Mycenaean and New Kingdom Egyptian tombs of the second millennium B.C. are nearly identical, yet distinctly different from those encountered in similar glasses of different origin. It seems likely that the same cobalt ore

was used as a colorant in the glass found in both of these geographic regions.

NEUTRON AND X-RAY DIFFRACTION

Magnetic Structure of MnSn_2

Recent measurements of the magnetic and electrical properties of the intermetallic compound MnSn_2 , a body-centered tetragonal structure, indicate a number of unusual features. The magnetic susceptibility passes through a weak maximum at 325°K, continues to rise on cooling to a pronounced peak at 86°K, and then abruptly decreases at 73°K to a low value which is maintained down to helium temperatures. The salient features of the magnetic behavior are paralleled by anomalies in the electrical conductivity and volume.

Neutron diffraction studies show that above the abrupt transition at 73°K, MnSn_2 is antiferromagnetic with a Néel temperature in the neighborhood of 325°K, the temperature of the upper susceptibility maximum. However, the superstructure lines characteristic of the antiferromagnetic state appear to saturate in intensity near nitrogen temperatures and show no anomaly in passing through the region of the large susceptibility maximum at 86°K. The magnetic structure consists of ferromagnetic (110) planes which alternate along the direction perpendicular to the sheets. Individual moments are oriented parallel to the direction of alternation and reach a magnitude of $2.35 \mu_B$ at 77°K.

The abrupt transition at 73°K is marked by the disappearance of the high-temperature antiferromagnetic diffraction pattern and the appearance of a new pattern characteristic of a modulated spin structure below this temperature. The low-temperature structure is a simple modification of the spin arrangement above the transition, in which the magnitude of the moment is no longer constant but varies sinusoidally along the direction perpendicular to the ferromagnetically aligned sheets. Thus, the short-range structure and spin direction are essentially the same above and below the transition. The observed modulation has a wavelength of $\approx 18.2 \text{ \AA}$; the amplitude of the modulated moment is $3.11 \mu_B$ at 4.2°K.

Magnetic Structures of Rare-Earth Intermetallic Compounds With Cobalt and Nickel

Magnetic measurements have been reported in the literature for a number of new transition

Figure 7. Hexagonal Cu_5Ca structure.

element-rare-earth compounds having the hexagonal Cu_5Ca structure, shown in Figure 7. Saturation moments determined for the series Co_5X , where X is a member of the rare-earth series, suggest that in these compounds the rare-earth moment is antiparallel to that of the cobalt, whereas in the Ni_5X series the nickel behaves as though it had zero moment. These ideas are supported by neutron diffraction studies of Co_5Ho and Ni_5Er . In the case of the erbium compound the best fit with the diffraction results is obtained with $\mu_{\text{Ni}} = 0$ and $\mu_{\text{Er}} = 7.7$ Bohr magnetons, in agreement with the observed macroscopic moment. The zero moment for nickel suggests that the three valence electrons of the rare-earth atom completely fill the 3d shell of the nickel. The departure of the erbium moment from the theoretical value of 9.0 Bohr magnetons is not unusual for the second half of the rare-earth series and may, as indicated by recent calculations, be ascribed to crystalline field effects.

The Xenon Tetrafluoride Crystal Structure

The crystal structure of the low-density phase of the recently discovered xenon tetrafluoride has been determined.

Xenon tetrafluoride crystallizes in the monoclinic system with the unit cell constants $a = 5.03 \text{ \AA}$, $b = 5.90 \text{ \AA}$, and $c = 5.75 \text{ \AA}$ (all $\pm 0.03 \text{ \AA}$), and $\beta = 100 \pm 1^\circ$. The space group is $C_{2h}^5 - P2_1/n$, and there are two molecules in the unit cell.

The F-Xe-F bond angle is $90.8 \pm 1.1^\circ$. Since the molecule is required by the space-group symmetry to be planar and centrosymmetric, these results indicate that any departure from a square planar configuration for the molecule is insignificant.

The thermal vibrations of the molecule, as derived from anisotropic thermal parameters, are readily interpreted in terms of rigid body translations and rotations with root-mean-square am-

plitudes of ≈ 0.12 Å and 6° respectively. The latter correspond to torsional oscillations with frequencies of ≈ 50 to 70 cm^{-1} .

The structure is shown in Figure 8.

The Structures of HCrO_2 and DCrO_2

The nature of the hydrogen bonds in HCrO_2 and DCrO_2 has been the subject of a nuclear magnetic resonance and an infrared investigation. It was found in the NMR study that the vibrational amplitude of the hydrogen atom normal to the bond is larger than the amplitude along the bond. The differences in the infrared spectra were explained on the basis of different potential functions for the O—H—O and O—D—O bonds. The lowest vibrational level in the O—H—O system is above a barrier (if one exists), and the bond is symmetric. The lowest vibrational levels in the O—D—O system are below the barrier, detectable splittings of the energy levels occur, and the bond is asymmetric.

A neutron diffraction study of polycrystalline HCrO_2 and DCrO_2 was carried out in the past year. Intensity data from the two substances were refined by the least-squares method with the constraint that the Cr—O distance be the same in the two substances. The O—D—O bond is found to be asymmetric with $\text{O—D} = 0.96 \pm 0.04$ Å and $\text{O—O} = 2.55 \pm 0.02$ Å. The symmetry of the O—H—O bond cannot be determined, but agreement with observation is as good with a symmetric bond as with any other model. The O—H—O bond length is 2.49 ± 0.02 Å. These results are consistent with those of the previous NMR and infrared studies.

Crystal Structure of Acetamide

Solid acetamide exists in two crystalline modifications which differ markedly in the yields of products obtained on irradiation with high energy electrons. The crystal structure of one of these modifications has been known for a number of years, and the structure of the other has recently been determined in this laboratory. Although the shapes of the molecules in the two forms are identical, the way in which the molecules are linked together by hydrogen bonds is quite different, one of the forms consisting of individual molecules linked together in a complex and beautiful three-dimensional network, the other of dimers linked together in chains. Although these differences in hydrogen bonding clearly must be capa-

Figure 8. The unit cell of xenon tetrafluoride. The molecules have a square planar configuration.

ble of explaining the differences in chemistry observed, the detailed explanation is not obvious.

It is of interest that the structure of the orthorhombic form was determined directly from the intensity data by one of several methods of direct structure determination which have been under investigation in this and other laboratories. Work done so far gives rise to the hope that the solution of crystal structures will be placed on a more routine basis in the not too distant future.

Crystal Structure of Sodium Nitroprusside, $\text{Na}_2\text{Fe}(\text{CN})_5\text{NO} \cdot 2\text{H}_2\text{O}$

The crystal structure of sodium nitroprusside has been determined by an analysis of three-dimensional x-ray diffraction data. The nitroprusside ion lies in a mirror plane and has approximately C_{4v} symmetry. The important distances are Fe—C , 1.90 ± 0.02 Å; C—N , 1.16 ± 0.02 Å; Fe—N , 1.63 ± 0.02 Å; and N—O , 1.13 ± 0.02 Å.

The fact of prime interest to inorganic chemists is that the ligands are colinear with the metal atom, which is displaced slightly in the direction of the NO group from the plane of the four pseudoequivalent CN groups.

Each sodium ion lies at the center of a distorted octahedron composed of four cyanide groups and two water molecules. These octahedra share edges in such a way that each cyanide group is coordinated to two sodium ions, as is each water molecule; the Na^+ -ligand distance is ≈ 2.5 Å in every case. The nitroso group is coordinated only to the ferrous ion. The water molecules do not lie near enough to other electronegative atoms to permit significant hydrogen bonding.

Figure 9. Crystal structure of sodium cobalt molybdate.

Crystal Structure of Sodium Cobalt Molybdate

The sodium cobalt molybdate prepared and studied in this laboratory crystallizes in the space group D_{2h}^{16} - $Pnma$ of the orthorhombic system. The unit cell dimensions are $a = 5.245 \pm 0.003$ Å, $b = 10.778 \pm 0.005$ Å, and $c = 18.017 \pm 0.006$ Å. There are four formula units in the cell.

Complete three-dimensional x-ray data out to $\lambda^{-1} \sin \theta \approx 1$ were collected with Mo $K\alpha$ radiation by film methods and were visually estimated. The structure was solved by three-dimensional Patterson methods and was refined by both Fourier and least-squares techniques. The least-squares refinement was applied not only to the usual positional and thermal parameters but also to the site occupancy factors, for only in this way could the details of the composition be established.

The paucity of structural information on complex oxide systems and the interesting properties, both structural and physical, of such systems prompted the present detailed refinement of the structure. The result is more complicated and more interesting than had been anticipated. From the

analysis of the x-ray data the formula of the compound was found to be $\text{NaCo}_{2.31}(\text{MoO}_4)_3$. This composition is consistent with chemical analyses and suggests that cobalt is probably present in two valence states. The structure is formed by a framework of MoO_4 tetrahedra and CoO_6 octahedra, with the tetrahedra providing links between sheets and columns formed by the octahedra. In the sheets the octahedra share corners and edges; in the columns they share faces. In both octahedral sites cobalt is present to $\approx 75\%$. A zigzag void left by the MoO_4 links is made up of trigonal prisms sharing edges and is filled by sodium atoms. The structure is shown in Figure 9.

Crystal and Molecular Structure of Titanium(IV) Ethoxide

Both speculation and controversy on the stereochemistry of the trimeric titanium(IV) alkoxides have followed the discovery of their trimeric nature in solution. Opinions have differed on which structure is stereochemically reasonable and on which structure will account in a natural way for the hydrolysis products of titanium(IV) alkoxides. In

Figure 10. Unit cell of iron nitride, Fe_4N .

this laboratory titanium(IV) ethoxide, $\text{Ti}(\text{OC}_2\text{H}_5)_4$, has been found to be a tetramer in the solid. This result not only fails to confirm one of the proposed structures but also makes unreasonable the assumption that the species in solution are identical with those precipitated from solution. The structure proposed here has several satisfying features,

the most prominent being the octahedral coordination of the titanium atoms and the readily visualized termination of polymerization.

X-Ray Scattering Factor in Fe_4N

The x-ray scattering factors of the elements at low scattering angles are dependent on their states of oxidation. Comparison of the x-ray intensities of the low angle superlattice reflections of Fe_4N , illustrated in Figure 10, with the normal lattice reflections has shown that nitrogen is negatively charged in this compound. Although theoretical scattering factors for nitrogen have not been calculated beyond the state N^{-1} , the experimental data suggest that the oxidation state of nitrogen is perhaps N^{-3} . For this result to be consistent with the magnetic moment of iron in Fe_4N it must be concluded that there is covalent bonding between iron and nitrogen.

Nuclear Engineering

In December 1962 Dr. Francis T. Miles, Deputy Chairman of the Nuclear Engineering Department, accepted a two-year appointment as Director of the Division of Reactors in the Department of Technical Operations of the International Atomic Energy Agency, Vienna, Austria. Dr. Miles had been with the Nuclear Engineering Department since 1948.

Dr. Herbert J.C. Kouts, Associate Head of the Nuclear Engineering Department's Reactor Physics Division, was one of five U.S. scientists to receive the AEC's E.O. Lawrence Award for 1963 for recent meritorious contributions in the field of atomic energy.

Basic research is the first and largest, in terms of man-years of effort, of three categories that describe the current program of the Department. This research 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, and the direct conversion of heat into electricity.

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, high-temperature volatility and fluidized bed processing schemes, radiation engineering methods, and waste processing devices.

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 settled bed, chemonuclear, and rotating bed reactor concepts.

Reactor evaluations are also performed for the AEC on a great variety of reactor concepts.

The Reactor Physics Division has been reorganized to aid in accomplishing the diverse tasks for which it is now responsible. The Division now consists of a Theoretical Group; an Experimental Group; an Analysis Group, which serves as a bridge between theory and experiment; an Evaluation Group, which analyzes reactors in the con-

ceptual stage; and the Sigma Center, which compiles and evaluates neutron cross sections. The value of this rearrangement is already apparent in the improved functioning of the Division.

Construction of the High Flux Beam Research Reactor (HFBR) progressed during the year and was about 65% complete at the end of fiscal 1963. The more conventional parts of the project are complete; the work remaining lies in the sensitive area of the reactor core, biological shield, experimental facilities, instrumentation, and control devices.

Good progress has been made in various departments in design and construction of experimental equipment. Experiments are expected to begin as soon as the reactor runs at low power early in calendar 1964.

In February 1963 the Nuclear Engineering Department began publishing the bimonthly *High-Temperature Liquid-Metal Technology Review*. The purpose of this journal is to provide an effective means of keeping workers in the high-temperature liquid-metal field informed of current developments. This field is becoming increasingly important as the development of power systems for space vehicle application progresses at an ever-increasing rate.

Arrangements have been made for the many contractors engaged in research and development work in the high-temperature liquid-metal field for the AEC, NASA, and the Air Force to send their unclassified technical reports to BNL for review. The *Review* will cover all phases of liquid-metal technology pertinent to the space power development program, including materials development, corrosion, heat transfer, fluid dynamics, instrumentation, component development, physical properties, and power systems.

The High Intensity Radiation Development Laboratory (HIRDL), including all cells and equipment, has been essentially completed. Cell equipment is undergoing initial tests.

During the year Department personnel and personnel from the Medical, Biology, and Physics Departments operated the gamma facility and conducted lecture programs at exhibits sponsored

by the US AEC Division of Special Projects in Santiago, Chile; Bogotá, Colombia; Bangkok, Thailand; and Vienna, Austria. In Bangkok and Vienna the research reactor program associated with the exhibit was also staffed by BNL personnel.

REACTOR PHYSICS

Theoretical Reactor Physics

In the area of neutron thermalization, both space and time-dependent eigenvalue problems have been emphasized. The discovery that continuum as well as discrete eigenfunctions are required in the solution of some problems has led to a number of questions regarding the asymptotic form of these solutions. Other areas of study included the theory of the scattering law, the Milne problem, the calculation of temperature coefficients in reactor lattices, and the neutron spectrum in a medium with a temperature discontinuity. A review paper on computational methods in neutron thermalization has been prepared for the summer meeting of the American Nuclear Society, and a review of the sensitivity of various reactor parameters to accurate knowledge of the scattering law was prepared for an AEC committee.

In the area of reactor kinetics, problems in reactor stability have been emphasized, particularly the conditions for Xe and temperature instabilities. New analytical methods for treating the nonlinearities of these problems have been developed and have been checked by machine calculations. The analytical methods developed to treat resonance absorption of neutrons in U lattices have also been checked and found to be in excellent agreement with Monte Carlo calculations. A number of comparisons of theory with integral experiments have been carried out. Recent data from Snell experiments agree with present cross section information within the limitations of the latter. In particular, more accurate inelastic cross sections for U^{238} and fission cross sections for the threshold detector Np^{237} are needed. Calculations of the bucklings of U^{235} -graphite minimum reflection critical assemblies have been completed.

Experimental Reactor Physics

Minimum Reflection Critical Experiments. These experiments are performed with bare U-graphite critical assemblies supported ≈ 20 ft above the ground in a thin-walled silo with no shielding in order to minimize neutron reflection. Measure-

ments are complete on the first assembly and very nearly so on the second.

The characteristics measured thus far include (1) critical mass and buckling, (2) prompt-neutron generation times, (3) thermal-neutron disadvantage factors, (4) temperature coefficients, (5) reactivity and decay constant of the fundamental mode as a function of gap between adjacent portions of the assembly, and (6) the nature, magnitude, and origin of the neutron return and its effect on critical-mass determinations. In addition, a number of measurements designed to enhance safe operation of the assemblies have been carried out.

In the first assembly a small unexplained discrepancy exists between measured and calculated critical bucklings. The largest source of perturbation in this assembly was the relatively heavy control rods and control-rod channels; these were appreciably reduced in size for the second assembly, and the flux traverses in the latter demonstrate that the perturbation from this source has been reduced to a practical minimum, with a resultant increase in the precision of the measurements. A much improved method of correcting for the remaining perturbation has also been devised.

Special foil techniques were employed in the first assembly to study the problem of neutron return. Sufficient information about the characteristics of this return was obtained to permit a correction for the relatively small effect on critical size to be made with confidence.

The measurements of prompt-neutron generation time (by pulsed-neutron techniques) and of the thermal-neutron disadvantage factor in the first assembly are in agreement with the theoretical calculations.

In the second assembly a second, independent method of studying the effect of neutron return on critical size was employed. This method, based on the use of thin reflectors, gives results in general agreement with those obtained by the foil technique mentioned above, but is more direct.

The disadvantage factor in the second assembly was in fair agreement with the calculated value, and preliminary analysis indicates agreement in the neutron lifetime.

Construction of the third assembly is well under way.

Uranium-Water Lattices. During fiscal 1963, two further sets of experiments were completed on the properties of slightly enriched U fuel in light water. One set entailed the use of 3%-enriched

uranium oxide rods, 0.500 in. in diam, and stainless steel clad. The other involved 1.3%-enriched U metal slabs, 0.125 in. thick, and unclad.

The macroscopic properties of 20 lattices of the oxide rods were measured. Five lattices differing in water-to-fuel volume ratio were constructed, and measurements were made both with pure water moderator and with boric acid in solution in three concentrations.

Five lattices of U metal slabs were studied. Because of corrosion problems that would have attended the use of boric acid, only clean water was used in these assemblies. The buckling and reflector savings were measured, as were the cell parameters leading to information on thermal utilization, resonance capture, and fast fission effects.

High Flux Beam Research Reactor. The HFBR mock-up was rebuilt twice during the year, in successively closer approximation to the final reactor design. Figure 1 is a photograph of the final mock-

up which reproduces the design core in all respects important for the neutron physics behavior.

Additional experiments now under way will lead to final design values of such engineering parameters as power peaking factors, control-rod heat generation, thermal flux distributions, and control-rod worths.

Cold-Neutron Production. During the year the slow-neutron chopper began to yield data; it has been set up at the Neutron Source Reactor (NSR) in connection with studies of the design of a cold-neutron production facility for the HFBR and other reactors. Comparisons of the spectra from hydrogenous scatterers at room temperature and at liquid nitrogen temperature showed a disappointingly small enhancement (by a factor of only ≈ 2) of the neutron intensity at 5 Å. The inability to achieve better thermalization with any thickness of cold moderator was attributed to the design of the insulation about the moderator and liquid nitrogen and to the absorbing effect of the liquid nitrogen itself. Additional problems encountered were the presence of Bragg reflection peaks in the

Figure 1. Final mock-up of the HFBR design core.

initial and modified spectra, caused by the crystal effects of the graphite in the NSR thermal column, and the presence of too much room background.

The facility was therefore rebuilt; a different arrangement of insulation and cooling liquid was used, a heavy-water thermal column was constructed, and the neutron beam is now extracted through the building shield into a trailer on the outside. The revised situation is found to be quite satisfactory. The source intensity is higher, the signal-to-noise ratio is reduced by a factor >10 , and the spectrum shows lack of structure from cross section peculiarities. Final measurements of spectra from several geometries at temperatures down to that of liquid helium are about to begin.

Considerable assistance has been given in this research by Dr. Vance Sailor and his group in the Physics Department.

New Source Reactor. A new reactor is being constructed in the Critical Assembly Area in order to provide experimental facilities for basic reactor physics measurements on water lattices. The new reactor is much like the present NSR, i.e., it is a H_2O -moderated, graphite-reflected, split core of swimming-pool fuel elements. Instrumentation and control consoles are being assembled. It is estimated that the reactor will be ready for use by October 1963.

Reactor Physics Analysis

Analysis of Uranium-Water Lattices. The analysis of the results of all the $U-H_2O$ lattice experiments done at Brookhaven and elsewhere has proceeded at a more rapid rate recently because of the formation of a reactor analysis group in the Reactor Physics Division. Some of the early results were included in two papers presented in 1962 at an IAEA-sponsored meeting at Vienna. Later studies have provided much additional insight into the properties of light water reactors. Among the most notable conclusions are the following.

1. The lack of validity of asymptotic reactor theory in the exponential assemblies that are generally studied can be a source of considerable systematic error in extracting the material buckling from the experimental results. At least some of the discrepancies observed between the results of different methods of inferring the buckling can be theoretically explained in this way.

2. The inference of lattice anisotropy in the neutron migration area from exponential experiments can be entirely erroneous because of the influence

of radial flux transients, particularly when small assemblies are used to emphasize the leakage in one particular direction.

Sigma Center

Neutron Cross Section Compilation Group. The second edition of BNL 400, *Angular Distributions in Neutron-Induced Reactions*, has been published. Considerable effort has gone into preparing a digital machine program for magnetic tape storage of neutron cross section information. Experimental data and recommended "best values" can both be accommodated, and the file can be updated simply by making a new tape. The program will allow more flexible searches than the conventional card file does. The information obtained in a search will be printed out mechanically in tabular form, and an automatic plotting routine will be available for graphical presentations. These tapes should be valuable adjuncts to the present Sigma Center files, both in preparing compilations and in meeting more specialized requests.

Reactor Cross Section Evaluation Group. The elastic and inelastic scattering of neutrons by eight heavy elements has been fitted by the optical model with energy-independent parameters. The scattering of heavy ions is likewise consistent with the optical model.

Statistical analysis of neutron resonance parameters shows their distributions to be in reasonable agreement with experiment. A statistical theory approach to the properties of quantum systems is being explored as a means of achieving better understanding of the properties of physically observable systems.

Calculations of the nuclear properties of N^{14} and the scattering of He^3 by He^4 demonstrate the range of applicability of the theoretical models used.

Reactor Evaluation and Advanced Concepts

Settled Bed Reactors. Increased emphasis was placed on settled bed reactors during the year, with major investigations in the areas of settled bed characteristics, reactor physics, and fuel development.

Flow tests on mock-up systems indicate a high degree of stability for a dense, randomly packed bed of spheres. Voidage studies indicated little variation in the average density of a bed containing large numbers of spheres. However, preliminary measurements of local variations were inconclusive. A technique for the direct volumetric measurement of the void fraction of packed par-

ticulate beds has been developed. A transparent, bottled-shaped container is used to provide a large reduction in cross section in order to magnify changes in the level of the top of the bed. A commercial vibrator is used to aid in bed compaction. Highly reproducible results are obtained. The vibrator was used in a study of the effect of controlled addition of spheres to the bed. When the time allowed for addition was short, the results indicated larger void fractions. However, after a certain threshold time there appeared to be very little dependence.

A technique involving x-ray or γ -ray attenuation for void measurement is also under development since it has the advantage of leaving the particulate bed undisturbed. Bench-scale equipment has been assembled to study methods of random loading and packing of particulate beds for maximum compaction.

Broad-scoped studies of the physics of the fast settled bed reactor were carried out. These included studies of reactor stability, breeding potential, fuel burnup, and control. The measured local variations in settled bed densities were found to have a negligible effect on over-all reactivity in large beds. Initial breeding ratios of ≈ 2 were obtained in axial flow reactors with Na as the coolant, which reflects the hardness of the spectrum in these reactors as well as the recent upgrading in η values for Pu. Similar results were obtained with heavy metal coolants. If the large rise in coolant temperature that from present indications is feasible for these reactors is indeed realized, fuel doubling times of only a few years would become practical.

The design of a combined hydraulic-critical experiment for broad studies of settled bed characteristics has been initiated. The nuclear characteristics of randomly packed, dense, and loose particulate bed states, as well as fluidized bed states, will be investigated in zero power experiments. A hollow, MTR-type assembly with an internal, water-moderated bed of U-Al spheres is currently favored.

Fuel development work on UC spheres has continued. Out-of-pile evaluation of UC fabricated by both casting and powder metallurgical processes indicates that at this time the cast material is the most promising fuel. Hypostoichiometric fuel is being investigated because it is compatible with Na. The hypostoichiometric UC spheres enriched to 20% in U^{235} for the in-pile capsule test have

Figure 2. Radiograph of NaK-filled in-pile capsule.

been received. In the hope of developing a fuel in which the present exact carbon control in fuel preparation may be relaxed, a study has been started on the substoichiometric single-phase monocarbide region of the U-Zr-C system. The compatibility of $ZrC_{1.05}$ with Re has been established with short time tests ($\frac{1}{2}$ hr) at 2300°C , and high-temperature x-ray studies of carbide supported on a heated Re filament have begun.

The in-pile capsule assembly and vertical hole facility at the Brookhaven Graphite Research Reactor (BGRR) have been completed. The first dummy in-pile capsule (containing no liquid metal) has been successfully tested. The second dummy capsule, which contains liquid metal (NaK), has been filled and is now being evaluated in the dummy in-pile facility. A radiograph of this capsule (Figure 2) indicates the location of the fuel in the central tube of the lower chamber. The dark area in the upper chamber is the static load used to simulate the force between the particles in an actual reactor system.

Organic-Cooled Reactor Studies. The cancellation of the Experimental Organic-Cooled Reactor program by the AEC drastically curtailed the scope of these studies, and they were terminated on June 30, 1963.

Capsule tests of the fouling of 304 SS surfaces by terphenyls to date have shown either complete absence of detectable film deposits or barely detectable traces of α -Fe. Particulate Fe as Fe^{59} was found to transfer from the coolant to the heater surface but with a calculated equivalent in film thickness of only $0.03\ \mu$ in 92 hr. No evidence was found of Fe solubility in *p*-terphenyl in isothermal runs at temperatures up to 425°C . Temperature-induced mass transfer tests have been carried out with polished tabs of 304 SS, 2S Al, Al 288, mild steel, and SAP (sintered aluminum powder) in capsules with wall temperatures of 410° at one end and 270°C at the other. Studies of the stability of condensed aromatic compounds to heat and radiation were carried out. *p*-Terphenyl, naphthalene, phenanthrene, pyrene, chrysene, and triphenylene appear to be promising on the basis of their low pyrolytic and radiolytic decomposition at temperatures up to 400°C .

Direct Conversion. Studies have been carried out of MHD* systems as alternatives to SNAP*

turbogenerators for generating electricity. A model MHD generator was operated in magnetic fields up to 13,000 gauss with Hg as the working fluid with an efficiency of 50% at a maximum power output of 10 w and a pulse rate of 2 cycles/sec. Studies of pulsed fission plasma reactors indicate that UBr_3 or UBr_4 would be much more suitable gaseous fuels than UF_6 because of their lower dissociation temperatures.

Fuel Cells. The characteristics of a thermally regenerated cell utilizing the Pb-PbBr₂-Br₂ system were investigated. Thermoelectric effects were small, and no significant stray current flow through the cell was found. An unexpectedly high internal ohmic resistance was found for the cell. In addition, the cell resistance increased with time.

Chemonuclear Reactors. The characteristics of a boiling O_2 chemonuclear reactor for ozone production have been investigated. The oxygen is used as moderator, coolant, and process medium, and all the fission energy is removed by boiling O_2 ; no usable thermal power is produced. At an operating level of 25 Mw, the reactor produces 130 tons/day of ozone. A series of studies of UF_6 -fueled reactor cores with HF, CF_4 , DF, and $\text{HF} \cdot \text{CF}_4$ gaseous moderators has been carried out.

METALLURGY

Reactor and General Metallurgy

Research in reactor metallurgy includes study of the containment problems of liquid-metal coolants, the production of controlled composition alloys for research, and general consultation on materials throughout the Laboratory.

Materials for Containing Boiling Liquid Metals. Since experiments with inhibitors added to Hg to decrease the corrosion of carbon steels indicated this technique to be only marginal, effort has been concentrated on investigating the refractory metals as container materials. Capsule tests made early in the program indicated that Cb, Cb-1 wt % Zr, Ta, and Mo were all resistant to attack by boiling Hg.

A thermal convection loop fabricated of a Cb-1 wt % Zr alloy, and containing Hg boiling at 647°C (1200°F) and superheated to 760°C (1400°F), was operated in a vacuum chamber for 7697 hr, at which time a rupture occurred in the superheater section. Figure 3 is a photograph of the fracture area. Metallographic, electron beam microprobe,

*MHD=magnetohydrodynamic; SNAP=systems for nuclear auxiliary power.

Figure 3. Fracture area in Cb-1 wt % Zr loop containing boiling Hg.

Table 1

Results of HFBR Fuel Element Tests

Fuel element*	Type	% Burnup of the enriched U	Status
5	ETR (J)	33-39	(In-canal probing.) 0.080-in. probe passed all channels. 0.092-in. probe would not pass freely.
6	ETR (D)	29-36	Hot cell examination showed minimum swelling and no detectable distortion of the plates or channels.
7	ETR (D)	19-23	(In-canal probing.) 0.1005-in. probe passed through all channels with some difficulty.
8 9	MTR (K)	21-27	Hot cell examination showed minimum swelling and no detectable distortion of the plates or channels.

*Elements 1 to 3 were discussed in last year's annual report; No. 4 was not tested.

and chemical analysis did not conclusively prove that failure was due to a corrosive process. Neither were corrosion products found. The presence of cracks in the fracture area and the boiling instabilities during operation of this loop have led to the tentative conclusion that failure resulted from thermal stress fatigue. Capsule experiments are now under way to determine conclusively the cause of failure.

The effect of adding Ba, O, and Mg to Na on its corrosion of Cb-1 wt % Zr alloy at 1204°C (2200°F) is being studied in boiling reflux capsule tests.

No corrosion has been detected, by radiographic examination, in a natural circulation loop which operated for 5000 hr at a boiler temperature of 1093°C (2000°F) and a superheater temperature of 1204°C (2200°F).

General Metallurgical Studies. A technique has been developed for vacuum-brazing heater elements for a heat transfer test section to be used in a loop designed to obtain heat transfer information on boiling K.

Alloys have been prepared for various groups at the Laboratory by arc or induction melting. Some of these were Pd-Fe, Fe-Cb, Li-In, ZrC, Hf-Fe, Ir-Bi, Ho-In, Fe-C, Fe-Cr, and Fe-Ni.

Cu single crystals 2 in. in o.d. and 8 in. high were grown for use in the Chemistry Department's neutron diffraction equipment.

HFBR Metallurgy. Five additional prototype fuel elements for the HFBR have been irradiated in the Materials Testing Reactor (MTR) and the Engineering Test Reactor (ETR). These elements had 3 wt % Si added to the 35 wt % U-Al core, which was clad with 6061 Al. All were mechanically assembled by roll-swaging the fuel plates to the side plate.

Table 1 summarizes the new results obtained. Roll-swage-assembled elements withstood high burnup much better than the peened-lug-assembled elements tested (and reported on) previously. Pre- and postirradiation microstructures of the core alloy having the highest burnup are shown in Figures 4 and 5. The dark bands within the UAl_3 particles either indicate partial transformation of the UAl_3 to UAl_4 , or are localized areas of high fission gas retention. Type J test elements were identical to ETR flat-plate elements except for the composition of the core alloy. Type D elements differed in that the end fuel plates were made thicker for greater rigidity. Type K elements were of the MTR type with curved plates but otherwise identical with type D.

A sample coupon of 3% Dy₂O₃ dispersed in and clad with stainless steel showed no significant dimensional changes after 1.4×10^{21} nvt (1 yr) in the MTR. A 6-mil increase in thickness can be attributed to a visible oxide on the coupon.

Alloy Theory and Nature of Solids

Liquid-Metal Corrosion Fundamentals. The possibility that the selective attack often observed

in liquid-metal corrosion results from electrochemical action is being investigated. The rate of dissolution may be affected by currents arising from electromotive forces (emf's) which may be produced by differences in free energy of dissolution or the difference in thermopower between the solid and liquid metals. Studies are therefore being made of electrodiffusion in liquid alloys and of the sources of the emf's.

Figure 4. Microstructure of 30% U-Al alloy containing 3% Si, 500X. Etchant, 0.5% HF in H₂O.

Figure 5. Microstructure of plate identical to that in Figure 4 after 45% burnup of the U, 500X.

1. **Electrodiffusion studies.** In dilute solutions of Ag in molten Bi it appears that a dc current of 1000 amp/cm² changes the apparent diffusion coefficient for the Ag ions from 7×10^{-5} cm²/sec to $\approx 3 \times 10^{-4}$ cm²/sec against the electron flow. Electric mobilities for Ag migration in Bi under a current flow of 1000 amp/cm² are $\approx 2 \times 10^{-4}$ cm²/v-sec. This value is dependent on the duration of the experiment and may also be affected by the current density and the Ag concentration.

2. **Emf studies.** The emf of the liquid-metal cell Fe:Bi:Fe-5% Cr ranges from 0.5 μ v at 350° to 400°C to 0.2 μ v at 500°C. The presence of dissolved Fe reduces the thermopower of liquid Bi by 2 to 3 μ v/°C between 400° and 600°C.

3. **Solubility studies.** The solubilities of Fe, Cr, Co, Ti, Zr, Cb, and Ta have been measured in liquid Hg at temperatures between 500° and 700°C. The results, along with those of more than 50 other liquidus curves obtained in liquid Bi and Pb-Bi alloys, were compared with published theories of solubilities with no success.

Capsule experiments were performed which indicate that Cb-1 wt % Zr alloy is susceptible to stress attack by Hg and by Hg and Mg at 750°C.

Energy Transfer in Thin Films. Thin films of 97% enriched LiF (in the 100-A range) were produced by vacuum evaporation techniques and exposed to a thermal neutron flux of 2.8×10^{17} nvt. Electron microscopy of these irradiated films demonstrated that the products of the $\text{Li}^6(n,\alpha)\text{H}^3$ reaction transfer enough energy to the LiF matrix to produce visible tracks (Figure 6), even though the energy is relatively low (≈ 2.5 Mev). In one case a track of what is assumed to be an α particle from the $\text{Li}^6(n,\alpha)\text{H}^3$ reaction was produced in a Cr film which was in intimate contact with the LiF film (Figure 7).

The proper conditions for producing tracklike films are the subject of a continued, intensive investigation. The factors known to influence the observation of tracklike "damage" are the thickness, density, and structure of the film and the rate of energy transfer per unit track length.

Figure 6. Electron micrograph of tracks from the $\text{Li}^6(n,\alpha)\text{H}^3$ reaction in vacuum-evaporated film of enriched LiF. Total exposure to thermal neutrons, 2.8×10^{17} nvt; magnification, 45,000 $\times$.

Figure 7. Electron micrograph of track from the $\text{Li}^6(n,\alpha)\text{H}^3$ reaction in enriched LiF, Cr-shadowed. Total exposure to thermal neutrons, 2.8×10^{17} nvt; magnification, 45,000 $\times$.

Figure 8. Sputnik-4 fragment.

Metallographic Studies of Sputnik-4 Fragments.

Metallurgical and radiochemical analyses were performed on portions of steel recovered after the disintegration of the U.S.S.R's Sputnik-4 over Manitowoc, Wis., on September 5, 1962. The material of this fragment was found to be a hot-rolled carbon steel with hardness measurements similar to those found in a structural steel with a tensile strength of 55,000 to 60,000 psi. Figure 8 shows the portion of the fragment examined. The upper surface of the material probably underwent heating to or near the melting point.

A melted steel agglomerate that had formed at the bottom of the specimen was found to have on its surface a white powder containing large amounts of MgO. As the steel is low in Mg, it must be assumed that the material was near or in contact with some Mg alloy.

Radiochemical analysis did not show the large excess of tritium previously reported in satellites exposed to the November 1960 solar flare.

Radiation Effects

Effects of Neutron Irradiation on the Mechanical Properties of Body-Centered-Cubic Metals. The mechanism of neutron irradiation damage in body-centered-cubic (bcc) metals is being studied by determining the changes in mechanical properties at ambient to liquid He temperatures. The yielding and fracture properties and plastic deformation characteristics have been determined for pure Fe and Fe alloys as a function of the grain size, integrated exposure to fast neutrons ($E > 1$ Mev) up to 10^{20} nvt, testing temperature, and postirradiation annealing temperatures. Similar studies on Ta and Nb have been started.

Irradiation decreases the dependence of yield strength on grain diameter which exists for unirradiated Fe and steels. For pure Fe, an exposure

of 2×10^{18} nvt essentially eliminates this dependence. However, for pure Fe alloyed with 0.11 wt % C, much higher exposures are required to cause a significant change. These observations have been explained by postulating the formation of immobile sessile dislocation loops on the slip planes and the precipitation of C atoms into radiation-produced vacancies. The results, however, were ambiguous. An alternative analysis, which is based in part on a thermally activated rate process and agrees with the yield and flow data, is now being developed.

The yield strength vs temperature curve of irradiated pure Fe exhibits a sharp increase and the reduction of area curve a sharp drop at $\approx 125^\circ\text{K}$. Slip trace studies using irradiated single crystals of Fe are planned to determine the deformation characteristics in this temperature range.

Electron Microscopic Study of the Effects of Neutron Irradiation on the Properties of Iron and Other bcc Metals. Examination by electron transmission microscopy of specimens of annealed pure iron foil irradiated to a total fast-neutron exposure of 2×10^{18} nvt and then deformed plastically revealed no apparent differences in substructure between these specimens and similar but unirradiated specimens.

A lead-walled cave was constructed, and equipment for sectioning irradiated tensile test bars by electromagnetic spark discharge machining was installed and tested and is now ready for use. Techniques for producing electron-transparent areas in sections cut from test bars by electrolytic polishing have been developed.

Irradiation Effects in Graphite. Neutron irradiation of graphite is being studied at Brookhaven in an attempt to understand more fully the radiation and annealing reactions that occur and their effects on the physical, chemical, thermal, and electrical properties of graphite.

1. BGRR studies. The technique of alternately irradiating and annealing graphite on a triweekly basis has been applied to the BGRR, with subsequent measurement of height changes in the reactor and property changes in several hundred monitoring samples dispersed throughout the reactor. This procedure has resulted in net dimensional recoveries of samples and reactor height.

2. Kinetics of graphite-bromine reactions. A kinetic study of the exchange of normal and radioactive bromine in graphite-bromine lamellar compounds was made at temperatures of 30° to 50°C .

Natural and synthetic graphite powders were investigated. A volume diffusion mechanism was used to interpret the data. Diffusion coefficients of 10^{-9} to 10^{-8} cm²/sec and an activation energy of 11 to 14 kcal/mole were calculated for the movement of bromine in the lamellar compounds.

3. Radiation damage studies. Results of monitoring studies have yielded a quantitative radiation damage picture that accounts for the dependence of various properties of graphite on irradiation temperature and gives values for the migration of the single interstitial, the absolute rate of displacing atoms, and the proportionality constants for the vacancy and di-interstitial contributions to various properties.

The property changes in alternately irradiated and annealed graphite after a relatively large initial exposure are different from the changes in continuously irradiated graphite. These differences have been explained on the basis of successive reactions of different interstitial species in which some of the species reach steady-state conditions. Kinetic analyses of such systems predict that in the early stages of reirradiations the decomposition of existing damage is greater than the rates of formation of new damage. The analyses are supported by experiments and by the above-noted dimensional recovery in the BGRR.

The effects of annealing frequency on the properties of irradiated graphite receiving short first irradiations were also investigated. Changes in sample dimensions, *c*-axis values, Hall coefficient, electrical conductivity, and thermal conductivity were measured. Here also, radiation damage decreased with increasing annealing frequency.

Behavior of Iodine in Graphite. Iodine can be physically adsorbed and chemisorbed on graphite at temperatures of 200° to 800°C. The adsorption is variable because of the sensitivity of the chemisorption sites to heat treatment and chemical treatment.

At 25° and 100°C, iodine probably forms very dilute lamellar compounds at a slow rate. On decomposition, these compounds leave residual iodine in the graphite, which is stable in vacuum at 950°C. The maximum concentration of residue was 600 ppm after a sample had been exposed for 20 days at 25°C in saturated iodine vapor. The residue has no effect on the adsorption of iodine at 100°C or the surface area of the graphite.

The rate of take-up of residual iodine at 25°C is enhanced by prior heating to 2000°C and ex-

posure to water vapor at 900°C, which suggests the existence of a surface barrier that hinders the formation of the dilute lamellar compound.

Xenon Diffusion in Carbides. A series of experiments has been completed on the release of Xe from UC powder at very low temperatures (185° to 1000°C). In this temperature range, release of Xe is much faster than is predicted by the diffusion results obtained between 1000° to 1400°C. The kinetics of the low-temperature release are not consistent with a normal diffusion model. The release data fit a model in which the gas in the first 3 or 4 surface layers is released over a spectrum of activation energies, with the maximum contribution at 27 to 35 kcal/mole. This low-temperature release model successfully accounts for high apparent diffusion coefficients and low activation energies at low temperatures. The model can also account for some of the gas contributing to the "burst" effect on postirradiation heating.

Studies on Xe diffusion from ZrC and ZrC-UC solid solutions have begun. ZrC_(1-x) of variable *x* have been prepared by the reaction of ZrH₂ and lampblack.

CHEMISTRY AND CHEMICAL TECHNOLOGY

Reactor Chemistry

High-Temperature Equilibria. Most metals dissolve to some extent in their own fused salts. Little is known about the nature of the resulting dissolved species, although the question is one of both scientific and technical interest. In the past year two experimental techniques, absorption spectrophotometry and chronopotentiometry, have been found to be useful in this field. The system Pb-PbCl₂ was studied by observing the spectra of a series of liquid PbCl₂ samples which had been equilibrated with Pb-Au alloys of differing Pb concentration. From the results it was possible to determine subhalide concentration as a function of Pb activity. The functional relationship was such as to indicate that the subhalide species was Pb₂Cl₂. The system Mg-MgCl₂ was studied to find subhalide concentration as a function of Mg activity. A similar procedure was followed, involving equilibration of MgCl₂ with a series of Pb-Mg alloys, but the subhalide was determined by anodic chronopotentiometry instead of from spectral data. The dissolved species proved to be of the same type here too, namely Mg₂Cl₂.

Table 2

Decomposition of Fluorocarbons by Electron Radiation

Compound	G, molecules destroyed per 100 ev absorbed
Perfluorobenzene, C ₆ F ₆	2.15
Perfluorocyclohexane, C ₆ F ₁₂	3.1
Perfluorobiphenyl, C ₁₂ F ₁₀	1.4
Perfluorobicyclohexyl, C ₁₂ F ₂₂	1.6
Perfluoronaphthalene, C ₁₀ F ₁₈	1.7

In other high-temperature programs, thermodynamic properties of a variety of compounds and mixtures were obtained from galvanic cell measurements.

Xenon Compounds. Soon after the discovery of xenon tetrafluoride at Argonne National Laboratory was announced, experiments on the irradiation of Xe-F₂ mixtures showed that combination could be induced by this means at or near room temperature. The reaction vessel was a pre-fluorinated Ni tube, equipped with a pressure gauge, which was placed in a gamma field of $>10^6$ rads/hr. Since the pressure dropped at a conveniently measurable rate, the radiation-induced reaction offers promise as a method for studying reaction kinetics and mechanisms. It appears that XeF₂ is the primary product and that it is the only product at sufficiently low temperatures. Its radiation yield is quite high; G values up to 15 have been obtained.

Radiation Chemistry of Fluorocarbons. The determination of the radiation stability of a series of selected fluorocarbons, with analysis of their decomposition products, has continued. Recent results have made possible a comparison of alicyclic and aromatic fluorocarbons, as shown in Table 2. It is interesting that the two-ring compounds are more stable than single rings. Analysis of the radiolysis products showed another curious feature; i.e., no unsaturated gaseous compounds (C₁ to C₄) were produced from perfluorocyclohexane, while appreciable quantities were formed from perfluorobicyclohexyl.

Radiochemical Analysis Research

Chemistry of Actinide Elements and Homologues.

Study continues of the extraction synergism between thenoyltrifluoroacetone (TTA) and tri-*n*-octylamine (TnOA). Am was found to hydrolyze at $\leq 4 \times 10^{-3}$ M [H⁺], but in the presence of 2 M

LiCl no hydrolysis occurs down to 2×10^{-4} M [H⁺]. In the absence of TTA, dilute TnOA in benzene extracts no Am from 2 M LiCl at acid concentrations between 0.01 and 2×10^{-4} M, but the presence of small amounts of TnOA greatly enhances the extraction of Am by TTA. A method has been devised for measuring this effect quantitatively.

A study of the synergism between TnOA and acetylacetone established that the two extractants do not interact with each other and in fact produce an antisnergistic effect in the extraction of Th.

Fluorescence in actinide chelates is being investigated because of its intrinsic interest, for its potential usefulness in rapid qualitative spectroscopic analysis, and to determine whether actinide chelates in a plastic matrix may act as a self-exciting laser.

A reported color reaction between Nd and 3,3'-diaminobenzidine was investigated and found not to occur.

The hydrolysis of Ce⁺³ was investigated by adding a known amount of base to the solution, measuring the pH, and determining whether the change in pH was exactly equal to the amount of base added. In the region between 0.01 and 1 M Ce⁺³ one predominant species was found, namely, Ce₃(OH)₅⁺⁴. This study involved using the glass electrode to make potential measurements which are reproducible to within 0.2 mv.

Electrochemical Studies. Incremental polarographic studies of U(VI) in ethylenediaminetetraacetic acid point to disproportionation of the primary electrode product, U(V), at an appreciable rate. Current reversal chronopotentiometric measurements on this system are in excellent agreement with calculations based on a mathematical model used to describe this system by computer analysis.

Studies of anodic depolarization of the dropping Hg electrode in fused LiNO₃-KNO₃ eutectic by various anions indicate that soluble mercurous complex species are formed in the presence of Cl⁻ or Br⁻. A study of the behavior of CrO₄⁻² and Cr₂O₇⁻², dissolved in this eutectic, at the dropping electrode indicates that Cr₂O₇⁻² reacts significantly with Hg and that both species give a cathodic wave just prior to the onset of NO₃⁻ reduction. Molten *n*-methylpyridium bromide has been found unsuitable as a solvent for polarography at the dropping Hg electrode except perhaps in cases involving the more noble metals.

Nuclear and Radiochemical Methods of Analysis.

Activation analysis is being made more specific in

certain cases by counting characteristic x rays following internal conversion. This technique has been successfully used in the analysis of trace amounts of Cd and Gd deposited on an Al alloy plate, and it shows promise for the analysis of traces of Co in the residue from distilled Hg.

The possibility has been investigated of using unique gamma-ray spectra resulting from radiative capture as a basis for a new technique in radioactivation analysis. At present the method cannot be applied generally, but it may be of interest for certain special cases.

A method involving gamma-gamma spectrometry has been developed that permits determination of Co^{60} in the presence of twice as much Fe^{59} and 400 times as much Co^{58} .

A solid-state detector to detect charged particles from neutron-induced reactions is being investigated as a means of determining small amounts of B^{10} and Li^6 and has been applied to the measurement of thicknesses of thin films of Li^6F . The same detector without the neutron beam has been used to determine U in Pd-U alloys.

Development of Procedures. Procedures under study include a method of determining water in organic compounds via coulometric titration using Karl Fischer reagent and an x-ray fluorescence method for determining Rb and Y. Daily capacity of a microcombustion train has been increased 50% by automation. Equipment modifications have been made which permit determination of $<3 \mu\text{g}$ Fe reproducibly and in agreement with results obtained elsewhere.

Release of Fission Products From Fuel Elements. This program is directed toward achieving a fundamental understanding of the fission product release process to provide information for evaluating the consequences of a reactor accident. The effect of chemical environment on the nature of the release from metallic fuel samples was studied over a wide range of fission product concentration corresponding to total irradiations ranging from 3.0×10^{14} to 5.4×10^{19} nvt. Fission product iodine was released into He at 1200°C in combined form, apparently as a uranium iodide, rather than as elemental iodine. Calculations indicate that UI and UI_2 may be important gaseous species released from fuels having iodine concentrations corresponding to burnups of at least 50,000 Mwd/ton U. These uranium iodides react in air to form UO_2I_2 which further dissociates to UO_2 and I_2 .

In contrast to the He results, the U fuel is oxidized in air at 1200°C to U_3O_8 with subsequent release of elemental iodine. Depending on the U oxidation conditions, large fractions of the released elemental iodine are found to absorb on particulates.

Much less Ba-La and Ce was released from the fuel samples into air than into He because of the formation of the nonvolatile oxides of these fission products. A negligible quantity of Mo was released from U into He; however, in air a large quantity was released as MoO_3 .

Surface Area Measurements on Graphite. During the past year a new method has been developed for measuring the specific total area of powders and porous materials. It has been used, however, almost exclusively on graphite. The method involves the measurement of adsorbed Kr with Kr^{85} tracer. It is much quicker than the conventional Brunauer-Emmett-Teller method and gives more accurate results at the lower specific areas.

With nuclear graphites the opening of closed pores was found to be the principal cause of the increase of surface area with decreased particle size. Some graphites show an appreciable internal surface area which is independent of particle size and is attributed to interconnecting pores. These values may be used to characterize graphites.

Fuel Reprocessing

Reprocessing Reactor Fuels by Volatilization Through the Use of Inert Fluidized Beds. The use of an inert fluidized bed for reprocessing spent reactor fuels is based on the heat-transfer and gas-mixing properties of such beds. These properties permit highly exothermic reactions between massive solids and gases to be carried out under controlled conditions and result in relatively uniform attack on the solid reactant.

Reprocessing of Stainless Steel-Clad Fuel. Although stainless steel is attacked by chlorine at $\approx 600^\circ\text{C}$, major difficulties arise when adapting this reaction to the reprocessing of SS-clad fuels. First, there is the problem of corrosion in such a system; second, UO_2 reacts with chlorine, which results in a mixture of solid and liquid products, the latter tending to cake the Alundum bed material with ultimate loss of fluidization. In view of the difficulties attending chlorination reaction, the effort has been shifted to a fluoride-promoted oxidation system outlined below.

It has been found that SS is severely attacked by oxygen at 700°C when immersed in an Alun-

dum fluidized bed containing ≈ 1 wt % AlF_3 . The attack is more pronounced if the bed is prefluorinated with F_2 for $\approx 1/2$ hr, although the SS sample need not be present during the fluorination period. The oxidation product consists of a mixture of SS oxides which exfoliate from the sample in layers and are ultimately reduced to coarse powder by the action of the fluidized bed. In Table 3 is shown the rate of attack on type 304 SS samples made from $1/4$ -in. tubing. In addition, two preliminary U recovery experiments have been carried out with 12-in. Yankee rod sections in which the oxidation reaction was followed by fluorination; the results of these experiments are listed in Table 4. Both the oxidation reaction and fluorination reactions proceed smoothly and without difficulty.

Preliminary corrosion tests indicate Inconel to be a satisfactory container material.

Aluminum Alloy Fuel. The inert fluidized bed process has been applied to the recovery of U from Al-clad U-Al alloy reactor fuels. Separation is

Table 3

Oxidation of Type 304 Stainless Steel
(25 g AlF_3 added to 2000 g prefluorinated
Alundum bed material)

Run No.	Temperature, °C	Penetration rate, mils/hr
21	700	5.0
22	700	7.0
23	700	5.0
24	650	0.0
25	700	6.6
26	650	0.1

Table 4

Recovery of Uranium
From Yankee Fuel Element Sections

Run No.	Sample wt	Total U charge (estimated), g	Residual U* in bed	Wt U* recovered, g
27	141.2	110	300 ppm (0.60 g)	79
28	146.8	113	260 ppm (0.52 g)	90

*Excluding unreacted UO_2 fragments in conical bottom.

achieved by reacting the fuel element with HCl and thereby removing Al as volatile AlCl_3 . The U residue, which is nonvolatile, is subsequently reacted with F_3 and recovered as UF_6 .

HCl-Al reaction rates have been measured with 1×4 -in. Al-clad U-Al alloy coupons immersed in a $1\frac{1}{2}$ -in.-diam fluidized bed of 60-mesh Alundum under a variety of conditions of temperature and gas flow. The results are given in Table 5, and a representative plot of reaction rate and utilization vs temperature is presented in Figure 9. Fluorination of beds containing 500 ppm U from single-coupon U-Al hydrochlorination experiments reduced the U concentration to 50 ppm. In addition, a parallel-plate subassembly (11 plates weighing a total of ≈ 160 g) was reacted with 100 vol % HCl at 300°C . After 60 min, $\approx 90\%$ of the sample was reacted. In subsequent fluorination of the bed resulting from this experiment, the U concentration in the bed was reduced from an estimated 5000 ppm (based on original charge) to 50 ppm as determined by x-ray fluorescence analysis of bed samples.

Volatility Reprocessing Pilot Plant. Design has been completed of a cold pilot plant to investigate

Table 5

Bench-Scale Hydrochlorination Experiments
(100% HCl, 60-mesh Alundum bed, 1.5-in.
Inconel reaction vessel)

Run No.	Initial temperature, °C	Superficial velocity, ft/sec	Rate, mils/hr
1	350	0.5	109.6
2	300	0.55	124.4
3	275	0.55	123.5
4	400	0.7	265.3
5	250	0.5	113.9
6	350	0.48	156.6
7	300	0.45	82.6
8	340	0.5	115.7
9	400	0.5	128.8
10	250	0.4	99.1
11	350	0.45	105.2
12	250	0.7	118.3
13	350	0.7	156.9
14	300	0.7	140.6
17	300	0.7	128.6
18	350	0.7	165.3
19	400	0.7	187.2
20	350	0.9	208.5
22	400	0.9	192.3

the reprocessing of a variety of reactor fuels via the inert fluidized bed volatility method. Construction is in progress, and the plant will be brought on stream in fiscal 1964. The primary purpose of the unit will be to demonstrate the feasibility of reprocessing graphite matrix fuels by the above method on a realistic scale. Subsequent investigations will be made using other types of fuel such as SS-clad UO_2 and Al-clad U-Al alloy fuels.

Nitrofluor Volatility Process. Engineering-scale equipment fabricated from Monel is being assembled in the new Volatility Studies Laboratory to investigate the dissolution behavior of U-Zr alloy fuel. A solution of $\text{NOF} \cdot 3\text{HF}$ and HF will be used as the dissolving agent rather than N_2O_4 -HF solution, since it is less corrosive and will allow the dissolving step to be performed at atmospheric pressure or below. The solvent $\text{NOF} \cdot 3\text{HF}$ is the high-boiling residue resulting from distillation of a mixture of NOCl and HF; the gallon amounts required for the above study will be prepared by a manufacturer of fluorine chemicals.

Further work with UO_2 power reactor fuel was deferred until the behavior of Pu is better understood. Low-level Pu experiments were recently started to investigate the volatilization of Pu from the fuel material salts accumulated in the evaporator.

The new method of volatilizing U compounds by treatment with NOF gas (or the vapor from $\text{NOF} \cdot 3\text{HF}$) at $\approx 400^\circ\text{C}$ has shown promise as another means of removing U contamination from fission products. Various U compounds, or the

isolated salt produced by the dissolution of U metal or compounds in $\text{NOF} \cdot 3\text{HF}$, are volatilized as NOUF_6 in this treatment. Several fission product element salts produced in $\text{NOF} \cdot 3\text{HF}$ behaved differently. The Nb salt was more volatile than NOUF_6 , whereas the Zr and Ru salts were not volatile. The salt NOMoF_6 transferred in the absence of NOF.

Studies on the corrosion of Monel in N_2O_4 -HF solutions at temperatures up to 150°C have proved useful in elucidating the variable behavior found in previous work. The use of a sensitive electrical resistance probe has made possible the continuous determination of corrosion rates. In static solutions at controlled temperatures, the conditions under which a protective film forms on Monel have been found. The film that best resisted cooling and reheating of the solvent was one formed in 30 mole % NO_2 -70 mole % HF solution at 100° or 125°C . Under several other conditions no protective film formed, or there was indication of film breakdown and re-formation upon thermal cycling.

The solvent N_2O_4 -HF was shown to be useful for treating graphite-matrix fuel containing UC_2 particles coated with pyrolytic graphite. The matrix was disintegrated by the solvent at 150°C and the coating split open into half shells, which allowed the UC_2 to dissolve. Washing of the graphite residue with fresh solvent removed all but 0.23% of the U, which indicates that more than 99.7% is recoverable. A limited number of experiments were performed on the recovery of U from classified Rover rocket fuel.

Figure 9. U-Al alloy hydrochlorination. Rate and per cent utilization of HCl vs temperature.

Figure 10. Heat transfer of NaK flowing in-line through a bundle of rods under conditions of fully established flow.

Figure 11. View of alkali-metal heat transfer facility showing the instrument panel in the foreground. The facility can circulate 150 gallons of metal per minute at temperatures up to 900°F.

Liquid-Metal Heat Transfer Research

During the year there were three active experimental projects. In the first, heat transfer coefficients were measured for in-line turbulent flow of NaK through an unbaffled rod bundle. The bundle consisted of 19 rods, 1/2 in. in o.d., spaced in an equilateral triangular array with a pitch : diameter ratio of 1.750. Data have been taken in the 280° to 500°F range. Figure 10 shows some typical results.

The meanings of the symbols in Figure 10 are as follows:

- Nu = Nusselt number = hD_e/k ,
- h = heat transfer coefficient,
- D = o.d. of rods,
- D_e = equivalent diameter of bundle,
- k = conductivity of liquid metal,
- Pe = Peclet number = $D_e v \rho C_p / k$,
- v = average linear velocity,
- ρ = density of liquid metal,
- P = distance between rod centers,
- C_p = heat capacity of liquid metal,
- Pr = Prandtl number = $C_p \mu / k$, and
- μ = viscosity.

As liquid-metal heat transfer data go, the agreement with theoretical predictions is reasonably good, considering the rather low temperature drop between rod surface and the bulk stream, which usually fell in the 7° to 10°F range. The heat generating capacity of the rods and the high thermal conductivity of the NaK are the two principal factors preventing the attainment of higher temperature differences. Information such as that shown in Figure 10 is useful in the thermal designs of reactor cores and shell-and-tube heat exchangers.

The second project involves the measurement of velocity and temperature profiles for Hg flowing through annuli. This is a fundamental study, and its significance goes beyond the particular metal and geometry used. The project has just entered the data-taking phase.

The purpose of the third and largest experimental project is to obtain fundamental heat transfer information on forced-convection boiling and condensation of K at temperatures up to 1800°F. The loop for this project is under construction, with data-taking scheduled to begin in the spring of 1964.

In one analytical study, an improved theoretical expression for Nusselt number was obtained for cross flow of liquid metals through rod bundles by applying inviscid flow analysis. The derivation is based upon the assumption that, for a rod located in the interior of a bundle, the circumferential variations of both the tube-wall temperature and the hydrodynamic potential can be expressed by cosine-type distributions.

Ultimate Waste Disposal

Phosphate Glass Process. Construction of the phosphate glass pilot plant shown in Figure 12 was completed during the year, and a number of satisfactory preliminary runs were made in which steady-state conditions of operation were achieved. Glass production rates up to 1.9 ft³/24 hr were obtained (it is estimated that 1 ft³ of glass would be produced in the treatment of waste from reprocessing of spent fuel containing 1 ton of U).

Of critical importance in developing the phosphate glass process is the evaluation of the corrosion resistance of Pt exposed to the molten phosphate at 1200°C to determine its suitability as a liner material for the oxidation resistant Inconel 702 crucible. To date, the 8-in.-diam crucible used in the pilot plant has been in the presence of Purex phosphate glass at 1200°C for 1800 hr. No signs of deterioration attributable to corrosion have been observed.

Recently the residence time necessary for the formation of glass in the high-temperature crucible was found to be much shorter than had been assumed. In some experiments with small holdup volumes in the crucible, the required residence times were not more than 1 to 2 min. Considerable advantage may be gained, therefore, through a reduction in the size of the crucible, an objective that fits well into the present experimental program with the bench-scale unit which utilizes induction heating of the 3-in.-diam Pt crucible.

Rotary Calciner. Modifications of the rotary calciner pilot plant were completed during the year, and a continuous plant run of ≈ 800 hr was made. In particular, a new feed system based on the use of a pressure-cycled spray feed was installed in the plant, and pretesting and installation of the new rotary seal were completed. The seal design featured a small (0.003-in.) gap between the faces of the rotating and nonrotating discs, maintained by means of three rollers mounted at the periphery, and a continuous inward flow of superheated steam

Figure 12. Phosphate glass pilot plant.

through the gap to oppose any tendency for outward escape of gases or dust from the calciner.

The purpose of the extended plant run was to test the major mechanical components and to determine general performance characteristics of the plant operating as a unit, as well as to obtain data to serve as the basis for an over-all evaluation of the rotary calcination process for treating high-level radioactive wastes. Operation of the plant during the extended run was considered satisfactory in most respects. However, the need for further improvement of the rotary seal design to eliminate excessive wear between the rollers and the supporting face of the nonrotating disc is evident.

APPLIED RADIATION

The program of the Radiation Division includes studies of the mechanisms of chemical reactions initiated by radiation (Radiation Research Section), studies of selected radiation-induced chemical processes (Radiation Processing Section), and the development and characterization of large-scale radiation sources (Radiation Engineering Section).

Radiation Chemistry Research

Radiation Effects in Organic Solids. Oxygen can enter and diffuse through the layer structure of pure propionamide and solid solution of propionamide-acrylamide over the composition range from zero to 40% acrylamide. This effect is demonstrated by the ability of oxygen to quench radiation-produced radicals in these crystals, as shown by electron spin resonance (ESR) measurements, and by the concurrent decrease in postirradiation polymer yield. Above 40% acrylamide concentration, both effects become small.

The yield of radiolytic hydrogen from solid solutions of propionamide-acrylamide as a function of composition and at two temperatures is shown in Figure 13. The difference in yield at the two temperatures is ascribed to the fact that, at the doses employed, no polymerization occurs at dry ice temperature, whereas practically all of the polymerizable monomer has reacted at the higher temperature. Therefore the room-temperature radiolyses were essentially performed on the system propionamide-polyacrylamide. The polymer has a higher G value for hydrogen formation than the monomer. The nonlinearity of the room-temperature hydrogen curve can be explained in terms of energy transfer from both the propionamide and polyacrylamide to residual monomer.

Radiation Chemistry of Aromatics. Iodine is capable of scavenging part of the methane produced in the radiolysis of *p*-xylene, but none of the hydrogen. Both the hydrogen yield and the non-scavengeable portion of the methane yield are temperature independent between 20° and 110°C.

Figure 13. Hydrogen yield as a function of composition of solid solution of propionamide-acrylamide.

Table 6

G Values of Major Gaseous Products Formed in the Gamma Irradiation of Toluene

	39°C	100°C
G_{total}	0.15	0.17
G_{H_2}	0.14	0.16
G_{CH_4}	0.010	0.015
$G_{\text{C}_2\text{H}_2}$	0.002	0.003

Radiation-induced isomerization of *p*-xylene is negligible. The formation of high molecular weight products from the three isomeric xylenes is independent of dose rate in the liquid state and is greatly reduced in the solid state. These results are qualitatively consistent with a mechanism involving free radicals and excited molecules.

The G values for the major gaseous products obtained from toluene at 39° and 110°C over the dose range 1 to 50×10^6 rads are given in Table 6. Preliminary results indicate that the temperature coefficients for total gas, methane, and hydrogen formation are of the order of 1 kcal or less.

The following dimeric products formed during toluene radiolysis have been definitely identified: bibenzyl; diphenylmethane; 4-methyldiphenylmethane; biphenyl; 2,2-, 3,3-, and 4,4-dimethylbiphenyl; and a mixture of benzyldiphenyls. A number of dimeric products are still unidentified. No evidence was obtained for the presence of any of the terphenyls, bicyclohexyl, or phenylcyclohexane.

Polymerization Mechanisms. The conductivities of several polynuclear aromatic salts with sodium in tetrahydrofuran have been measured. Sodium fluorene exhibits measurable dielectric loss at concentrations as low as 10^{-6} M , but these solutions are not stable on standing. Sodium anthracene forms reasonably stable solutions, but there is some question as to the correlation of the optical and ESR spectra of this anion as a function of concentration.

The radiation-induced polymerization of α -methylstyrene has been reported here previously to be highly sensitive to traces of moisture. A re-study of the radiation polymerization of styrene indicates that this monomer is also sensitive to traces of water. The highest rate of polymerization of this monomer so far achieved (at room temperature and 250,000 rads/hr) is 24% per megarad, compared to the rate of 2% per megarad previ-

ously reported by various workers. Molecular weight determinations indicate a change in the rate of initiation with drying and not merely an efficient chain transfer mechanism involving water.

High-Temperature Physical Properties Measurement. X-ray diffraction measurements on thoria have now been extended to 2800°C. Re metal has been examined to 3000°C; the work on Pt has been extended to 1750°C; and V has been examined to 1750°C. No first-order phase transition has been found in this temperature range. Such a transition was suggested by Seybolt and Sumison, [*Trans. AIME* 197, 292 (1953)].

The data are not accurate enough at present to rule out the possibility of a second-order transition. The coefficients of expansion of these materials will soon be published.

Considerable interest has been evidenced lately in the possibility of using borides as refractory materials in many applications. Some rare-earth borides have been prepared and examined at room temperature by x-ray diffraction as a preliminary to high-temperature work and to help elucidate the crystal chemistry of these materials. Terbium and ytterbium dodecaborides have been prepared by arc-melting the pure elements in stoichiometric proportion. These could not be prepared from the oxides. Erbium, holmium, dysprosium, and gadolinium diborides have also been prepared by arc-melting the pure elements. These apparently have a hexagonal unit cell and are probably of the AlB_2 -type structure.

Some U-Pd alloys have been prepared and examined by x-ray diffraction at room temperature. This also is a preliminary to high-temperature work. These alloys are being considered for possible use in chemonuclear reactors.

Isotope Development

The following is a partial list of accomplishments in the development of ways of making available potentially useful isotopes.

Strontium-87m Generator. A generator from which Sr^{87m} can be readily milked from its Y^{87} parent has been developed. A novel method was developed for making superior RbCl targets, used in preparing Y^{87} . Experiments are under way to verify calculated excitation functions for the Y^{87} -producing reaction.

High Specific Activity Magnesium-28. Several systems using formation recoil to separate Mg^{28} , formed by (t, p) reaction, from stable Mg were

studied. Contrary to early results, mixtures of fluorides of Li and Mg were shown to produce Mg^{28} when irradiated with neutrons and thus to behave like the metallic alloy or mixtures of other salts of these two elements. No evidence was found for a double fluoride of Mg and Li. Other experiments showed the impracticality of the $Si(n, x)$ reactions for producing carrier-free Mg^{28} routinely. The half-life of Mg^{28} was found to be 20.88 ± 0.06 hr.

Other Triton-Induced Reactions. No evidence for the (t, p) or (t, n) reactions on Ba^{138} or the $Mg^{24}(t, n)Al^{26}$ reaction was found. Attention has been turned to the $Si^{30}(t, n)P^{32}$ reaction and to reactions leading to the formation of Ar^{42} .

Computer Applications. Studies of the possibility of utilizing an IBM 7090 computer to analyze decay curves and to resolve complex gamma spectra are progressing. The latter problem involves describing simple spectra by unique polynomials and complex spectra by the sums of such polynomials; difficulties encountered are believed to be due to errors introduced by rounding off, with the loss of many significant figures, and should be eliminated by a new program under examination. (Attempts are also being made to simplify complex gamma spectra and render them more susceptible to analysis by using two different detectors chosen so as to permit electronic subtraction of the Compton part of the spectrum.)

Arsenic-72 Generator. The chemistry of Se is being studied preparatory to developing a generator from which As^{72} can be milked from the Se^{72} parent. Formation and hydrolysis constants of $SeCN^-$ have been measured, and work is in progress on the extraction chemistry and chromatographic behavior of the complex between Se and *o*-phenylenediamine.

Iron-52. The $Cr^{50}(\alpha, 2n)Fe^{52}$ reaction will be used with enriched Cr^{50} to prepare high-purity Fe^{52} by means of a chemical separation process whose development is nearly complete.

Cesium-132. The $I^{127}(\alpha, 2n)Cs^{129}$ reaction has been used to establish successfully conditions for producing carrier-free Cs^{132} via the reaction $I^{129}(\alpha, n)Cs^{132}$. Cs^{132} is of interest for calibrating whole-body counters used subsequently for detecting Cs^{137} .

$V^{51}(n, \alpha)Sc^{47}$ Reaction. From a study of the decay of Sc^{48} an upper limit of 0.3 mb was calculated for the cross section of this reaction.

Alpha Bombardment of Calcium. Alpha bombardment of natural Ca can lead to four products,

the formation reactions for any one of which would be of interest: Ca^{47} , Ca^{50} , Ti^{42} , and Ti^{44} . Experiments to observe them are under way.

Tagging Protein With I^{124} . It has been demonstrated beyond doubt that usefully large activities of I^{124} can be bound to cancer-free gamma globulin reproducibly and in high yield.

Reactor Neutron Cross Sections. Preliminary measurements of cross sections for reactor neutrons in a specific experimental hole in the BGRR have established a relationship that can be used for estimating other (n, α) and (n, p) reaction cross sections.

Half-Life of Aluminum-28. The half-life of Al^{28} has been redetermined to be 2.238 ± 0.006 min.

Radiation Processing Research and Development

This program is concerned with investigations of the application of nuclear energy to the synthesis and production of industrial chemicals. The effort is divided into two main areas, radioisotope radiation processing studies and fission fragment chemonuclear studies.

The studies on the use of radioisotope radiation for the production of chemicals include (a) an in-

vestigation of the homopolymerization of ethylene by Co^{60} gamma radiation, (b) a survey program on the copolymerization of ethylene with a number of other monomers, (c) a survey program of a number of promising exothermic systems induced by Co^{60} gamma radiation, and (d) the development of the engineering principles involved in applied radiation chemistry processes.

The yield and rate of polymerization of ethylene in a Co^{60} gamma field were determined under a variety of pressure, temperature, and intensity conditions.

The polyethylene polymers produced throughout these experiments consisted of fine white powder with properties dependent on pressure and irradiation conditions. Generally, the polymers show intermediate density values of 0.93 to 0.94, have a high degree of crystallinity after annealing, and at lower total doses are not cross-linked. Further rate data and polymer characterization await an experimental study under constant pressure conditions in static and flowing systems.

An extensive series of exploratory experiments has been made on the random copolymerization of ethylene gas with a number of liquid and gaseous monomers by Co^{60} gamma radiation. This in-

Table 7
 Co^{60} Gamma Copolymerization of Ethylene

Run No.	Ethylene copolymer	Copolymer characteristics			
		Initial mole ratio, ethylene/comonomer	Final mole ratio, polyethylene/copolymer	Density, g/cc	Crystalline melting point, °C
1	Styrene	7.4	—	1.000	noncryst.
2	Divinylbenzene	21.2	—	—	—
3	Methyl methacrylate	17.5	3.6	0.956	125
4	Methyl acrylate	31.6	2.2	0.955	123–126.5
5	Vinyl acetate	5.5	7.1	0.963	105–106.5
6	Allyl acetate	6.5	93.2	0.939	122
7	Isobutylene	8.98	—	0.908	103–107.5
8	<i>trans</i> -2-Butene	8.2	—	0.954	103–107.5
9	<i>cis</i> -2-Butene	6.7	—	0.963	125–126
10	1-Butene	10.8	—	0.912	102
11	Isoprene	18.7	—	0.956	122
12	Propylene	5.5	—	0.910	95
13	Acrylonitrile	3.8	0.24	1.120	noncryst.
14	Chlorotrifluoroethylene	27.8	13.2	1.004	122
15	Vinyl chloride	7.3	1.3	—	noncryst.
16	Carbon monoxide	7.9	1.95	1.090	112.5
17	Vinyl pyrrolidone	14.4	27.7	1.008	120.5
18	Methyl vinyl ketone	10.9	51.7	0.942	125

vestigation is primarily directed toward the identification of the copolymers and homopolymers formed in a mixture of the monomers. Positive identification of a copolymer of ethylene with most of the monomers listed in Table 7 has been obtained. It has not yet been possible to establish identification of a copolymer of ethylene with butadiene or styrene.

Figure 14 shows the infrared spectra for a sample of radiation-produced polyethylene and for a copolymer of ethylene with CO. A definite change from the structure of the original homopolymer takes place when CO is included.

A survey program is under consideration on inducing exothermic reactions by Co^{60} radiation. It includes (a) partial oxidation reactions, e.g., ammonia oxidation for nitric acid and benzene oxidation for phenol production; (b) metal deposition reactions, e.g., from metal carbonyls and organometallic compounds; and (c) radiocatalytically induced reactions.

It is generally realized that the use of isotopic radiation sources awaits development of the appropriate technology and demonstration of its use in a chemical process system. For the purpose of developing this much-needed radiation engineering technology, a high-pressure gamma loop facility has been designed. The loop will consist of a stirred 12-in.-diam $\times$ 3½-ft-long reactor (see Figure 15) which will contain up to 30,000 curies of Co^{60} ,

a circulator, heat exchangers for temperature adjustment, and an analytical system. The loop is primarily designed to handle the polymerization of ethylene at pressures up to 10,000 psig, at a circulation rate of 1740 lb/hr. The facility, however, is designed to be versatile; equipment changes can be readily made to allow study of a variety of radiation-induced process systems.

The fission fragment studies include (a) an experimental program for the determination of the fission fragment energy deposition efficiency of various thin-sectioned fuel elements, and the evaluation of G values in static capsule tests for certain chemical reactions, such as the formation of NO_2 from N_2 and O_2 and CO from CO_2 ; (b) the development and fabrication of fission fragment sources and fuel elements; (c) the design and construction of a chemonuclear in-pile loop facility; and (d) the design and evaluation of various chemonuclear reactor and process concepts.

In the formation of NO_2 and N_2O from N_2 and O_2 using the fission sources, a G_{NO_2} value of 1.2 and a $G_{\text{N}_2\text{O}}$ value of ≈ 1.0 are the highest values obtained to date at ≈ 3 atm pressure. Attempts are being made to obtain G formation values as a function of pressure, temperature, and foil thickness.

In the development of chemonuclear source and fuel material attempts have been made to fabricate thin fuel elements having the required high-temperature oxidation resistance and mechanical stability. After some investigation an alloy consisting of a solid solution of U in Pd, containing up to 30 wt % U, has proved to be ductile enough to be rolled on a Sendzimir mill to thicknesses of $< 3 \mu$. Tests in an air stream at temperatures up to 1000°F and flow rates up to 30 ft/sec have indicated that a very thin oxide film is formed on the surface of the foil and the foil loses some of its ductility; however, the foil generally appeared quite stable. In-pile burnup tests are in progress to determine the effects of radiation damage on the strength of the material and on mass transport from the material. Various configurations of packed sections with spacing between foils equivalent to the range of the fission fragment are being aerodynamically tested in high-temperature, high-velocity air streams. A theoretical study is being initiated to determine the strength of material required to produce the most stable packed configuration under the flow conditions required. Both ordered and random arrays for a critical core loading are under consideration.

Figure 14. Infrared spectra for polyethylene and for ethylene-CO copolymer produced by Co^{60} gamma radiation.

Figure 15. High-pressure gamma loop experiment. Arrangement of reaction vessel with external source.

PLAN

SECTION-"B-B"

SECTION-"A-A"

A revised design and hazards report on the in-pile chemonuclear loop was completed and favorably reviewed by the Reactor and Critical Experiments Safety Committee. Design detailing of the in-pile section is nearing completion, and component purchasing has begun.

A Chemonuclear Workshop attended by 36 industrial, governmental, and university representatives was held at Brookhaven from October 29 to November 2, 1962. The entire status of the art was reviewed. A report on this meeting and program recommendations is in preparation.

Radiation Engineering

High Intensity Radiation Development Laboratory. The High Intensity Radiation Development Laboratory (HIRDL) is essentially complete. Installation and testing of the operational and safety equipment have been completed. Radiological testing of the integrity of the shielding of both cells, using 20,000 curies of Co^{60} , has been accomplished. The majority of HIRDL personnel have been familiarized with all operational and safety equipment.

Phase I of the encapsulation procedure for 600,000 curies of Co^{60} now on hand has commenced. This entails inspection and decontamination of Co^{60} sources which were received from the ETR.

The hazards report for the operation of HIRDL has been approved by the Laboratory Safety Committee and is being prepared for required distribution.

Continual checks of the water level in the canal complex indicated that the daily fall in level had suddenly increased from $\approx \frac{1}{8}$ in. to 8 in. An investigation showed that the leak was not in the plumbing but in the walls or floor of the canal. This problem will be corrected by the installation of a stainless steel liner.

The shielding properties of the air-duct entranceways to the irradiation cell have been tested and found to conform to design specifications.

Twenty-four BNL standard flat sources containing 2440 curies of Co^{60} have been leak-tested and shipped to Mission, Texas, to be used by the U.S. Department of Agriculture in its screwworm fly irradiation program.

The BNL standard strip source designed for irradiation at the Savannah River Plant has been approved by the Savannah River Operations Office of the AEC. Forty-two slugs, each contain-

ing four strips, were shipped to Aiken, S.C., and are now in one of the SRP reactors.

Finite Buildup Factors From Point Sources in Finite and Semi-Infinite Homogeneous Media.

Progress has been made on the experimental determination of buildup factors for point sources in finite and semi-infinite homogeneous media. Experimental measurements have been made in infinite and semi-infinite media along an axis perpendicular to the plane of the air-water interface and at 30° and 60° to this vertical axis. Experiments thus far indicate a 10% change in the infinite buildup factor at the air-water interface in a semi-infinite medium at ≈ 6 mean free paths from the point source. Data are now being interpreted for points up to within a fraction of a mean free path of the source.

A computer program, based upon the Monte Carlo calculational method, has been written for the determination of finite buildup factors in cylindrical, homogeneous targets. A similar program is in progress for finite buildup factors in rectangular targets.

Gamma Spectrum Analysis. Refinements in the computer program for the response matrix involved in the development of an unfolding method of spectrum analysis of gamma spectra in an absorbing medium are still under way.

Measurements have been made of the degraded gamma-ray spectrum from a Co^{60} source in three segments of a large U-shaped air duct in a concrete shield with two 90° turns. Unfolding of the spectrum is in progress at present.

Solar Cell Dosimeter. Two additional reports concerning solar cell dosimeters are nearing completion. These final reports incorporate all the latest information and results obtained from the studies at Brookhaven of the n-on-p solar cell dose rate meter and the p-on-n solar cell integrating dosimeter.

Electrical Discharge in Shielding Glass. A number of bulk shielding glass samples have been irradiated at a dose rate of 5×10^5 rads/hr to total doses of up to 10^8 rads.

These preliminary experiments indicate some correlation between the Ce content of the shielding glass and the total dose at which controlled discharge will occur. Glasses with the highest Ce content seem to discharge more readily and at lower total doses than those with low Ce content.

Shipboard Fish Irradiator and Grain Irradiator Studies. The Vitro Corporation has been selected to work with BNL on feasibility and conceptual

design studies for a fish irradiator to be installed on an experimental trawler for the U.S. Bureau of Fisheries and for a bulk grain irradiator. These conceptual designs are nearing completion.

Co⁶⁰ Fluid Irradiator for Medical Research. A fluid irradiator was designed and fabricated for

the BNL Medical Department for use in extracorporeal blood irradiations. A 1100-curie Co⁶⁰ source was installed, and dosimetry checks were made. The unit was reviewed by the Laboratory Safety Committee and turned over to the Medical Department for immediate use.

Applied Mathematics

As is to be expected, the work of the Applied Mathematics Department* of Brookhaven National Laboratory encompasses a broad spectrum. It ranges from research in such areas as differential and integral equations, pattern recognition, and computer design to the straightforward preparation and maintenance of computer programs for various purposes. These projects are often carried out in collaboration with members of other Laboratory groups whose work in the natural and life sciences requires the use of computers to process and analyze experimental data or to solve real physical problems. The Department is charged with the administration and operation of a complex of digital computers for the use of the Laboratory as a whole. Instrumentation Division personnel are also involved in this effort.

COMPUTER FACILITY, SYSTEMS, AND UTILITY PROGRAMS

Because of the continuing increase in demands on the computing facility, a number of additions and improvements have been made during the past year. To meet increased printing requirements, a second 1401 computer was installed early in the year. During the third quarter, the 7090 was converted to a 7094. At the same time the magnetic tape system was modified to increase input-output speed. During the last quarter, a CDC 924 was added to the installation. The latter is a medium-scale, general-purpose, binary computer which will relieve some of the load on the 1401's and perform various scientific calculations and data acquisition problems to which a smaller machine is better suited. In February a small CALCOMP plotter was installed to assist in the onerous task of preparing graphs of results produced by the computers.

The 7094, together with the indicated peripheral equipment, is now operating on a 3-shift basis, 5 days a week. It is expected that early next year 7-day operation will be necessary. The following

tabulation indicates the increase in usage over the past year on the 7094 itself.

Quarter	1st	2nd	3rd	4th
Hr/quarter	670	770	860	970

In interpreting these figures two facts should be noted. First, the figures represent hours the machine is actually in use on research problems. They do not include time for maintaining the machine, for putting on new problems (replacing reels of tape, etc.), for making modifications to the monitor system which automatically operates the machine, or for training personnel. These operations account for >300 hr/quarter. Consequently, only a small increase in utilization can be obtained from the present 5-day/week operation. Second, the increase in usage is actually greater than the above figures indicate because the modification of the machine raised its efficiency by $\approx 50\%$, so that in terms of actual work the volume during the last quarter was about twice that during the first.

Figures for the Merlin computer, which is used for various special problems, are more irregular, particularly as it was used full time for several months for "on-line" monitoring of an experiment with the AGS.

Although manufacturers of large-scale digital computers usually supply programmed monitor systems to operate the machines, most computer installations, especially in such scientific laboratories as Brookhaven, find that these monitor systems do not meet their special needs. In consequence, a part of the effort of the staff of the Applied Mathematics Department is expended in modifying and improving these systems to meet the special requirements of research workers in the Laboratory. In particular, at the time of the conversion of the 7090 to a 7094, substantial changes were incorporated in the 7094 monitor system. These included extensions to the FORTRAN language.

The orderly development of a useful, well-documented subroutine library, whose scope covers the requirements of a large class of problems, is a continuing effort of members of the Department. Only two examples will be mentioned here.

*Effective July 1, 1963, the Applied Mathematics Division became the Applied Mathematics Department.

The speed of double precision operation on the 7094 is so much greater than on the 7090 that many hitherto expensive calculations are now easily within reach. The previously reported work on matrix routines is being revised to take advantage of this increased computing power. A number of problems, almost intractable with standard numerical formulations, yield readily to a Monte Carlo formulation. The Monte Carlo method is a statistical simulation or model of the physical process of interest. The calculation involves the collection of random samples from this simulation of the process and statistical analysis of the sample population. Of course many refinements are introduced to increase the efficiency of the sampling procedure. Since the sample sizes are usually large and only their average properties are used, there is no need for high precision in subcalculations. A set of subroutines for the common special functions has been prepared which systematically sacrifices precision in the interest of greater speed.

RESEARCH AND PROGRAMS DEVELOPED IN COLLABORATION WITH OTHER GROUPS IN THE LABORATORY

Members of the staff of the Department have continued to work with the Solid State Group of the Physics Department in the study of radiation damage in crystals. A number of improvements have been introduced into this set of programs, and a detailed report on their current status and capability will appear in the near future.

The design of the spark-chamber film reader, mentioned in last year's report, was completed early in the fiscal year. Construction is now virtually complete, and a number of tests have been run with satisfactory results. This work was carried out by the engineering staff of the Department in collaboration with members of the Physics Department and the Instrumentation Division. The output of the device is on magnetic tape. In parallel with the engineering work, an extensive set of 7094 programs for the processing of the data has been written and checked out as far as possible with mocked-up input. The entire system is expected to be in operation about the middle of next year. The close working arrangements between the engineers and the analysts have had mutually beneficial effects.

Members of the staff, in collaboration with members of the Bubble Chamber Group of the

Physics Department, as well as with staff members of the Lawrence Radiation Laboratory in Berkeley, have continued to work on various necessary modifications and additions to the spatial reconstruction and kinematic fitting programs to be used in connection with the on-line flying-spot digitizers under construction at the Laboratory.

The work begun last year, in collaboration with physicists from other institutions, to provide programs for calculating the production cross sections for W particles from photon and neutrino collisions with nucleons, is completed and extensive calculations have been made.

The Instrumentation Division has built for the Medical Department a device consisting of 32 coincidence counters arranged on a circle for the purpose of measuring the intensity of radiation between any 2 counters. The application of the device is related to the fact that some radioactive materials injected into the bloodstream of a patient will be absorbed more rapidly by certain tumors than by normal tissue. It has been observed by a member of the Department that in idealized form this problem reduces to that of finding a function on a disc when the function's integral over all chords is known. A classical theorem gives this function as the solution of an integral equation which can be transformed into Poisson's equation. Study is now under way to determine to what extent this mathematical theory can be applied to the solution of the real practical problem. This, of course, involves careful consideration of such matters as signal-to-noise ratio, scattering, and the finite apertures of the counters.

All the projects briefly described above are of considerable duration. Short-term projects of varying degrees of complexity arise continually and are too numerous to mention. Members of the Department consult frequently and informally with research workers from the wide variety of fields encompassed by the program of the Laboratory. In addition, members of the staff of the Department, at intervals, give courses on computer programming for others in the Laboratory.

APPLIED MATHEMATICS RESEARCH

Although the work briefly discussed below has involved virtually exclusively members of the staff of the Department, its direction in a number of instances has been motivated, at least in part, by considerations of the requirements, both long-

range and short-range, of the Laboratory as a whole. More generally, the work is always directed toward those areas of mathematics that impinge on the other scientific disciplines. Work has been done during the year in the areas of theoretical physics, integral equations, partial differential equations, computer-programmed pattern recognition for bubble-chamber film, and new concepts in the design of computers.

Theoretical Physics

A soluble model of quantum field theory in which a four-point coupling is appended to the original Lee interaction has been studied. In this model two particles are obtained with quantum numbers appropriate to a V particle. One of the two particle states is identified as a physical V particle, while the other may be identified either as a bound or an unstable N -theta particle system. The presence of these two eigenstates gives rise to a zero in the N -theta scattering amplitude, and it is shown that knowledge of the location of the zero may be exploited for the solution of the corresponding dispersion relation.

The studies on the feasibility of doing a complete Feynman diagram calculation on computers have been reduced to a more systematic study of the graph-theoretical properties of Feynman diagrams. The study in the main consists of two parts. The first is the generation of algorithms for the treatment of graphs in a computer. These consist, for example, of (a) generation of all trees of a given graph, and (b) generation of all cut-sets of two trees of an arbitrary graph. It has been found that for a given graph which consists either of Hamiltonian circuits or of subgraphs whose removal results in a graph with a Hamiltonian circuit, a unique algorithm exists for the generation of all cut-sets of two trees. The second part of the study is concerned with the investigation of several pertinent problems in graph theory proper. This work is in progress.

The exact solution of the Bethe-Salpeter equation for a scalar-scalar system in the general mass case has been found and discussed.

Integral and Differential Equations

Research involving integral equations has been carried out in the field of the spectral theory of singular integral operators. This work has implications for perturbation theory, where a perturbing operator causes both a shift in location of the con-

tinuous spectrum and a change in multiplicity. Important examples of both phenomena occur in elementary particle physics and have so far defied rigorous mathematical analysis. More broadly, an obvious lacuna exists in the entire mathematical theory of such spectra. Accomplishments to date include the construction of a complete spectral representation for a reasonable class of singular integral operators, with the consequent possibility of analyzing in detail the spectral shifts and multiplicity changes caused by perturbations of this type.

In the field of differential equations, a considerable amount of work has been done on overdetermined boundary value problems, the overdetermination being mathematically compensated for by leaving unspecified coefficients in the differential equations themselves. Since these coefficients correspond to such physical quantities as diffusivity in conducting media, the work has various physical applications.

Programmed Pattern Recognition

This designation for the work to be described is perhaps too pretentious, since the objectives of the effort are deliberately limited to the analysis of bubble-chamber film by the use of general-purpose computers. However, the ideas and methods that have been developed in this connection have implications in a number of other areas. Such devices as the flying-spot digitizer being developed at Brookhaven simply pump into a computer in digital form all the information which is on a bubble-chamber film. A major portion of this is "noise" or is of no interest, and in the present mode of operation, therefore, the film has to be prescanned and the areas of interest on each set of photographs specified to the computer by means of a separate input. The desideratum is the automatization of this prescanning and the elimination of the secondary input. Purely economic questions are also involved. There must be some assurance that the computer programs will run sufficiently rapidly to keep the digitizing equipment busy. In consequence, considerable effort was devoted initially to such considerations, with ultimately affirmative results. The over-all process of this automatic scanning has been divided into two phases. The first consists in a program that provides a listing of individual track segments with descriptions of each in terms of appropriate parameters, together with a residue of those digitizations of

points that are not associated with tracks. The program provides detailed information at track ends for input into the second phase of the program, which is concerned with the organization of the data into provisional events by an identification of all vertices resulting from an identified physical process. The program must then reject various spurious vertices, separate those of secondary interest from the important ones, and finally re-examine the residue from the first phase for the existence of various short and/or sparse tracks. The first phase of this work is essentially complete, and work on the second phase is well along, although logical problems that are clearly nontrivial must still be faced.

Computer Design

This is a broad and complex field, evolving at an almost incredible rate both industrially and in work being done at universities and laboratories. A number of novel concepts in the field are currently being investigated, and one in particular is being studied in the Applied Mathematics Department. This is the idea of an associative memory, or, more precisely, a memory in which an individual location is addressable in terms of its con-

tent rather than its position or index number. A study of this type is needed because, although there is considerable literature on the implementation of associative memories, not much thought has been given to an integrated computer system that makes use of associative memories. At first sight, a computer whose main store consists only of associative memories would seem to be an extremely useful computational tool. Closer examination of the implications of such a computer, however, indicates that such an arrangement would make it necessary to abandon the more desirable features of current computers. It is now believed that what is required for a most efficient use of an associative memory is a hybrid computer that uses conventional as well as associative memories. The possible organizations of such computers are currently being investigated. In particular it has been observed that an appropriately organized machine of this type would simplify the multiprogramming problem by orders of magnitude.

In pursuing this study, the Department has been in close contact and collaboration with members of the staffs of the Los Alamos Scientific Laboratory, the Lawrence Radiation Laboratory, the University of Illinois, and the University of Chicago.

LIFE
SCIENCES

Biology

The activities of the Biology Department center on the special facilities of the Laboratory and include studies of the biological effects of radiation and the use of isotopes for the elucidation of basic problems in biology. In general, problems are being investigated by the methods of molecular biology. The growth of the Department has been increasingly in the direction of this approach to biology and has involved studies on protein structure, enzyme kinetics, the molecular structure and function of antibodies, the molecular structure of chromosomes and its relation to the mutation process, etc. These concepts and techniques have found immediate application in such pressing problems as the nature of radiation-induced mutations, the intimate nature of the mechanism of radiation damage in plants and animals, and the details of the basic reactions involved in photosynthesis.

Each year the Department sponsors a symposium on a topic of current interest in biology. This year the symposium, entitled *Meristems and Differentiation*, was attended by 250 scientists in addition to members of the Brookhaven laboratory staff and will be published as the 16th volume in the Brookhaven Symposia series.

This report briefly indicates major areas of research and some findings made during the year.

ANIMAL PHYSIOLOGY

Radiation-Induced Aging

Radiation causes a decrease in the life expectancy of animals which closely resembles the natural aging process. A study of both natural and radiation-induced aging is being undertaken to determine the causes of each. It has been postulated that aging results from the accumulation of viable mutations in the somatic cells of the body. This theory gains support from the fact that radiation both shortens the life-span and causes mutations. A quantitative evaluation of the theory requires a measure of the mutation frequency in somatic cells. Chromosome aberrations in liver cells have been assumed to be proportional to

these mutations. Aberrations have been found to increase linearly with age in normal animals and to reach surprisingly high values while the animals are relatively young. After a single dose of x rays the aberrations increase strikingly and are eliminated slowly over a period of months. When animals are subjected to chronic gamma irradiation the aberrations increase only slowly, and with equal doses this form of radiation is only about $\frac{1}{4}$ as effective in producing aberrations as is acute radiation. Acute neutron irradiation produces severe chromosome damage which does not decrease appreciably over a period of a year. Chronic neutron irradiation causes a rapid increase in aberrations and is just as effective as acute neutron irradiation. The development of aberrations with age in normal mice of both long-lived and short-lived strains has been measured, and the life expectancy has been found to be inversely proportional to the spontaneous mutation rate in somatic cells. In all cases so far investigated there has been a close correlation between chromosome aberra-

Figure 1. Relationship between the chromosome aberrations in liver cells of normal mice and the age of the animal. The data are for strains having quite different median life-spans, as indicated by the arrows. Two groups of mice of each strain were used, one group 8 weeks old and one ≈ 11 months old (old breeders) at the start. This experiment demonstrates that longevity may be determined by the stability of the genetic elements in the somatic cells.

tions and life expectancy. This adds strong support to the somatic mutation theory of aging. The mutation rate in somatic cells is enormously higher than in gametic cells, a circumstance that ensures the ultimate death of the individual and the survival of the species.

Delayed Effects of X Irradiation in the Brain of the Monkey

A continuing clinical, histochemical, and neuropathological study is being made of monkeys in which the right cerebral hemisphere was exposed to 3500 rads of x rays in a single or divided dose. Following a single dose, damage appeared in young monkeys after a latent period of ≈ 3 months and after about twice this period of time in older animals. Divided doses may not produce a neuropathological effect – one monkey is still alive some $2\frac{1}{2}$ years after irradiation. Lesions may occur at an early stage without the appearance of electroencephalographic changes or clinical signs of brain involvement.

Insulin and Carbohydrate Metabolism in Liver

It is readily shown that injected insulin increases glucose uptake by muscle and adipose tissue. In contrast, marked care is required to demonstrate a direct effect of insulin on glucose metabolism in the liver because insulin causes hypoglycemia which elicits counterregulatory factors that mask the effect of insulin in liver. However, when glucose is infused along with the insulin in such fashion that neither hyperglycemia nor hypoglycemia develops, the insulin infusion depresses the production of new glucose molecules by the liver almost completely. This effect of insulin was brought to light earlier by tagging the circulating glucose pool with uniformly labeled C^{14} -glucose and examining the diluting effect of C^{12} -glucose molecules released into the circulation by the liver. Recently it was found that incorporation of the C^{14} of circulating C^{14} -glucose into liver tissue and especially into liver glycogen is greatly increased during the insulin infusion (with matching glucose infusion). Percutaneous needle biopsy samples under local anesthesia furnished the liver tissue in which C^{14} incorporation was measured. When glucose-6- C^{14} was used the hexose units of the deposited C^{14} -liver glycogen were tagged only in the 6 position. Thus, the glucose molecules enter the liver directly from the blood under the influence

of insulin and are incorporated intact into liver glycogen. The rate of insulin infusion required to inhibit maximally the production of C^{12} -glucose by liver is also high enough to induce some extra incorporation of C^{14} -glucose from blood into liver glycogen. When insulin is infused at greater rates the C^{14} incorporation into liver glycogen is increased roughly in proportion and reaches a value 70 times the control rate when over-all glucose uptake by all tissues is increased ≈ 5 -fold. Since in liver insulin *reverses the direction of net flow* of glucose molecules, facilitation of glucose flow across the cell membrane, in both directions, as occurs in skeletal and heart muscle, cannot be the mechanism involved in the hepatic effect of insulin.

Effects of Radiation on Proliferative Cell Systems

Analysis of effects of radiation on proliferative cell systems such as intestinal mucosa has been carried from whole animal to cell and is now centered on the effects on DNA (deoxyribonucleic acid) synthesis in proliferating cells. Study of the synthesis primarily depends upon measurement of the incorporation of a radioactively labeled precursor into the DNA by means of autoradiography. It has been established that soon after irradiation with moderate doses the uptake of the radioactive tracer into DNA is sharply reduced in some, but not all, proliferative systems; where a reduction occurs it concerns all cells evenly. The problem is to establish the precise nature of this effect. The most obvious interpretation is that DNA synthesis is reduced, but the underlying cause might equally be a decrease in permeability of cells to the precursor, increase in availability of precursor arising from increase in production within the system or elsewhere, reduced stability of the DNA formed in irradiated cells, or increase in catabolic activity. Although experimental consideration of these possibilities is still in progress, it appears at present that the depression of labeled precursor uptake into DNA involves a combination of the factors.

Antibody Specificity

The fundamental problem involved in antibody specificity is whether the specificity, i.e., the ability of each antibody to react only with its particular antigen, results from genetic change or rearrangement of the peptide chains in normal gamma globulin. Genetic change requires that antibodies differ in amino acid content or sequence, while

rearrangement does not. To distinguish between these alternatives, the amino acid compositions of two rabbit antibodies were determined by use of methods that reduced experimental errors to $<1\%$. Although the amino acid compositions of the two antibodies were similar, small but significant differences were observed. The antibody directed against negatively charged phenylarsonic acid had the higher arginine and isoleucine content, while the antibody directed against positively charged phenyltrimethyl ammonium ion had the higher aspartic acid and leucine content. The differences are too large to be explained on the basis of impurities in the preparations, since measurements of binding capacity by equilibrium dialysis, of molecular weights, and of contamination during purification procedures showed the antibodies to be at least 99.5% pure. Furthermore, the differences in charged amino acid residues are those that might be expected to occur at the active sites, since an aspartic acid or glutamic acid residue is known to be present at the active center of the ammonium antibody and an arginyl residue has been implicated at the active center of the arsonic antibody. Finally, the possibility that the results reflect genetic differences in the antibody molecules unrelated to specificity was minimized when the same amino acid differences were found in antibodies isolated from single rabbits and shown to be identical in their genetic types. The findings support the hypothesis that synthesis of specific antibody is genetically controlled. Further testing using antibodies directed against uncharged moieties is under way.

GENETICS

Arginine Mutants in *Salmonella*

In analyzing genetic properties of arginine mutants of the bacterium *Salmonella typhimurium* it was observed that certain mutant strains gave wild-type variants in crosses with themselves. These mutants are called "selfers." Crossing was accomplished by the transduction method, in which transducing phage is used as a vector for carrying genetic material from one type of bacterium into another. The evidence indicated that the following explanations cannot account for the wild-type variants: contaminated phage, presence of wild-type transducing fragments in the phage, suppressor mutations, an unusual association be-

tween the transducing fragment and the bacterial chromosome, suppression of the growth of revertants on the control plates, or greater residual growth of bacteria on the experimental plates. Correlations have been observed between frequency of wild-type variants and phage multiplicity, number of bacteria, and ultraviolet irradiation of phage. These correlations also apply to transductants. Therefore it is probable that the appearance of wild-type colonies in selfing is in some way connected with the transduction process. Two possibilities are considered: (a) that these colonies are transductants, produced by unequal crossing-over involving adjacent bases of the DNA of a gene; or (b) that they originated through mutations because of an increase in mutability of a selfer gene in the presence of a transducing fragment. In favor of possibility (b) are recent findings that excess wild-type colonies appeared in crosses in which deletions covering a selfer were donors. Tests with 166 cysteine, arginine, tyrosine, and phenylalanine mutants show that $\approx 33\%$ are selfers.

Nuclear Protein Synthesis During Chromosome Replication

Treatment of root meristems of *Vicia faba* with 5-aminouracil (5AU), a structural analogue of thymine, results in partial synchrony of cell divisions. Normally $\approx 20\%$ of the cells are in dividing stages, but, after 18 hr of exposure to 5AU, divisions practically cease. Fifteen hours after removal of the tissue from the analogue, the frequency of cell divisions reaches a maximum of $\approx 80\%$. Autoradiographic studies with H^3 -thymidine and H^3 -cytidine, as well as double labeling with H^3 -thymidine and C^{14} -thymidine, clearly showed that cells enter DNA synthesis during 5AU treatment but that most of them fail to complete the process until the analogue is removed, whereupon a simultaneous resumption of synthesis results in synchrony. This technique for controlling mitotic divisions was used to accumulate large numbers of metaphase chromosomes in which the nuclear protein was labeled with H^3 -arginine. Autoradiographs of these chromosomes showed that almost 100% were labeled in the first division, whereas very few retained the label in second-division metaphases. This result strongly suggests that a major fraction of the nuclear protein leaves the chromosome or turns over during one DNA replication cycle.

Figure 2. Partial synchrony of cell division in the root meristem of *Vicia faba*. Left: Exposure of the root tip to 5-aminouracil for 18 hr arrests cell division, and the cells accumulate in interphase. Right: Some 15 hr after removal of the tissue from the uracil, >70% of the cells are in some stage of division.

Chromosome Aberrations and Reproductive Integrity

It has generally been considered that one of the primary causes of radiation-induced loss of reproductive integrity in both higher plant and animal cells is the loss of genetic information that occurs following induction of chromosome aberrations. Studies of the radiation response of single meristematic hair cells of *Tradescantia occidentalis* have allowed a critical re-examination of this relationship. Dose response curves for reproductive integrity after exposure to acute doses of x rays were remarkably similar to those obtained from a variety of mammalian cell lines, having a D_0 of 149 r and an extrapolation number of 1.6. Detailed observations were made of all forms of chromatid and chromosome aberrations induced after irradiating every stage of the mitotic cycle of these same cells with a range of doses of acute x rays. From comparisons of these two sets of data it was

apparent that even in diploid cells such as these a considerable amount of genetic loss could be tolerated, and that there was no simple relationship between chromosome aberrations and loss of reproductive integrity.

Fate of Transforming DNA

Study of the molecular fate of newly introduced transforming DNA in pneumococcus has continued. Earlier it was shown that entering DNA is converted about equally to small fragments and single strands. The latter material presumably contains the genetic information corresponding to an introduced marker, although it lacks the ability to transfer this information until converted to native DNA within the cell. Recent support for this hypothesis has been obtained from experiments on the recovery of the ability of the isolated single-strand material to transfer its genetic information after annealing *in vitro* with added non-

marker single strands. An increase in transforming ability of ≈ 100 -fold is observed. This is presumably due to the formation of double-stranded molecules, one strand carrying the marker, which can enter and transform the cell.

Amylomaltase Locus in *Pneumococcus*

Some progress has been made in a study of the amylomaltase locus in pneumococcus. Forty different mutations in this locus have been obtained following treatment of either cells or isolated transforming DNA with various mutagenic agents. Of these, 33 can recombine with each other to give the normal type and therefore appear to involve alterations at single sites, while 7 mutations appear to be multisite in that they fail to recombine with 2 or more mutant types which recombine with each other. From the pattern of overlapping of the multisite mutations it is possible to divide the locus into a linear array of segments into which the single sites fall unequivocally. Further study of the nature and mode of recombination of the mutants is in progress.

Cooperative Radiation Mutation Program

This long-range program is a cooperative project designed to use the facilities of Brookhaven

National Laboratory to irradiate seeds, cuttings, and whole plants in attempts to induce beneficial mutations. Plant breeders and cytogeneticists provide the plants and seed material and are responsible for the culturing of irradiated material and the screening for mutations. Approximately 300 scientists in 45 states and 25 foreign countries are participating in this program. G.A.L. Mehlquist of the University of Connecticut has released two new carnation varieties which may be available for commercial distribution next year. A.L. Andersen of Michigan State University reports a new variety of bean which is resistant to three known strains of common bean mosaic. The recent work of G.W. Burton and D.K. Ourecky of the Georgia Coastal Plain Experiment Station, Tifton, Ga., is concerned with the effects of recurrent irradiation and chemical mutagens on pearl millet (*Pennisetum glaucum*). They find that ethylmethane sulfonate (EMS) treatments delayed the emergence rate and reduced seedling growth more than thermal neutron treatments; the EMS treatments delayed heading 2 to 7 days, whereas thermal neutrons delayed heading only 2 to 3 days. Thermal neutrons produced about twice as many visible mutants in field-grown plants from treated seed as EMS treatments.

CELL PHYSIOLOGY

Nuclear Variables and Radiosensitivity in Plants

Continuing study of the manner in which nuclear variables control radiosensitivity in plants indicates even closer correlation between *interphase nuclear volume* divided by *somatic chromosome number* (interphase chromosome volume) and sensitivity (measured by acute lethal exposure) than that found earlier between nuclear volume and the sensitivity. Calculations of the energy absorption required for a lethal effect based on the data indicating correlation between lethal exposure and interphase volume give a roughly constant value of 3.6×10^6 ev per chromosome for each of the 16 species of herbaceous plants studied. This implies that the apparent differences in radiosensitivity in plants actually represent differences in radiation exposure required for absorption of a critical amount of energy per chromosome. Thus, the larger the interphase volume the less exposure is needed to produce a lethal effect. Preliminary

Figure 3. The relationship between interphase chromosome volume (nuclear volume/chromosome number) and acute lethal radiation dose (left) and that between the interphase volume and absorbed energy per chromosome (right) are indicated for 16 species. Note that the absorbed energy per chromosome for a lethal effect is about the same in all the species examined, in spite of wide ranges of lethal exposure (0.6 to 75 kr), nuclear volume (43 to 1758 μ^3), and somatic chromosome number (6 to 136).

findings in 13 species of woody plants also indicate a nearly constant energy absorption ($\approx 1.6 \times 10^6$ ev per interphase chromosome) for lethal exposure. It is not yet clear why the energy required for lethality in the woody plants is less than in the herbaceous plants.

Further examination of the role of length of mitotic cycle in determining the sensitivity of plants to chronic irradiation indicates that the important factor is the amount of energy absorbed by the nucleus during one mitotic cycle. For example, with daily exposure to 200 r per 20 hr, a cell with a 20-hr cycle will exhibit the effects of 200 r, while a cell with a 10-hr cycle will exhibit the effects of 100 r. The mitotic cycle time is correlated with the DNA per cell and nuclear volume.

Cytogenetic damage is a major factor in radiation-induced death and growth or yield reduction. Such damage is highly correlated with nuclear volume, interphase chromosome volume, DNA per chromosome, and mitotic cycle time. If either the cycle time, nuclear volume, or DNA per cell is known, the other two parameters can be estimated. Then, from the nuclear volume and chro-

mosome number, the sensitivity of a given plant species can be estimated. Prediction of approximate radiosensitivities from limited information of the kind considered has proved useful, and as knowledge of the interaction of the variables is refined such prediction will be an even more valuable tool.

Kinetics of Cell Populations

Appropriately timed and ordered administration of C^{14} -thymidine and H^3 -thymidine to growing cell populations, combined with subsequent autoradiographic detection of the radioactive label and thus of the thymidine incorporated into DNA, provides a relatively simple procedure for kinetic study of such populations. The procedure estimates the duration of the various phases of the cell cycle. The duration of each phase is fairly constant in a given cell population under well-controlled conditions. For *Tradescantia* root tips the method indicates that relatively large doses of x rays (≈ 1000 rads) have little effect on the duration of DNA synthesis, whereas comparatively modest doses extend the period between the syn-

Figure 4. Replication of chromosomal DNA during meiosis in *Triturus* testes. The animal was given tritium-labeled thymidine several days prior to examination of the chromosomes. The thymidine is incorporated into the newly formed DNA of the chromosome and is detected by autoradiography. Left: Eleven pairs of chromosomes from a cell in metaphase I are seen. The arrows indicate homologous chromosomes that are unequally labeled with the tritium. Right: The chromosomal material from a cell in prophase exhibits localized labeling.

thesis and cell division. Further, very small doses of x rays (≈ 1 rad) or 1 to 8 disintegrations of tritium markedly prolong the time between cell division and initiation of DNA synthesis. The radiation dose required to produce prolongation of the pre-DNA synthesis period is remarkably less than that required to affect other biological parameters. This suggests need for additional caution before dismissing possible radiation effects of presumed tracer amounts of radioisotopes.

Chromosome Duplication

Comparison of DNA replication on homologous meiotic chromosomes of *Triturus* testes has been made by means of suitable labeling of the chromosomes with a radioactive precursor of DNA and autoradiographic detection of label associated with the chromosomes. It appears that DNA synthesis on homologous chromosomes does not proceed in synchrony. This is in contrast to earlier presumption. In most dividing cells DNA synthesis is confined to a discrete portion of interphase. In the *Triturus* cells, although most of the synthesis is similarly confined, DNA formation does occur at a slow rate during a portion of the long meiotic

prophase. This continued synthesis may have bearing on the genetic phenomenon of crossing-over.

Chromosomes in *Amphiuma*

Amphiuma tridactylum, a three-toed salamander native to the Gulf coast, has exceptionally large chromosomes, of such range in size and shape that each can be individually recognized. Since leukocytes and cells from several organs of the adult animal grow in sterile culture, many cells can be obtained showing these large chromosomes at cell division. Study of such cells clearly indicates the diploid chromosome number to be 28 (man has 46) and not 24 as presumed from earlier work. *Amphiuma* chromosomes are particularly suitable for direct assessment of effects of radiation and chemicals and for study of chromosome action and duplication.

Adapter Ribonucleic Acid

Adapter ribonucleic acid (RNA) is the carrier of amino acids to the template for protein synthesis. Part of its function is to arrange the amino acids in a specific order prior to peptide synthesis. Each adapter combines with one, and only one,

Figure 5. *Amphiuma* chromosomes. At the left is a culture of leukocytes. The chromosomes can be seen in the dividing cell at the center. At the right the 14 pairs of chromosomes from a dividing cell are arranged according to size. The smallest is appreciably larger than the largest human chromosome.

amino acid; and each is presumed to have a trinucleotide sequence which hydrogen-bonds to a complementary site on the messenger RNA template. Physicochemical measurements indicate that adapter RNA is a single polynucleotide chain ≈ 67 nucleotides long. It has been proposed that this chain has a bend near the middle, with the two halves of the chain interacting in double helical fashion. A more recent and detailed model suggests that the only nucleotides not in double helix configuration are the three in the bend and the two on the nucleoside end that combines with the amino acid. Such a configuration would ideally serve the function of adapter RNA in protein synthesis. To test this postulated structure it would be useful to have a chemical method of isotopically labeling those nucleotides not in double helix configuration.

Some exploratory work bearing on the possibility of such labeling has been carried out. Formaldehyde forms a Schiff base with the amino groups of adenine, guanine, and cytosine. However, while the purines and the pyrimidine are constituents of both kinds of nucleic acid, it is known that most RNA's react with formaldehyde but that DNA, under the same conditions, does not. The inactivity of the bases in DNA is believed to be caused by steric hindrance imposed by the native double helical configuration of the nucleic acid. Most forms of RNA also show double helical character, but of limited stability. Hence RNA reacts with formaldehyde, although at a slower rate than monomeric nucleotides. Conceivably, conditions might be found that would stabilize the helical regions of RNA and make them unreactive to formaldehyde. To this end the reaction of nucleotides and nucleic acids with 2% formaldehyde was measured at 10° in 0.1 *M* potassium phosphate, *pH* 7.4, containing 0.01 *M* MgCl_2 . Reaction was measured by increase in light absorbance at 260 $\text{m}\mu$. Under the test conditions

Figure 6. Proposed structure for adapter RNA. A single polynucleotide chain interacts with itself by forming a bend near the middle. Hydrogen-bonding between nucleotides in the two halves of the chain results in a double helix configuration. Three bases at the bend are of necessity unpaired. Guanine from one end of the chain forms a Watson-Crick base pair with the cytosine third from the other end. Two nucleotides on the end bearing the amino acid are flexible. The molecule is ≈ 100 Å long by 20 Å wide.

Figure 7. Apical meristem of a fern. Removal of the apical cell (top, center) by mechanical dissection is thought to stop formation of new leaf primordia but not to affect development of existing primordia. For further study of the relationship between the apical and other meristematic cells the deuteron microbeam is being tested as a means of selectively removing cells.

5'-mononucleotides react rapidly, DNA not at all, and 5-RNA only slightly. Without Mg^{++} and/or at higher temperatures 5-RNA reacts at appreciable rates. The results are taken to mean stabilization of adapter RNA in 0.01 M $MgCl_2$ at 10° and steric hindrance of reaction with formaldehyde. Nucleotides not in the helical configuration should, however, be reactive. Although the lability of the Schiff base precludes direct use of labeled formaldehyde for detection of exposed nucleotides, it has been found that these bases may be stabilized by reduction to N-methylnucleotides.

Morphogenesis in Plants

Meristems are bodies of plant cells from which new cells, tissues, and organs develop. A particularly outstanding morphogenetic change involving these bodies is the transition of the shoot meristem from the vegetative to the reproductive state; i.e., the meristem changes from one that produces leaves to one that forms floral primordia. As a preliminary to detailed study of events and

processes involved in such change, the development of the shoot meristem in *Arabidopsis thaliana* from time of sowing seed to the stage of floral transition has been established for two conditions of growth. The transition takes 9 days under continuous and 18 days under 12-hr light. Shoot meristems in lower vascular plants, e.g., ferns, are also of special interest, since many possess a dominant apical cell or group of cells. It is stated that when this cell or group is destroyed the shoot meristem loses its continuing morphogenetic potential and ultimately ceases to develop. For study of the relationship between the activity of the apical cell(s) and the morphogenetic activities of the meristem as a whole mechanical microdissection has been used. However, refinement of this technique is desirable, and to this end the deuteron microbeam is now being used. Preliminary work involving the effective levels of dose and target areas is under way. When completed, the relationship between apical cell(s) and meristems as a whole will be examined.

Role of Respiratory Metabolism in the Formation of Chloroplasts

Chloroplasts are often considered to be relatively independent organelles whose chief function is to provide carbon and energy for cellular metabolism. Many normally photosynthetic cells grow perfectly well under conditions such that the formation of the chloroplasts is selectively inhibited, provided that suitable growth substrates are supplied. Since chloroplasts contain RNA and perhaps even some DNA, the degree to which chloroplasts develop and function independently of the remainder of the cell has been the subject of much speculation. As part of a study of the biochemistry of chloroplast development, the extent to which the remainder of the cell participates in this development has been analyzed. The green alga *Euglena* was used for this study. During greening it was found that a first effect of light is to promote, surprisingly enough, not the synthesis of chloroplast protein, but rather the synthesis of respiratory proteins, especially enzymes of the hexose monophosphate shunt. As the peak in this synthesis is reached there is a rapid depletion of storage carbohydrate (a 1,3- β -glucan). Apparently the resources of the cell are first marshalled to provide carbon and energy for the synthesis of chloroplast protein. Following this initial period there begins a rapid synthesis of chloroplast protein and a decrease in the respiratory proteins. The latter are presumably broken down to provide amino acids for the synthesis of chloroplast proteins, since there is little change in the protein per cell during greening. These and other analyses indicate a massive involvement of the cell as a whole in the development of a photosynthetic metabolism.

Plant Physiology: Photoperiodism and Development

Photoperiodic control of flowering in axenically cultured *Lemna* is being established under conditions such that no chlorophyll develops, in order to permit assays of the concentration and state of the photoreceptor (phytochrome) during various portions of photoperiodic cycles. The preliminary work required has led to the observation of a new photoperiodic phenomenon. In *L. perpusilla*, a short-day plant, extended dark interruptions of the main light period cause an increase in the critical dark period required for flowering. This

result can be interpreted, on the basis of some observations on a different system reported by the Beltsville group, as due to an increased concentration of phytochrome brought about by the extended dark interruption. The control of phytochrome concentration by phytochrome may provide the basis for a general theory of photoperiodic timing, when the projected *in vivo* assays can be made.

Two other experimental systems are being used to study the actions of the photoperiodically effective red and far-red radiations. The red-sensitive and red-insensitive elongations brought about by various substrates in excised stem segments of *Pisum* seedlings are being further characterized in histological and metabolic terms and with respect to sensitivity to ionizing radiation. Tissue cultures of biennial *Hyoscyamus niger*, a plant in which flowering is photoperiodically sensitive only after vernalization (cold treatment), are being employed in efforts to determine whether this vernalized state can be acquired, maintained, or modified in a system more susceptible of analysis than the intact plant.

BIOCHEMISTRY

Protein Structure

Certain features of the structural configuration of a protein molecule in solution may profitably be explored by studying the consequences of modification of the molecule by chemical or enzymic reagents. In a few instances modified proteins have been found to occur in nature. One of the best known of these is ribonuclease B (RNase B), which accompanies the more prevalent enzyme ribonuclease A (RNase A) in the pancreatic secretion of cattle. RNase B was isolated here for the first time last year and was shown to have an overall amino acid composition identical to that of RNase A, but to possess in addition a carbohydrate moiety composed of five residues of mannose and two of glucosamine. The relationship of the carbohydrate content to the protein has now been elucidated. In view of the ease with which the carbohydrate may be removed from ribonuclease B, a special approach had to be taken in dealing with the problem of degrading the protein without affecting the oligosaccharide side chains. Like RNase A, the B enzyme contains four

disulfide bonds. These were cleaved by reduction in a denaturing solvent, and the thiol groups exposed were specifically and quantitatively alkylated with acrylonitrile to afford reduced, cyanoethylated RNase B in high yield. The reduced, alkylated protein was hydrolyzed cleanly with trypsin to afford 15 principal peptides, all except one of which were identified with peptides derived from RNase A subjected to a similar series of reactions. The single peptide that differed contained the carbohydrate originally present in RNase B and was therefore a glycopeptide. It was isolated with the aid of molecular sieve chromatography over cross-linked dextran gel as a first step. The peptide was that known to be derived from residues 34 through 37 in the amino acid sequence of ribonuclease. The relatively large carbohydrate side chain attached in the region of residues 34 to 36 does not affect directly the structural configuration of the active site of ribonuclease, for both RNase A and RNase B do not differ in specific activity or specificity of action. Since other work has shown that the region around residue 33 is relatively readily accessible from the solution environment, it is very likely that the carbohydrate in RNase B is attached to the surface of the molecule.

Amino Acids at the Active Site of Chymotrypsin

Understanding of the mechanism of the amazing catalytic action of enzymes would be of key importance in chemistry as well as biology. Thus, continuing attempts are being made to unravel the relation between the structure and function of these proteins. Emphasis has been upon chymotrypsin, since its amino acid sequence has been largely determined and therefore modification of specific amino acids can be correlated with their position in the protein. Photooxidation revealed earlier that activity is lost when a single histidine in the B-chain of the protein is oxidized and that fractional loss of activity occurs when methionine residues are oxidized. To demonstrate the positions of the methionines, peroxide oxidation, iodoacetate alkylation, and photooxidation have been employed. It was found that one methionine residue in native chymotrypsin is reactive while the other is not. The reactive residue is separated by two residues from the serine known to be involved in enzymic action. The other methionine is separated from the serine by 14 residues and must be

in the interior of the protein, since when the protein is unfolded the otherwise unreactive methionine is oxidized.

The position of the exposed methionine in the amino acid sequence and the protection against irradiation afforded by substrate both place the methionine near the serine. Despite this close geometric approximation and the conversion of the methionine by oxidation from an oily to a polar residue, the amino acid is associated with but 60% of the enzymic activity. In other words, chymotrypsin bearing an oxidized methionine has 40% of the native activity. Thus, methionine is not essential for enzyme action. The buried methionine also can be oxidized without complete loss of activity. This methionine appears to be concerned with the velocity of catalysis, while the surface methionine involves binding of substrate. The elimination of both methionines as essential elements in catalysis by chymotrypsin places additional emphasis on the histidine residue. Consideration of models indicates that histidine on the protein must be in an environment substantially different from ordinary solution in order to be effective in catalysis.

Subcellular Enzymology

The zymogen granule fraction isolated from homogenized pancreas by differential centrifugation appears to be qualitatively and quantitatively identical in protein composition to pancreatic juice obtained by direct cannulation of the pancreatic duct. The zymogens (inactive enzymes) studied – trypsinogen, chymotrypsinogens A and B, and the multiple forms of procarboxypeptidases A and B – are all of the well-documented bovine pancreatic proteases and account for $\approx 78\%$ of the proteins in pancreatic juice. The proteolytic enzymes in both granules and juice are in the zymogen form. The active carboxypeptidase B obtained from the secretion in earlier work represents conversion of the zymogen to active enzyme by the procedures used for isolation. Re-evaluation of the amounts of chymotrypsinogens A and B in pancreatic juice by a newly developed chromatographic system confirms the weight ratio of 2:1 found previously by use of another procedure. During the re-evaluation it was found that chymotrypsinogen B, in contrast to A, is partially inactivated in acid solutions. Since the chymotrypsinogen B usually studied is prepared by acid

extraction of the gland, comparison of such material with the natural zymogen may be of interest.

Non-Heme Protoporphyrin in the Erythrocyte

In addition to the protoporphyrin present in erythrocytes as the iron complex, heme, the cells also contain some free, i.e., non-heme, protoporphyrin. The role, if any, of this material in the economy of the cell is not known. It arises from the same precursors and by the same pathway as heme porphyrin, and clearly not from the latter. During work on the synthesis of hemoglobin in intact avian erythrocytes incubated *in vitro* with glycine-2-C¹⁴ as porphyrin precursor, it was found, contrary to expectation, that the specific activity of the free porphyrin, i.e., C¹⁴ per unit of material, was appreciably less than that of the precursor glycine in the cell. However, the specific activity of the free porphyrin that accumulated in the plasma during the incubation approached equivalence to the specific activity of the glycine. Thus it appears that the newly synthesized, labeled porphyrin does not mix readily with the preformed material. It was found further that the newly formed porphyrin was mostly associated with the readily sedimentable fraction of the cell contents, while the preformed material stayed with the liquid phase of the cell. Although the nature of the separation of preformed and newly synthesized porphyrin within the cell is not clear, the separation does indicate a difference between the porphyrins that may be of significance.

BIOPHYSICS

Biological Effects of Cosmic Rays

From the many physical measurements of the radiations in space, the radiobiological effect to be expected in a satellite can be computed. However, it seemed desirable to test prediction with actual biological experiments. The only radiations encountered for which there is no laboratory experience are the heavy cosmic-ray primary particles. These consist of stripped atomic nuclei having masses as high as that of iron and traveling at very high speeds. Interest in the experiment is centered on these particles. Corn seeds of a special genetic stock were flown in satellites and returned to the laboratory, where they were germinated and grown. The early leaves were examined for abnormalities which would indicate radiation dam-

age to the embryo. The extent of each damaged spot on the leaf gives a measure of the size of the ionization track that traversed the embryo. The seeds employed were of a genotype that is heterozygous for alleles controlling green vs yellow-green color of the leaf. Thus a mutation could readily be induced in a cell of the embryo which would change the color of the progeny of that cell in the plant, and therefore the damage observed was almost entirely genetic. Samples were retrieved from two satellites flown in polar orbit for 27 and 49 hr. The number of leaf spots in plants grown from the samples was significantly greater than in the controls only for the second flight, and here the difference was just significant. This is exactly what would be predicted from the physical measurements. Thus, within the limits of this biological system, nothing unexpected was found.

Transport Through Biological Membranes

Theoretical investigations directed toward a better understanding of material transport through the limiting membranes of living cells are continuing. Particular attention is being paid to open and closed circuit systems containing two or more membranes of different sets of properties. The open circuit systems demonstrate the phenomena of secretion and absorption, which are as yet dimly understood in biological systems. The closed circuit systems produce spontaneous electric and material currents. Model isothermal systems constructed of liquid phases and membranes alone (no metallic phases present) in which both an electric current and a material current could be demonstrated have been constructed and studied. The theory of the closed circuit system can account for the forces producing the biological phenomenon called protoplasmic streaming.

Another model system under experimental study is one that will spontaneously reach a stationary state set by the energy made available by an enzyme-catalyzed chemical reaction occurring in one of the phases of the transfer system. While as yet the quantitative data obtained with the present apparatus do have the desired precision, indications are that it will be possible to construct a system that will mimic in many respects the ion distribution patterns exhibited by actual cells in their basal state.

One experimental finding of the past year is that a mutual property of an ion and a membrane,

Figure 8. Pathways for dissipation of excitation energy at 294° and 77° K in *Cps. ethylicum*. The symbols *L* and *F* represent nonradiative loss and fluorescence respectively. The percentages shown are estimates of the quantum yields in a 1-day-old culture. The efficiency of energy transfer to chlorophyll-770 at 294° K is probably higher than estimated.

the ionic transport number, does not greatly depend upon the concentrations of the ions in the adjoining phases when the ions are univalent. The transport numbers of ions of higher valence, however, show an increasing dependence upon the concentrations. These studies are being continued in the hope that some information may be gained concerning the obviously different behavior of ions of different valence in their transport in actual biological systems.

Energy Transfer in Photosynthesis

The new chlorophyll-770 from green bacteria has been purified as a water-soluble chlorophyll-protein complex by ion exchange chromatography. The complex from *Chloropseudomonas ethylicum* has a molecular weight of $\approx 1.4 \times 10^5$, which includes at least six chlorophyll groups per molecule. Chlorophyll-770 extracted from the complex and dissolved in ether has an absorption spectrum identical to that of bacteriochlorophyll from purple bacteria. Fluorescence studies of the green bacteria have elucidated the pathway of excitation energy transfer from *Chlorobium* chlorophyll, the main light-absorbing pigment, to chlorophyll-770, a relatively minor pigment. Efficiency of transfer in *Cps. ethylicum* is between 33% and 77%. The decrease in the fluorescence yield of chlorophyll-770 *in vivo* as the intensity of excitation is decreased indicates that this chlorophyll may be directly coupled to the chemistry of photosynthesis.

Figure 9. Absorbancy changes in chloroplast fragments from *Euglena gracilis* caused by irradiation with 0.70- μ light of high intensity (10^{-8} einstein/cm²-sec). The change demonstrates the reduction of cytochrome *b₆*. Measurements were made with a double-beam spectrophotometer of the Chance type.

Spectrophotometric studies of light-induced cytochrome reactions in algal photosynthesis have shown that two photochemical systems operate in *Anacystis nidulans* and *Euglena gracilis*. One system mediates a light-induced oxidation of cytochrome, and the other mediates a light-induced reduction. The cytochromes observed *in vivo* were high potential pigments: cytochrome *f* in *Anacystis* and cytochrome-552 in *Euglena*. In *Euglena* chloroplast fragments depleted of cytochrome-552, a light-induced reduction of cytochrome *b₆* was observed at high light intensity, and a light-induced oxidation at low intensity. This was the first observation of a light-driven reduction of cytochrome *b₆* in a system derived from an oxygen-evolving

organism. The action spectrum for cytochrome b_6 reduction (12%) peaked at $\approx 680 \text{ m}\mu$, whereas the action spectrum for cytochrome-552 oxidation (50%) *in vivo* peaked at $\approx 705 \text{ m}\mu$.

ENVIRONMENTAL BIOLOGY

Radiation Ecology

The program in environmental biology was established in 1961 to attempt to define the changes that ionizing radiation might induce in the structure and function of natural ecosystems, which are the basic biological units of man's environment. Ecosystems have geographical, temporal, and internal patterns, all subject to important alterations after acute radiation exposures in the range of hundreds to a few thousand roentgens.

The objective of this program is to define the nature and extent of alteration of these patterns which might be caused by ionizing radiation.

Two principal experiments have been established, one utilizing an old field ecosystem in the gamma radiation field, the other a new irradiation facility in a near-climax forest ecosystem. These two experiments provide opportunities to examine various aspects of the structure and function of ecosystems representative of the two extremes of the successional sequence characteristic of the eastern deciduous forest, a geographically defined ecosystem covering much of eastern North America. The emphasis of this research is on populations of plants, the primary producers of all ecosystems. It is clear now that (1) there is great variation among natural ecosystems in sensitivity of these

Figure 10. An infrared photograph of the irradiated forest ecosystem during the summer of the first year of exposure. The exposure rate at the margin of the circle of dead trees was between 40 and 60 r/day. The exposure at the control building was $\approx 2 \text{ r/day}$. Even at this exposure rate, effects on the growth of pine trees were measurable during the first year.

Figure 11. Comparison of radiation damage in two plant communities, an old field and a forest. In the forest no species of higher plant survived exposures >360 r/day, and all species of trees were killed by exposures >60 r/day. The old field community proved to be 5 to 10 times more resistant than the forest, which suggests that there is reasonable basis for expecting substantial variation among ecosystems in resistance to damage from ionizing radiation.

populations; (2) this variation may parallel certain types of environmental gradients; (3) plants in natural arrays are in general more sensitive to damage than has been anticipated from previous experimental work on radiosensitivity; and (4) secondary effects, especially those involving insects, are of vital importance in analyzing effects of low-level irradiation at the ecosystem level. Of these observations the interaction of various types

of environmental stresses with ionizing radiation to accentuate the direct effects of irradiation appears to be of particular importance. Stresses include those imposed by populations of organisms such as parasites and predators as well as by physical factors of the environment. These stresses appear to account in part for the increase in natural arrays over that measured under controlled conditions.

Medical Research

The research program of the Medical Department, based on studies leading to better understanding of biological processes in man, contributes to the knowledge of the effects of ionizing radiations upon the human being. Some clinical and laboratory investigations are directed toward enhancing beneficial applications of these radiations or improving measures for preventing or counteracting detrimental effects. Other investigations are centered on the biological processes of man in order that through the knowledge of normal function elucidations of diseases states may be furthered, and improved methods of diagnosis and therapy may be developed. These approaches are complementary, for, whether at the level of the single cell or the entire body, there appear to be no effects of ionizing radiation that have not been observed in naturally occurring diseases or produced by other toxic agents. Thus, the study of radiation effects contributes to the understanding of diseases, and vice versa, and the pace of progress in both is controlled by the advances in knowledge of normal biological processes.

The diversified talents and extensive facilities uniquely concentrated at Brookhaven National Laboratory provide unusual advantages for pursuing these objectives. The broadly based program of the Department incorporates the experience and skills not only of those devoted to research in the field of medicine, but of many from the various disciplines in other departments of the Laboratory. Similarly, not only are the facilities of the hospital, laboratories, and reactor of the Medical Research Center utilized, but the instrumentation and special laboratories of other departments and the large nuclear devices may be used as well. Thus, the program is enriched through the productive interchange of ideas, information, facilities, and services, and the opportunities within its framework are limited only by the scope of the vision and interest of the individual investigator.

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.

BIOLOGICAL EFFECTIVENESS OF FAST NEUTRONS

A 3-Mev Van de Graaff generator is employed to accelerate protons into a thin tritium target, which causes the emission of neutrons in all directions. However, the energy and flux of neutrons thus generated are strong functions of the angle between neutron path of travel and the beam target axis (both rise with decreasing angle in the forward direction). These features have been utilized to expose different groups of animals simultaneously to neutrons at several (generally five) discrete energy levels. Dosimetry and spectral measurements of linear energy transfer have been carried out (in collaboration with Dr. H.H. Rossi of Columbia University) with tissue-equivalent ionization chambers. Parallel comparison irradiations employed 250-kvp x rays or Co^{60} gamma rays.

Relative biological effectiveness of fast neutrons in causing spermatogonia depletion has been found greatest (≈ 5) at 0.43 Mev, with a decline as the energy was increased to 2.0 Mev. Still lower effectiveness has been found at 14 Mev. Material from exposures in the 2.0 to 6.0-Mev range is being evaluated. Cataract induction is most marked following exposures at 0.43 Mev, and somewhat less in the 1.00, 1.50 and 1.80-Mev groups. Studies of the effect of fast neutrons on depression of deoxyribonucleic acid (DNA) synthesis in the gut, which previously suggested a peak around 0.43 Mev, showed a similar degree of effect for narrow energy steps from 0.40 to 0.60 Mev. Dose rate studies in the literature pertaining to lethality in rats or mice exposed to x or gamma radiation revealed that radiation effectiveness increases as the cube root of dose rate, and that the change in radiosensitivity between any two given dose rates is of similar degree for several criteria-of-effect, including human skin erythema threshold. Formulas to describe the above relationships have been developed and will be more rigorously tested in a cell system whose members are relatively inactive during the periods required for exposure. The develop-

ment of abnormal anaphases in regenerating mouse liver is being employed in the evaluation of Co^{60} gamma irradiations over a dose rate span of 0.2 to 100 rads/min.

BIOLOGICAL AND PHYSICAL FACTORS OF NEUTRON REACTIONS

In this project clinical activities have been suspended, and an effort is being made to focus on those biological and physical factors of most significance in determining whether or not neutron capture therapy is feasible. A portion of the project is directed primarily toward determining the physical and dosimetric characteristics of the reactor beam in order to introduce modifications, as necessary, for optimal physical conditions in the application of the neutron capture process to the therapy of neoplasms.

To reduce the fall-off of thermal neutron flux in tissue obtained in experiments with the present neutron beam, Li^6 or cadmium thermal neutron "filters" have been introduced in order to produce an "epithermal" beam. The residual fluxes appear to be in the usable range. Detailed studies of penetration as a function of the thickness of Li^6 or cadmium filters and as a function of the reflector D_2O thickness are being carried out with use of a tissue-equivalent phantom head. Results indicate that it is possible to obtain reaction rates at a depth of 8 cm equal to those at the surface, in contrast to a fall-off by a factor of between 20 and 30 with the present beam. Detailed studies of gamma and thermal neutron distribution in depth have been done with the present beam with use of an anthropomorphic phantom under conditions simulating those used for neutron capture treatments. The gamma dose rates throughout the phantom have been found to be excessive, even though the beam is directed to a local region such as the head. Studies have been initiated on similar determinations using the epithermal beam.

In biological studies the distribution of B^{10} between normal tissues and spontaneously occurring tumors in dogs is being determined. The best partition obtained was 4 to 1 between a breast tumor and skin 15 min after injection of B^{10} . However, the boron concentration in blood was still greater than that in the tumor, and thus capillaries of normal as well as malignant tissue undoubtedly receive a high dose of radiation. Survival curves of HeLa S3 cells are being determined as functions

of the boron concentration and neutron flux. The effects of whole-body irradiation on the elements of the blood have been determined. When a dog's head is irradiated with a therapeutic dose (an integrated flux of 5×10^{13} thermal neutrons/cm²), death associated with a severe platelet depression occurs on the 9th day following irradiation. Results with skin of swine indicate that the effect is not reduced by fractionation of dose from the neutron-boron capture process.

EFFECTS OF 2-BEV PROTONS ON MAMMALS

Studies of fundamental problems in particle bombardment of mammals using the Cosmotron are only partially complete, and only illustrations of the types of problems investigated are discussed. Protons can be accelerated to energy levels as high as 3 Bev, and as many as 1.25×10^{10} particles/pulse (external beam) can be obtained over an $\approx 6\text{-cm}^2$ surface. Dosimetric studies and studies on cross-sectional uniformity of the 2.2-Bev Cosmotron beam are under way. A preliminary LD_{50} value has been obtained for mice exposed in the 2.2-Bev Cosmotron beam. Effects of the Cosmotron beam on transplantable and spontaneous animal tumors *in vivo* and *in vitro* are being evaluated. The easily reproducible and quantifiable phenomenon of activation of carbon, nitrogen, and oxygen in tissue may prove to be useful in direct animal dosimetry. A theoretical analysis of the pattern of energy deposition of negative π mesons in tissue is under way.

EXTRACORPOREAL IRRADIATION OF THE CIRCULATING BLOOD: EFFECTS ON LYMPHOCYTES

Techniques for the irradiation by a special Co^{60} source of the circulating blood in an external shunt have been developed, which allow a flow rate of 1200 ml/min and a transit dose of 900 rads to the blood. Equations have been developed relating the blood volume, volume of external shunt, and transit dose; thus dose distribution to the various fractions of the total blood volume can be computed. After 38 hr of irradiation, frank hemolysis with hemoglobinuria was observed. At this time 99% of the blood is estimated to have received $>29,000$ rads; 50%, $>41,000$ rads; and 1%, $>54,000$ rads. Granulocytes in the peripheral

Figure 1. Extracorporeal irradiation with a Co^{60} fluid irradiator source.

blood were increasingly of the immature type, and a shift to the left in the bone marrow occurred. The most prominent observation is lymphopenia of prolonged duration.

Extracorporeal irradiation has been combined with thoracic duct drainage and histologic study of tissues. From these studies it has been established that 2.5 to 5.4 lymphocytes enter the blood from all other sites of entry for every lymphocyte that enters through the thoracic duct. After 6 hr of extracorporeal irradiation, there is a detectable diminution in lymphocytes in the cortex of lymph nodes and in the cuff of small lymphocytes surrounding germinal centers. After 30 hr there is a striking and almost total disappearance of small lymphocytes from the cortex of lymph nodes and from the cuff around germinal centers of spleen and lymph nodes with intact germinal centers. This pathologic picture is clearly distinct from that produced by adrenal-mediated stress. It is believed feasible to deplete essentially the whole body of lymphocytes and to study the effect of this depletion upon immune processes, hemopoiesis, and fibroplasia.

RADIOSENSITIVITY OF ANTIBODY RESPONSES

Although conclusive evidence has appeared in the literature concerning the repressive effect of ionizing radiation on primary antibody responses when antigen is administered a short time after irradiation, relatively few studies have dealt with radiation effect on the secondary antibody response (specific anamnestic reaction). A repression of the secondary antitoxin response similar to that previously observed for the primary response was obtained when fluid toxoid was given as the second stimulus 1 hr to 3 days after exposure to 625 rads. A short-term exposure of 400 rads repressed the primary antitoxin response in mice elicited with fluid tetanus toxoid. Initial repression was followed by a typical primary response when absorbed tetanus toxoid was used for the primary immunization. These data indicate the efficacy of using absorbed toxoid to produce a primary immunization inasmuch as the antigenic depot provided by absorbed antigen is available to elicit a primary response when animals again recover the ability to produce antibody after irradiation.

In studies on the role of the thymus in immune mechanisms, techniques that circumvent many of the difficulties associated with air suction procedures have been developed for surgical extirpation of the thymus in 1-day to 14-day-old mice. Thymectomized mice were given a primary injection of 0.05 ml absorbed tetanus toxoid when 4 weeks old and were bled for serum and given a booster injection of 0.1 ml fluid tetanus toxoid 3 weeks later. The individual antibody titers 10 days later, determined by individual toxin-antitoxin titration, showed only a slight impairment of the primary antitoxin response; however, a severe repression of the secondary response was observed as compared to nonoperated littermates. The possibility is not excluded that, under the conditions of this experiment, wasting might have been responsible, at least in part, for the repression of the secondary response in thymectomized mice. The pathogenesis of wasting after postnatal thymectomy is as yet unknown.

RADIATION-INDUCED NEOPLASIA IN THE RAT

Early studies indicated that the female Sprague-Dawley rat, following whole-body radiation with doses of 400 r, developed a high incidence of breast neoplasms. The objective of the continuing studies has been to determine under what conditions the neoplasms occur and to elucidate the basic mechanisms involved. It was shown that normal ovarian function is necessary for maximal incidence of induced neoplasia, and that the neoplasms did not arise from direct irradiation of the ovaries, pituitary, or other endocrine organs. The histologic types of neoplasms obtained (adenocarcinoma, adenofibroma, fibroadenoma, and fibrosarcoma) did not appear to vary with the procedure used. Male rats also developed these types of neoplasia following exposure, but in smaller numbers. Neoplasms arose only in areas directly exposed to the beam; i.e., no "abscopal" effect occurred. The dose-effect response, for neoplasms scored at 1 yr, was approximately linear over the range 25 to 400 r. The curve appeared to go through zero dose at zero response. No data were obtained below 25 r, and the linear response did not hold above 500 r. These results suggest that neoplasia induction involves at least a two-stage mechanism. Both initial irradiation damage and a suitable endocrine balance must exist for this carcinogenic process to

take place. Results of studies designed to determine the effect of dose fractionation are being analyzed, but to date have failed to demonstrate a significant change in response with dose fractionation over periods of days to weeks.

THE TURNOVER OF Sr^{85} , Cs^{137} , Zn^{65} , Sc^{46} , Ca^{47} , AND I^{131}

A primary effort is concerned with short and long-term studies of the skeletal dynamics of Sr^{85} , Cs^{137} , Zn^{65} , Sc^{46} , and Ca^{47} in patients with normal and abnormal bone metabolism in order to (a) define rate of accretion, exchange capacity, body retention, and plasma clearance of the elements; (b) develop mathematical models from which extrapolations can be made; (c) determine relationships between excretion and body-burden data; and (d) establish baseline levels for use in health protection. These clinical investigations are supplemented with animal studies. Also involved is the effort to understand the relative rates of diffusion and hydrostatic forces in osmosis. Investiga-

Figure 2. Whole-body retention of Sc^{46} -labeled nitrilotriacetic acid, $10 \mu\text{C}$ given intravenously. (Data not corrected for radioactive decay.)

Figure 3. Sr^{85} retention following intravenous administration.

tions on the effects of various agents in altering turnover rates of the bone seekers are being pursued.

The long-term biological turnover data on Sr^{85} , Cs^{137} , Zn^{65} , and Sc^{46} in patients can be described equally well by a power function mathematical model in which the mean retention $R = 52.2t^{-0.175}$, or by a series of exponential functions. In the latter case, the function is dominated by a single exponential term, which, for Sr^{85} , gives a mean half-life of 850 days. The long-term supplementation of the diets of several patients with stable strontium and calcium was found to be without effect on the previously established Sr^{85} turnover rate. Cs^{137} , Zn^{65} , and Sc^{46} retention data can be described adequately by single exponential functions giving half-lives of 80, 335, and 1500 days respectively. A four-compartment model of calcium and strontium metabolism was developed by analogue computer analysis of the Sr^{85} and Ca^{47} data from the short-term kinetic tracer studies. The accretion rate and size of the rapidly exchanging compartment for calcium and strontium were identical in six patients with varying states of skeletal metabolism.

The gamma spectra of 400 Brookhaven employees have been obtained by the whole-body counting technique, and an IBM 7094 computer program is being programmed to analyze these complex spectra. A smaller population has been measured over long periods of time in an effort to correlate body burden and environmental levels.

The thyroidal accumulation of I^{131} during the 1961 nuclear weapons test series was measured in a group of pregnant women and controls in the spring of 1962; no detectable levels of I^{131} were found. A second, similar group measured in the fall, after the 1962 tests, showed levels of 20 to 160 pC only. In 4 offspring of these women measured from 18 to 34 days after birth, no significant levels of I^{131} could be detected.

The effects of aging and x irradiation on the chemical dynamics of skeletal metabolism in the rat were compared in terms of the accretion rate and exchange capacity of Sr^{85} in various bones. It was found that 2000 r local x irradiation resulted in a decreased accretion rate of the tibia, as normally occurs in the aging process. However, the exchange capacity of the irradiated tibia compared to its contralateral control appeared to increase slightly as compared to the decrease normally found in aging. Thus irradiated young bone was found to differ in certain respects from bone that had aged normally.

STUDIES ON THE CHEMISTRY OF THE α_1 -GLYCOPROTEIN

The serum glycoprotein level is quite constant in an individual under normal conditions, but is changed slightly by even a minor ailment. However, so little is known about the nature or number of the glycoproteins that information about their levels in disease is at present of little medical value. The chemistry of the α_1 -glycoprotein of human plasma, the best-known example of this class of proteins, has been under study in this laboratory during the past several years.

In attempting to establish unequivocally the number of polysaccharide units that may be linked individually to the polypeptide chain of the protein, hydrolysis of the polypeptide with trypsin has been utilized. This highly specific proteolytic enzyme hydrolyzes peptide chains only at lysine and arginine residues and might be expected to cleave the α_1 -glycoprotein at ≈ 26 places. The best available evidence indicates that hydrolysis at 2 to 3 of these anticipated sites does not occur. The fragments produced by tryptic hydrolysis have been separated in part by chromatography, and some components have been further purified by high-voltage paper electrophoresis. Attention has been limited to the components of the digestion mixture that contain carbohydrate.

The average molecular weights of the separated glycopeptide fractions have been studied by equilibrium methods in the ultracentrifuge. From the molecular weights found and from analyses for carbohydrates and amino acids, it has been found that the carbohydrate part of the glycoprotein is divided into 8 to 9 small units, linked individually to the protein. Since the ratios of the various monosaccharide units to each other remained the same in any of the fractions tested, it seems probable that the 8 or 9 carbohydrate units are identical.

One glycopeptide has been isolated from the digestion mixture in an apparently pure state; this has been found to be the polysaccharide bound to a hexapeptide consisting of one residue each of lysine, aspartic acid, threonine, proline, tyrosine, and phenylalanine. It is probable that the carbohydrate is bound through the β -carboxyl group of the aspartic acid.

STUDIES ON HYDROXYLYSINE AND COLLAGEN

Hydroxylysine is characteristic of collagen and has been isolated in significant amounts only from

this protein. Experiments have been repeated with more elaborate procedures for purification of collagen. Young rats were injected with C^{14} -labeled lysine and sacrificed at periods varying from 4 hr to 15 wk after injection. The C^{14} specific activities of lysine and hydroxylysine from the purified skin collagen preparations have been found to be exactly equal to each other in all cases. The results are consistent with the assumption that hydroxylation of lysine is completed during the process of incorporation into the collagen.

In order to study the biochemical mechanism of the conversion of lysine to hydroxylysine during collagen biosynthesis, doubly labeled lysine has now been used. The hydrogen atoms on carbon atoms 4 and 5 were labeled with tritium, and the carboxyl group was labeled with C^{14} .

In both *in vitro* experiments with polyvinyl sponge biopsy tissue from rats and *in vivo* experiments in chick embryos it has been found that one and only one of the four labeled hydrogen atoms is lost. This finding is consistent either with a direct oxidation of lysine or with the production of a double bond between carbon atoms 5 and 6, followed by the addition of the elements of water to produce hydroxylysine. These mechanisms may be illustrated as follows:

Hydroxylysine, found almost exclusively in collagen, has the structure $NH_2 \cdot CH_2 \cdot CH(OH) \cdot CH_2 \cdot CH_2CH(NH_2) \cdot COOH$. According to the usual protein peptide structure involving only α -amino groups, the amino-alcohol group on the left of the above chain should be free unless it is involved in cross-linkages with its amino or hydroxyl group. Preliminary studies designed to obtain information on the state of the hydroxylysine end groups indicated that, in both rat-tail collagen and the gelatin made from it, periodate reacted less rapidly and completely with the constituent

hydroxylysine than with free hydroxylysine. In studies with gelatin prepared from ox bones with use of the evolution of formaldehyde to follow the reaction rate, the reaction appears to consist of two components, a rapid one with optimum pH of 7 to 8, and a slow one that is more rapid in 0.1 *N* NaOH than in less alkaline solution. These results are consistent with the hypothesis that the hydroxylysine of bone gelatin exists in two forms, one which has its reactive side-chain free and readily available to oxidation by periodate, and another which has its side-chain chemically bound and reacts with periodate at a rate that depends on the rate at which the side-chain bonds are broken.

STUDIES ON NUCLEAR RNA IN HeLa CELLS WITH TRITIATED CYTIDINE

Studies on *in vitro* systems with enzymes have shown that ribonucleic acid (RNA) may be synthesized on a deoxyribonucleic acid (DNA) template. Increasing evidence is reported in the literature that this occurs *in vivo* as well. The cytological findings of initial incorporation of labeled RNA precursors into the nuclei of various cell systems and of subsequent appearance of labeled RNA in the cytoplasm favor the hypothesis of RNA synthesis on DNA. In the HeLa cells, previous studies have indicated the movement of nuclear RNA to the cytoplasm, and the autoradiographically observed transfer of labeled RNA was complemented by the finding of preservation of relative label distribution between cytosine and uracil throughout transfer. An examination of the behavior of labeled RNA in the nucleus during mitosis led to the following conclusions:

(1) RNA synthesis continued in cells in mitosis until late prophase. Most of the labeled RNA in prophase was associated with the chromosomes, more with the chromosomal surface than with the core. Nucleolar labeling amounted to <16% of the total nuclear labeling. The degree and pattern of nuclear labeling was similar in early prophase to that in interphase, which indicated that in the HeLa cell the synthesis of >80% of the RNA occurred on the chromosomes.

(2) With the progression of the labeled cells through the stages of mitosis, the labeling associated with the chromosomes contributed to cytoplasmic RNA. Even through anaphase 18 to 35% of the label remained attached to the chromosomes. It appeared unlikely that this chromosomal-

Figure 4. Labeled early megacaryocytic cell in mitosis.

labeled RNA contributed to the organization of the nucleoli at telophase.

(3) RNA synthesis resumed at telophase within the chromatin portion of the nucleus. Nucleotides as precursors for the resuming RNA synthesis were derived at least in part from the acid-soluble fraction of the cell in which they had remained throughout mitosis without exchange with nonlabeled nucleoside in the extracellular medium. The data support the hypothesis that RNA is synthesized in the mammalian cell on the chromosomes.

METABOLISM OF NUCLEIC ACIDS

Iododeoxyuridine (IDU), an analogue of thymidine, has been shown to be a specific label for DNA like thymidine. With IDU it is possible to detect *in vivo* small changes in DNA metabolism, such as those produced by 10 r of x rays or following the injection of 1 ppm cortisone. Dose dependence of the depression by Co^{60} gamma rays of the incorporation *in vivo* of IDU into mouse intestines

6 hr after irradiation has been determined. The depression appears to be proportional to dose from 5 to 50 r, with 25 r producing $\approx 50\%$ depression. No threshold is evident. The effect of the size of precursor pools on the efficiency of incorporation has been investigated by simultaneously injecting IDU, H^3 -thymidine, and carrier thymidine. Surprisingly, IDU incorporation is much more sensitive to thymidine load than is H^3 -thymidine, which suggests competition at several sequential steps. This is true even though the only discernible pool of precursor is extracellular: i.e., the time necessary for disappearance of IDU from the circulation corresponds closely to the time for its appearance in DNA. The half-times for both processes appear to be ≈ 3 min.

If 10 to 20 hr, depending on the tissue, are allowed to elapse after the initial labeling to permit complete excretion of the catabolic by-products associated with the labeling process, further loss of activity can be equated simply to cell death. To permit repeated counting of a tumor in the same

animal without interference from other parts of the body, a solid tumor of mammary origin is transplanted into the tail of a normal mouse. In the tumor, in contrast to the whole mouse, very slow turnover has been observed; this was not accelerated by large doses of x rays (20,000 r). Death of labeled normal cells has been observed after much smaller doses of radiation (500 r) but only when the radiation was delivered shortly after labeling, before most of the labeled cells had passed through mitosis. The study of cell death in the tumor following irradiation at a comparable time interval has not yet been possible.

OBSERVATIONS ON THE GROWTH OF CANCER CELLS IN VITRO UNDER HIGH OXYGEN TENSION

One of the most widely recognized differences between normal and malignant tissues is that the latter aerobically form appreciable quantities of lactate. However, concentrations of oxygen $>35\%$ have a deleterious effect upon cancer cells in culture. An attempt is being made to determine why, and at what level of cell metabolism, oxygen exerts its noxious effect.

When HeLa S3 cells are cultured in an atmosphere of $5\% \text{CO}_2 + 95\% \text{O}_2$, the rate of glycolysis is increased and lactic acid accumulates in the culture medium. If the cells are permitted to remain in an atmosphere of $95\% \text{O}_2$ for >48 hr, irrespective of a change of culture medium, irreparable damage ensues. A change in cell morphology is evident at ≈ 48 hr and becomes more pronounced at 72 hr, at which time it is obvious that many of the cells are dying. Thus far, it has not been possible to relate death to the oxidation of components of the growth medium, to the accumulation of metabolic end-products, or to pH changes in the medium.

The ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) synthetic activities of S3 cells under high oxygen tension have been investigated by using tritiated nucleosides. A significant inhibition of DNA synthesis was first detected at ≈ 30 hr, and at 36 hr only 7% of the cells were found to be actively synthesizing DNA, that is, capable of incorporating H^3 -thymidine. In control cell populations incubated in an atmosphere of $5\% \text{CO}_2 + 95\% \text{air}$, 25 to 30% of the cells were in DNA synthesis at all times. There was no demonstrable DNA synthesis in cells that had been exposed to a high concentration of oxygen for 48 hr or longer.

Tracer studies with H^3 -cytidine showed a similar depression of RNA synthesis.

The present concept is not that high oxygen tensions specifically inhibit nucleic acid synthesis but that the observed inhibition and cell death are the consequence of an effect upon some other vital metabolic pathway (or pathways). Other parameters are being explored, in particular the effect of high oxygen concentrations on the enzymatic activities concerned with glycolysis and respiration.

VITAMIN AND AMINO ACID METABOLISM IN NEOPLASIA

Recent clinical chemistry studies indicating elevated levels of a number of the intermediary metabolites of tryptophan in the urines of patients in various disease states have intensified interest in the relationship of disease to the metabolism of tryptophan. These studies have shown that in some neoplastic diseases there are elevated levels of urinary anthranilic acid, kynurenine, 3-hydroxykynurenine, and 3-hydroxyanthranilic acid. Two of these compounds, 3-hydroxykynurenine and 3-hydroxyanthranilic acid, have exhibited tumor-producing qualities in mice. To establish the normal metabolic pathway for these compounds in humans by the use of C^{14} -labeled compounds, some of these labeled intermediary metabolites of tryptophan have been synthesized.

The synthesis of DL-tryptophan-7a- C^{14} , anthranilic acid-carboxyl- C^{14} , 3-hydroxyanthranilic acid-carboxyl- C^{14} , and 3-hydroxy-DL-kynurenine-keto- C^{14} has been completed, as well as the resolution of a small quantity of 3-hydroxy-DL-kynurenine-keto- C^{14} into the D and L isomers. Preliminary studies of the metabolism of the two isomers of hydroxykynurenine are in progress.

STUDIES OF METABOLISM OF C^{14} - AND H^3 - LABELED CARBOHYDRATES IN DIABETIC AND OBESE SUBJECTS

For the past two decades biochemists have been preparing simple biological compounds like glucose, amino acids, and fatty acids with radioactive carbon (C^{14}) placed in one or more positions of the molecule. With this tracer the natural metabolic fate of many such compounds has been followed in greater detail than otherwise possible. Within the past few years a similar array of compounds labeled with radioactive hydrogen (tritium or H^3)

has become available. In addition, newer techniques of measurement of the very weak radioactive emission of tritium make possible similar studies of the metabolic transfer of hydrogen, which is intimately associated with utilization of chemical energy and perhaps hormonal action. In this laboratory, diabetic and obese humans and mice are being given these radioactive compounds (in some cases labeled with both C^{14} and H^3) to determine how insulin and other hormones act upon the metabolism, which may be deranged in these abnormalities.

Present concepts in biochemistry postulate that the hydrogen atom attached to the first carbon of glucose (in the aldehyde group) is transferred during metabolic oxidation to the coenzyme nicotinamide-adenine dinucleotide phosphate (NADP), which passes on some of this hydrogen eventually to reduce oxygen to water, but supposedly gives an appreciable fraction of this hydrogen to the reduction of intermediate organic compounds to fatty acids and other end-products of biosynthesis. If this transfer is a limiting factor in biosyntheses, it could help explain the well-known association between glucose utilization and synthesis of fats. By comparing different labeled compounds in regard to their relative transfer of C^{14} or H^3 to carbon dioxide or water and to fatty acids after injection into an animal or a patient, some information can be obtained as to the specificity of the hydrogen on glucose carbon 1 compared with other organic hydrogen.

It has been found that the water:carbon dioxide yield ratio ($H^3OH:C^{14}O_2$) in obese human subjects is $\approx 6:1$ at 30 min after injection of glucose labeled either in the 1 position (aldehyde group) or in the 6 position (carbinol group). Furthermore, lactic acid (an intermediate metabolite of glucose oxidation) which is labeled at the 2 position with both C^{14} and H^3 shows a $H^3OH:C^{14}O_2$ yield ratio of 3:1. Neither the hydrogen on carbon 6 of glucose nor on carbon 2 of lactic acid is transferred directly to NADP, as is at least some of the hydrogen on carbon 1 of glucose. If the latter had decided specificity for NADP (and fatty acid synthesis), then the $H^3OH:C^{14}O_2$ ratio should be lowest for the glucose-1-labeled compound.

Furthermore, by analysis of fat from the blood of these patients it has been found that there is somewhat more tritium in the neutral fats relative to the amount in total body water after administering lactic acid-2- H^3 than after giving glucose-

1- H^3 . However, the difference is not sufficient to account for the difference in the water:carbon dioxide yield ratio. These findings imply that fundamental changes in widely accepted concepts of the interconversion and function of coenzymes and the sources of metabolic hydrogen for fatty acid syntheses may be required.

Examination of total carcass and liver fatty acids from a laboratory strain of genetically obese and diabetic mice after administration of glucose-1- C^{14} , -1- H^3 shows higher incorporation of both isotopes than is found in lean control siblings, which agrees with other isotopic studies indicating hyperactivity of fat formation in this obese strain. Obese patients studied so far do not show this hyperlipogenesis in blood fats compared with lean diabetic patients. However, insulin in the diabetic increases the transfer of tritium to fats. The amount of tritium appearing in the fats, even of the total carcass and liver of the mice, is a very small fraction (2% or less) of the metabolized glucose-1- H^3 , which further suggests other sources of fatty acid hydrogen.

AUTORADIOGRAPHIC STUDIES OF GROWTH, AGING, AND REPAIR OF THE SKELETAL STRUCTURES

Tritiated thymidine and tritiated amino acids (H^3 -histidine and H^3 -glycine) have been used in a number of studies on cell proliferation in skeletal tissues and on cellular participation in the production of the collagen matrix of bones and teeth during growth, aging, and repair. In studies using tritiated thymidine, osteoclasts were shown to arise as needed by the fusion of osteoblasts. The labeling indices of skeletal tissues were determined in mice from birth to old age. The generation time of periosteal cells was found to vary from 7 to 19.4 days, comprising a presynthesis time of 6.7 to 18.5 days, DNA-synthesis time of 2 to 7 hr, postsynthesis time of 5 to 13.5 hr, and mitotic time of 0.5 to 1.5 hr. The periosteum has been shown to be important not only for circumferential growth and repair of long bones but also for the expansion of the epiphyseal plate, which contributes to longitudinal growth and the articulating surfaces for spherical expansion on the epiphysis.

To determine whether local periosteal or bone trauma is necessary to induce cell proliferation, mice were injected in the soft tissues over the periosteum at the mid-shaft region of the left non-fractured femur with 0.25 ml of saline, serum,

Figure 5. Autoradiograph (640 $\times$) of osteoblasts labeled with tritiated thymidine, participating in the fracture repair of a 5-wk-old mouse femur (1 hr after administration of label).

Figure 6. Autoradiograph (160 $\times$) of the femur of a 5-wk-old mouse. Periosteal cells (osteogenic layer) are labeled with tritiated histidine initially, but by 4 hr much of the label appears extracellularly.

or whole blood. Autoradiographic studies with tritiated thymidine revealed that the cells of the periosteum were equally stimulated by all the injected components. These studies are being extended to determine whether anoxia plays a role in eliciting the cell proliferative response. The effects of radiation on cell proliferation kinetics are also being investigated.

KINETICS OF ERYTHROCYTIC AND MEGACARYOCYTIC PRECURSOR PROLIFERATION IN DOG AND RAT

Beagle dogs were given a single intravenous injection of tritiated thymidine, and bone marrow samples were obtained from different sites during the first day after administration. Labeling indices (and grain numbers) of free pycnotic naked nuclei having the characteristics of the most mature erythroblastic ("orthochromatic normoblast-type") nuclei, were registered as a function of time after the injection. The first labeled free pycnotic naked nuclei appeared between 10 and 11 hr; 78% were labeled at 15 hr after injection of the precursor. From other studies it is known that the majority of the last dividing generation of nucleated red cell precursors need less than 1 to 1½ hr to proceed from the end of the DNA synthesis period through the premitotic rest period and the following mitosis. Accordingly, the transit time for the most mature nondividing generation of nucleated red cell precursors ranges between 9 and 14 hr under the conditions of the experiment. Strong evidence for nuclear extrusion of the most mature erythrocytic

precursors is the finding that the curve obtained from the labeling indices of pycnotic, most mature, erythrocytic precursors ("nucleated red cells") as a function of time after injection of tritiated thymidine, practically coincides with that of the free pycnotic naked nuclei. Labeling in pycnotic naked nuclei ingested by macrophages appears after labeled nuclei have been extruded from the most mature erythroblasts. The labeling index of phagocytized naked nuclei as a function of time after administration of tritiated thymidine roughly corresponds to that of free pycnotic nuclei, but not to that of lymphocytes. This observation indicates that most if not all phagocytized pycnotic nuclei in normal bone marrow originate from extruded erythroblastic nuclei rather than from lymphocytes.

The kinetics of megacaryocytic cells of the rat bone marrow were studied in a fashion similar to that employed for erythrocytic precursors of the dog. The changes in the percentages of labeled cells after injection of the tracer were registered separately for arbitrarily chosen successive recognizable stages of megacaryocytic differentiation. Emphasis was put on the progressive transition of labeled cells into a stage of maturation corresponding to initially nonlabeling cell forms. Results indicated the following: (1) A transit time of ≈ 40 hr from the most immature, still recognizable stage of megacaryocytic maturation to megacaryocytic disintegration. (2) Origination of recognizable megacaryocytic cells from unrecognized precursors which continuously synthesized DNA (with very short rest periods) for at least 1 to 3 days prior to maturation into recognizable stages. (3) Incorporation of more tritiated thymidine by labeled immature megacaryocytic cells than by other types of bone marrow cells (consistent with polyploidy). (4) A phase during which recognizable megacaryocytic precursors are able to synthesize DNA which lasts < 15 hr, whereas the latest phase of maturation lasts 25 to 30 hr. The process of nuclear segmentation appeared to be accomplished, as in the case of granulocytic leukocytes, in older cells which do not synthesize DNA.

Figure 7. Appearance of H^3 -thymidine-labeled segmented and pycnotic neutrophils in the peripheral blood after a "flash" injection of tritiated thymidine.

LIFE CYCLE OF GRANULOCYTES IN MAN

The life cycle of granulocytes in hematologically "normal" individuals and in patients with pathologically altered hematopoiesis, e.g., malignant and nonmalignant blood dyscrasias, is being studied by means of autoradiography with use of

tritiated thymidine as a stable DNA label. Preliminary analysis of results indicates a marked variability of the "release time" of newly formed granulocytes (time from formation of a metamyelocyte until release of the corresponding segmented granulocyte into the blood stream). In cases of apparently "normal" hematopoiesis, this time was found to be 3 to 4 days. This time was also found in patients with chronic lymphocytic leukemia,

that the life span of granulocytes is determined not only by random removal but also by an aging process which sets an upper limit for the transit time of granulocytes of 24 to 30 hr.

Nine patients with leukemia were given tritiated thymidine intravenously in a single injection, and serial blood studies and intermittent bone marrow aspirations were then performed. In one patient, blast cells in the bone marrow and in the blood

Figure 8. Neutron activation analysis for manganese and copper in medical samples.

multiple myeloma, chronic myelocytic leukemia, and myelofibrosis. In one case of lymphosarcoma and beginning bone marrow involvement, the time was 4 to 5 days, and in one case of refractory anemia with an "aleukemic" myelocytic leukemia and "Pelgerlike" blood granulocytes it was 5 to 6 days. The release time was shortened to 2 days in the case of bacterial infection.

The appearance and disappearance of labeled pycnotic granulocytes has been studied in three patients so far. It was found that labeled pycnotic granulocytes appeared 24 to 30 hr after the first segmented granulocytes became labeled. Their frequency in proportion to segmented granulocytes is about 1:300. This finding suggests that these pycnotic cells represent aged cell forms and

were labeled to the same extent 1 hr after injection of tritiated thymidine. In the remaining three patients, practically no labeled blast cells were found in the blood shortly after labeling, in contrast to the labeling in the bone marrow. It appears that in these patients "blast" cells were extruded only from the marrow when they no longer were able to divide. In the three patients in whom blood "blasts" did not label, labeled cells commenced their appearance in the blood within ≈ 3 hr and reached a maximum between 36 and 48 hr.

STUDIES OF PHYSIOLOGY OF TRACE METALS

This work is aimed broadly at defining body constitution, physiological behavior, organometal-

lic compounds, and clinical and therapeutic phenomena in which trace metals are involved. It has been established that (1) Injected radiomanganese leaves the bloodstream promptly, to become localized in the mitochondria. (2) A manganese-containing heme is present in the red cells of man and rabbit. As opposed to Fe^{59} , Mn^{54} labels only one generation of red blood cells. (3) The pathway of manganese is quite specific *in vivo*, and thus manganese-organometallic compounds might be assumed to be products of specific biosynthetic mechanisms rather than of metal substitution. (4) Manganese and zinc obey homeostatic control, while cadmium does not appear to be subject to such control. (5) Glucocorticoid (as opposed to minerocorticoid) hormones affect the metabolism of manganese but not that of zinc. (6) Manganese was shown to become bound by a β_1 -globulin of human and mouse plasma. Indirect evidence suggests that the trivalent state of the element becomes stabilized in the ensuing complex, and also that lower valence states of the metal might be bound by different sites than higher valence states. (7) Neutron activation analysis can be applied successfully to microsamples of biological materials.

The interaction of some trace elements of biological interest with phenothiazine drug derivatives useful as anti-Parkinsonism and antischizophrenic agents was demonstrated. Free radicals of the drugs were shown to be generated *in vitro* by manganese and iron under specific conditions. Initial work with the electron spin resonance spectrometer has centered particularly on redox reactions involving metal ion cofactors, and certain hormones were implicated in biological oxidation involving free radical mechanisms.

SODIUM AND HYPERTENSION

The objective of this work is to define the etiologic factors involved in human hypertension, a disease of increasing importance in the American population. Evidence exists that the consumption of sodium (as in table salt) is an important factor in this connection.

In studies designed to investigate the differences occurring in the response of humans to salt restriction in hypertension, it was shown by selective inbreeding of rats that clear-cut strain differences exist with respect to predisposition to salt-induced hypertension. Elevation of serum cholesterol was observed in some rats and dogs on high sodium

diets, which suggested the possibility that excess salt (i.e., sodium) consumption plays an accessory role in initiating or promoting arteriosclerosis, a condition whose complications are usually the actual cause of death in hypertension. Unpurified sea salt produced more hypertension than did sodium chloride alone, which indicated that other ions might augment the hypertensogenic effect of sodium. Ten patients on controlled sodium intakes were studied, and the rates of Na^{22} and K^{43} elimination from the body were measured with the whole-body counter. Total-body sodium and potassium were similarly estimated. The IBM 7090 computer at Brookhaven is being used for a detailed analysis of the very numerous data. Similar studies are under way with hypertensive rats using the same isotopes and a specially designed whole-body counter. Selective breeding of the two strains of rats, one of which is sensitive, the other very resistant to excess salt in the diet, is continuing in order to allow studies of factors responsible for the difference.

MEDICAL STUDIES OF THE PEOPLE OF THE MARSHALL ISLANDS ACCIDENTALLY EXPOSED TO FALLOUT

The objective of the annual medical surveys of the 239 Marshallese people accidentally exposed to fallout radiation in 1954 is to determine the long-term effects of whole-body gamma exposure, beta irradiation of the skin, and internal contamination.

No deaths resulted from irradiation and no advanced cases of radiation illness developed in the exposed Marshallese; thus the considerable knowledge gained from studies of the population with respect to the effects of fallout radiation applies in the sublethal dose range. The investigations involved direct examination of these people in the field, as well as studies of blood, serum samples, and other materials brought back to the Laboratory. Studies made during the past nine years include complete hematological evaluation for residual bone marrow damage, cancer and leukemia studies, development of batteries of tests to quantify aging criteria, verification of retardation of growth and development of exposed children by x-ray determination of bone age and anthropometric measurements, gross and histopathological examination of beta burns of the skin, and development of techniques for cytogenetic studies (chromosome aberrations) in tissue cultures of

peripheral blood and bone marrow and of beta-irradiated areas of skin. Body burdens of radio-nuclides have been determined by gamma spectrographic analysis with use of a 21-ton steel room constructed at Brookhaven and transported to the Islands, and by radiochemical analyses of urine samples. The relationship of the body burdens to environmental contamination is an important part of these studies.

POSITRON SCANNING

Positron scanning, with use of radioisotopes such as As^{74} , has been established as a useful clinical method for locating brain tumors. Certain compounds labeled with these radioactive positron emitters become selectively concentrated in brain tumors relative to the normal surrounding brain tissues. The scanning method depends on the principle that a positron is annihilated almost instantly after its emission, and two gamma rays are emitted in opposite directions. Thus a simultaneous count registered by two detectors indicates emission of a positron within the volume between the two detectors. If only two detectors are used, however, as is the case with positron scanners currently in use, it takes up to 40 minutes to scan the head. In the expectation that this time could be appreciably shortened, development of an instrument using a multiple array of detectors was undertaken.

A device has been constructed with 32 one-inch-diameter NaI crystals used as the detectors and including electronic circuitry suitable for recording coincidence counts between all possible pairings of the detectors. Since many of the lines connecting detectors fall outside the volume of interest, however, only 178 of the total pairings are usable.

Interpretation of the coincidence counts obtained has posed some difficult problems. The two principal approaches to using the counts to map the distribution of the radioactive source have involved the use of large digital computers. In one method the counts are regarded as a column vector in a system of 178 simultaneous equations with 178 unknowns. Solving such a large system of equations requires the use of a matrix inversion procedure, which in turn requires a larger number of memory locations than the available machines can provide, so that it has been necessary to partition the problem and to use magnetic tapes to store the intermediate results. In the second approach an analogue output is derived and dis-

played on an oscilloscope. The program for this approach in effect provides a brightening along the path connecting the two detector locations for which a coincidence count is recorded, with an exponential increase in the brightening at the location of the intersection of two or more paths. Although at present a large computer is necessary in the data reduction process, it is anticipated that special, smaller computers suitable for use in a clinical center can be developed, once the method has been established.

COMPUTER APPLICATIONS

Two large, high-speed digital computers, the BNL Merlin and an IBM 7090, are used in a variety of Medical Department problems, and development of further uses is under way. Among the existing uses are the calculation of neutron fluxes from activated gold foil data; spectral "stripping" with data obtained with the whole-body counter; statistical calculations such as least-squares fits and standard errors; generation of model systems for use in the interpretation of the behavior of radioactive tracers introduced into compartmented systems; calculation of molecular

Figure 9. Multidetector positron scanner for locating brain tumors.

weights from ultracentrifuge patterns; and correlation of information from the multidetector system under development for using positron emitters in the location of brain tumors.

A recent special computer application arose in the studies of the extracorporeal irradiation of blood, which involves shunting blood from an artery or vein through an x-ray beam and back into a vein. In such a process some portions of the blood recycle and are irradiated many times, while others may completely escape irradiation. The Merlin computer was used to generate curves giving the fraction of the blood that has received a given dose of radiation as a function of the number of cycle times; thus a basis is provided for interpreting the observed effects on the diminution of the white blood cell count.

An entirely different type of computer, an analogue computer, has been developed for the use of

the Medical Department by the Instrumentation Division. This instrument is designed specifically for simulating the time course of the behavior of labeled substances introduced into compartmented systems. There is provision for representing data points by generating a set of 96 dots, which are displayed on an oscilloscope simultaneously with up to 4 analogue curves. Fitting the analogue curves to the data by this method in effect solves the differential equations describing the model system used and provides answers in terms of the parameters of the system, such as the sizes of compartments and the rates of flow of the substance of interest between compartments. This instrument is most useful in the search for suitable models and for obtaining first approximations of the values wanted. For production runs using an established model and for cases in which a least-squares fit is needed, a digital computer program is used.

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

The Brookhaven Graphite Research Reactor (BGRR) operated throughout the year without a major operating incident. During 84.6% of the year operation was at full power. There were 15 scheduled shutdowns for changes in experimental equipment and maintenance work. On two occasions shutdowns were scheduled on short notice for the inspection or correction of operational difficulties. Five additional shutdowns of short duration occurred without notice; these were associated with human errors or malfunctioning of equipment. Power failure caused two shutdowns.

The graphite structure was annealed 15 times during the year. The procedure of annealing more frequently at lower graphite temperatures, initiated last year, was continued. It was found that annealing at a maximum temperature of 250°C did not produce the desired result, and the maximum graphite annealing temperature was gradually increased until significant recovery of growth could be measured following each annealing operation. This maximum temperature was found to be 350°C.

Between Christmas Day and New Year's Day the reactor was shut down for service, and extensive inspections and tests were made in areas that ordinarily are not readily accessible. One such inspection revealed that five bars of graphite had protruded across the gap of the reactor. Returning the bars to their original places and restraining them with pins was a relatively simple matter, but the event caused some concern, since it was the first evidence of deterioration of the moderator structure. An analysis was made of stresses that might have caused the bars to protrude. It is thought that effective annealing will prevent future occurrences of this type.

The emergency diagonal shot wells were also tested during the holiday shutdown. The shot

from one of the two wells failed to empty into the diagonal in-reactor tube. An inspection revealed that paraffin within the well had prevented the shot from dropping. Both wells were disassembled, cleaned, and retested. In addition, the reactivity worth of the wells was measured to be \$1.63. In the future these devices will be tested twice each year.

The Reactor and Critical Experiments Safety Committee reviewed the trichlorobenzene emergency system and recommended that it be deactivated because it constituted a possible hazard to the reactor. This was done, and the system has since been completely removed.

The various activities of the Reactor Division have been audited by several groups and committees during the year, including representatives of the Brookhaven Office, the New York Operations Office, and the Division of Operational Safety of the AEC; the Division of Reactor Safeguards of the International Atomic Energy Agency; the BNL Audit Group; and the *ad hoc* committees regularly appointed by the Laboratory's Director. In general, the results of these audits were favorable. A number of minor equipment and procedural changes were made in compliance with the various recommendations received.

An extensive hiring and training program was conducted throughout the year as the additional personnel required for the operation of the High Flux Beam Research Reactor (HFBR) were acquired. It is expected that all HFBR operators will be qualified to operate the BGRR and some will also be qualified on the Medical Research Reactor (MRR) before construction is completed on the HFBR.

Utilization of the Graphite Research Reactor

The most significant changes in the utilization of the reactor involved the facilities on top of the reactor. Last year the shielding facility which had become obsolete was removed, and this year the exponential reactor experimental facility was removed. With the need for such "thermal column" facilities definitely lessening, other uses for this space have been developed. Two new vertical holes 9 ft deep and 4 in. in diameter were drilled

in the moderator structure. A fuel test program involving sodium-cooled fuel pellets is planned for one of these holes, and a liquid nitrogen facility for experiments in solid state physics is being designed for the other. Several additional holes can be drilled to meet future demands for space.

The provision of new facilities at the reactor is motivated in part by the desire to maintain stable charges for use of the reactor. Figure 1 indicates that the expenses incurred in operating the BGRR have remained relatively stable since 1957 and are expected to remain so through 1965. The charges made to the users, however, depend upon total utilization of the reactor and can be expected to increase unless additional facilities are installed and new experiments replace those that have been completed. The availability of highly desirable experimental facilities within the HFBR is also expected to affect this situation.

Table 1 summarizes the use of the reactor and the associated charges. Approximately 35 of the BGRR's experimental holes are assigned to the Laboratory's research departments for projects which are described in the pertinent sections of this report. Eight facilities have been maintained for irradiations under controlled conditions of time and temperature for general use. Five experimental holes have been assigned for the graphite monitoring program which is now supported as a reactor control project rather than an AEC research project, a change that tends to increase users' costs. Outside organizations have accounted for continuous use of an average of four experimental holes. Brief descriptions of their activities are listed below.

Figure 1. Costs connected with operating the BGRR.

Bell Telephone Laboratories. Studies have successfully been made on the origins of antiferromagnetism in titanium sesquioxide over the temperature range from 1.4° through 711° K and in lithium cupric chloride dihydrate from 1.4° through 5.05° K. Very small upper limits have been placed on the maximum possible atomic moments of pure palladium at low temperatures, and all the protons have been located in the unusual compound K_2ReHg .

Rensselaer Polytechnic Institute. A circulating gas loop experiment is in progress to study the effects of various parameters (temperature, pressure, and gas composition) on the production of NO_2 from oxygen-nitrogen mixtures using fission fragment energy. The high-pressure stainless steel loop contains uranium-bearing glass wool (total U^{235} , 1.5 g). Nitrous oxide is being used as the dosimeter. In addition, static tests were carried out by irradiating sealed quartz ampules that contained various gaseous mixtures, with and without uranium, at different temperatures and different pressures.

Naval Research Laboratory. Short-term irradiation of several magnetic core and thin film materials was carried out to study changes in magnetic and physical properties caused by reactor radiation damage.

Columbia University. The measurement of the electron-neutrino angular correlation in the decay of He^6 was completed during fiscal 1963. A single-crystal neutron spectrometer, effective in the neutron energy range from 0.0006 to 10 ev, was used to measure total neutron cross sections of interest in the study of atomic motion in solids and liquids. Investigation of alpha-particle energy distributions and fission-fragment mass distributions in ternary and binary fission was continued with use of solid-state detectors. A precise value of the half-life of U^{235} for alpha emission was determined from the analysis of the alpha spectrum of natural uranium. The half-life of U^{235} obtained from these measurements is $(6.92 \pm 0.09) \times 10^8$ years.

Wright Air Development Center. The study of gamma-gamma coincidence following neutron capture, using a three-NaI(Tl)-crystal pair spectrometer, was terminated. The BNL Physics Department will continue the investigation.

Esso Research and Engineering Company. Short-term irradiations of terphenyl samples containing C^{14} as a tracer were carried out to study the effects of reactor radiation damage on this material when used as a reactor moderator.

Table 1

Summary of Reactor Use Charges

	Use charges (in thousands of dollars)							Percentage of total usage	Dollar amounts
	0	100	200	300	400	500	600		
<u>Fiscal 1963</u>									
Outside Organizations								9.5	\$ 100,996
Irradiation Service Group								3.1	40,992
BNL Research Departments									
Physics								58.9	688,002
Chemistry								9.8	110,520
Nuclear Engineering								15.6	182,927
Biology								3.1	40,860
								100.0	\$1,164,297
<u>Fiscal 1962</u>									
Outside Organizations								5.7	\$ 65,156
Irradiation Service Group								4.6	51,739
BNL Research Departments									
Physics								63.2	724,096
Chemistry								9.7	111,870
Nuclear Engineering								13.0	149,008
Biology								3.8	43,500
								100.0	\$1,145,369
<u>Fiscal 1961</u>									
Outside Organizations								10.5	\$ 121,621
Irradiation Service Group								7.4	84,720
BNL Research Departments									
Physics								53.4	615,933
Chemistry								8.7	99,900
Nuclear Engineering								14.2	165,193
Medical								2.0	23,896
Biology								3.8	43,410
								100.0	\$1,154,673

Brown University. Short-term irradiations of several types of alkali halide crystals have been made to study the relationship between radiation damage and thermal neutron dosage.

Naval Ordnance Laboratory. In cooperation with the BNL Physics Department (Solid State Division) diffraction studies were made by using single crystals and a polarized beam of neutrons. In addition, powdered magnetic materials were studied with use of a powder diffractometer.

General Electric Company. Studies of magnetic and crystal structure were performed from neutron diffraction patterns obtained, mostly at low temperatures, from the following materials: MnRh; Mn₃Sn-Mn₃Ge; Co₃O₄; CoAl₂O₄; FeAl₂O₄; and MnAl₂O₄; and calcia-stabilized zirconia.

Irradiation Services and Isotope Production

As shown in Table 2, the volume and income involved in providing irradiation services to outside organizations have in general decreased over the past three years. This trend probably reflects the increasing availability of similar irradiation services in commercial reactors as well as the AEC's policy of noncompetition. On the other hand, the volume and income figures for processed isotopes have shown an increase, since these items are in increasing demand but are not yet available commercially.

A year ago, a system of costing for irradiation services was instituted which reflected the value and volume of services in terms of reactor usage. While the usage indicated on this basis for irradiation

Table 2

Summary of Irradiation Services to Outside Users
(Handling and Other Charges Included)

	Fiscal 1963		Fiscal 1962		Fiscal 1961	
	Number	Volume, \$	Number	Volume, \$	Number	Volume, \$
Reactor irradiations	466	55,196	641	75,918	828	84,858
Processed radioisotopes	376	72,726	349	59,926	330	64,490
Co ⁶⁰ sources	4	19,442	3	3,077	6	6,098
Cyclotron irradiations	8	2,095	12	2,342	62	9,885
Total	854	149,459	1,005	141,263	1,226	165,331

Table 3

Types of Customers Receiving Shipments

	Fiscal 1963		Fiscal 1962		Fiscal 1961	
	% of Customers	% of Shipments	% of Customers	% of Shipments	% of Customers	% of Shipments
Hospitals	25	39	22	51	20	39
Industrial	35	22	36	24	39	30
Universities	27	34	26	19	24	24
Government	5	1	8	3	7	4
Foreign	8	4	8	3	10	3

tion services dropped 25% last fiscal year, the decrease this year was only 8%, and at the close of the year the usage rate appeared to be leveling off.

The distribution of the services covered in Table 2 is presented by type of customer in Table 3. While there are some year-to-year changes, no marked or significant trends are apparent.

Procurement of Special Materials

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, 299 purchase orders were placed for radioisotopes, 68 for stable isotopes, and 46 for special materials. Against these orders ≈ 581 shipments were received and processed. These figures represent an increase over last fiscal year of 4% in orders placed and 8% in receipts. Of the orders placed, $\approx 35\%$ were for the Medical Department, 17% for Nuclear Engineering, 16% for Biology, 16% for Chemistry, 14% for Physics, 1% for Instrumentation and Health Physics, and 1% for the Reactor Division.

The Isotopes and Special Materials Group is responsible also for annual inventories of radium sources and purchased stable isotopes and for negotiations for the loan of valuable isotopes. The number of radium sources at Brookhaven was essentially unchanged at 38 with a total activity of 5.86 curies and a value of \$39,495. The inventory of purchased stable isotopes (\$32,900) was about the same as last year's, since additional purchases totaling \$22,200 were offset by consumption valued at \$23,800. During the year the number of loan agreements for stable isotopes decreased from 43 to 39 with a value of \$180,000, exclusive of four special samples with an estimated value of \$1,064,000.

The Brookhaven irradiation programs in the Materials Testing Reactor (MTR) and the Engineering Test Reactor (ETR) during fiscal 1963 are summarized below.

BNL-18: Testing of Prototype Fuel Elements for the HFBR. This program, started in May 1960, involved the testing of nine fuel elements and was completed late this year.

BNL-21: Radiation Damage in Pure Iron. The irradiation of four capsules containing iron tensile

test specimens was completed in September 1962, and the program was terminated.

BNL-22: Radiation Damage in Graphite. Two of three instrumented capsules were irradiated in July 1962. They were removed from the reactor after a few days because of failure of the capsule connections under vibration. The program was held open with the expectation of redesigning the capsules but was finally terminated in April 1963 without further tests.

BNL-23: Radiation Damage in Carbon. The irradiation of three capsules containing diamond chips was completed in September 1962 and the program was terminated.

BNL-24: Radiation Damage in Carbon. The irradiation of three capsules containing diamond chips was completed and the program was terminated in February 1963.

BNL-25: Production of Special Research Isotopes. The irradiation of one capsule containing twelve enriched stable isotope samples was completed and the program was terminated in November 1962.

BNL-26: Neutron Irradiation Burnup Studies on Chemonuclear Fuel Materials. This program, initiated in December 1962, involved the irradiation of three capsules containing various uranium-bearing alloys and glass fibers. The irradiations were completed in June 1963, and the program will be terminated.

BNL-27: Irradiation Effects on Polyethylene. This program, initiated in February 1963, involved irradiation of one vented and two sealed capsules containing polyethylene samples. The irradiations were completed in June 1963, and the program will be terminated.

Source and Special Nuclear Materials Accountability

Table 4 presents a three-year summary of the amounts of source and special (SS) nuclear 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 of $\approx \$6,600,000$. The net increase from last year's figure of $\approx \$5,600,000$ was due primarily to additional heavy water and $U^{235} > 75\%$ received during the year.

The individual decreases in the amounts listed are the result of shipment of some surplus items, shipment of some irradiated natural uranium fuel containing plutonium for reprocessing, and the

Table 4
Source and Special Nuclear Materials on Hand
at End of Year (in kilograms)

	Fiscal year		
	1963	1962	1961
<u>Station BRL</u>			
Natural U	1,720	2,043	2,688
Depleted U	669	2,968	2,950
$U^{235} > 75\%$	211	142	69
$U^{235} < 75\%$	6,412	6,410	7,815
U^{233}	0.047	0.027	0.051
Pu^{239}	2	3	2
Th	204	216	252
Heavy water	53,591	15,030	13,179
<u>Station BRG</u>			
$U^{235} > 75\%$	99	108	84
<u>Station BRM</u>			
$U^{235} > 75\%$	3	3	3

approved discard of some irradiated normal and enriched uranium. In Station BRL, there was a large increase in the heavy water inventory due to receipt of material which will be needed for operation of the HFBR. The increase in $U^{235} > 75\%$ was due to receipt of more surplus fuel assemblies for use in critical experiments.

A purchase order for 3000 BGRR fuel elements, which was completed last fiscal year, was extended to cover an additional 975 fuel elements for delivery this year. Because of last-minute difficulties, however, the fabricator could deliver only 925 completed elements. Under the AEC policy of limiting the ordering of reactor fuel to yearly requirements, an order for ≈ 1400 BGRR fuel elements will be placed in the coming fiscal year.

Since BGRR fuel elements are carried on the accounting records at an assigned standard weight for the uranium content, the delivery of each additional order necessitates a revision in the standard weight. The revision is based on averaging the uranium content of the fuel elements on hand in the storage vault and the reactor with the uranium content of the new fuel elements received. Such a revision was made in July 1962, and another will be made in July 1963.

During this fiscal year, 9 shipments, involving 1782 spent BGRR fuel elements, were made by rail freight to the Phillips Petroleum Chemical

Processing Plant at Idaho Falls, Idaho. These shipments have reduced the inventory of spent fuel elements in the canal to the extent that the frequency of future shipments will be limited by the required cooling period for spent fuel after discharge from the reactor.

The revised SS accountability manuals for Stations BRG and BRM were issued in July 1962 after clarification of some policies with the International Atomic Energy Agency (IAEA). Under the Four Reactors Agreement with the U.S. Government, effective June 1, 1962, the IAEA performed two inspections this year. The first inspection (the second under the two-year agreement) was of the BRG facility on November 1, 2, and 5, 1962, by two inspectors, Dr. Dragoslov Popovic and Mr. Carlos Buchler. The second (third) inspection was made from May 5 through May 10, 1963, by Mr. Buchler and included both facilities, BRG and BRM. Both inspections involved auditing of the SS material inventories, accounting, and operating records for evidence of diversion, and review of facility usage in terms of peaceful purposes. The results of these inspections have been satisfactory.

Medical Research Reactor

The MRR was operated on 284 occasions during the year, and 281,496 kw-hr of operation were accumulated. The total integrated energy to date is 1,422,966 kw-hr. Some of the more extensive experimental programs conducted during the year were the investigation of chronic neutron irradiation effects on large numbers of mice (by the Biology Department), neutron irradiations of HeLa cells, and an investigation of the feasibility of using epithermal neutron beams for neutron capture therapy. The latter program, which involved numerous modifications of the treatment facility shutter configurations, will continue for some time.

Routine semiannual control rod inspections, conducted in September 1962 and March 1963, showed the MRR control rods to be in good condition. There were no occasions of unsafe failure or sticking of control rods during the year. The only instance of control rod system malfunction occurred in November 1962, when an intermittent short circuit developed in the wiring of one control rod coupling magnet, a safe type of failure.

In August 1962, the MRR nuclear incident control system was modified to include a direct automatic alarm indication to Security headquar-

ters and both visual and audible alarms at all reactor building entrances. An electrical interlock has been provided on the east air-lock entrance door to the reactor building. Persons desiring to enter through this door during reactor operations must receive permission from either the Medical Health Physics Group or the MRR operator. In addition, two of the four containment-building relief vents have been modified to limit the building's negative pressure in the event of a trip of the incident controller, a change that will simplify evacuation of the building in an emergency.

In January 1963, a new prototype control rod, which consists of a stainless steel bar containing 2.5% boron encased in a stainless steel sheath, was tested at the MRR for poison worth and operability. All operability tests proved satisfactory, and the total worth of the rod compared favorably with that of the present rods. These tests will be continued, after minor modifications, in anticipation of eventual replacement of the present rods with rods of this type.

A new improved pneumatic tube facility has been installed in the northwest experimental hole of the MRR. The operation of this new facility has been much simplified, and it will accommodate a sample holder similar to those used at the BGRR.

Internal leaks in the primary reactor heat exchangers were discovered in January 1963, and inspection of these units revealed severe pitting and corrosion of the secondary water side of the aluminum tubes. An attempt to repair the leaks by tube removal and plugging of the tube sheets was unsuccessful, and it was decided that replacement of the aluminum tube bundles with a more corrosion-resistant material was necessary. Investigations indicated that the use of stainless steel tubes would be practical, and new stainless steel tube bundles were ordered. Delivery is expected in July 1963. The installation should be completed in mid-August.

The absolute filters in the reactor exhaust air system were replaced in December 1962 with new units of the same type, since the differential pressure across these filters was approaching the maximum limits. Installation of the new filters reduced the differential pressure to the normal value.

HEALTH PHYSICS

The staff of the Health Physics Division increased from 66 to 72, in keeping with the contin-

ued growth of the Laboratory and the increasing complexity of operations. Six members of the Division are concerned with general safety, including safety engineering, construction safety, and problems related to the extensive use of liquefied gases, while eight are engaged in waste disposal and reclamation activities.

Radiation safety problems at the BGRR were somewhat decreased by a cleanup of the canal area made possible by removal of all the old-type natural uranium fuel elements. On the other hand, problems at both synchrotrons were accentuated by increases in beam intensity and in the scale of the experimental program. Most of the accumulated radioactive waste was shipped off site, an expensive and time-consuming project (see below). There were no major additions to capital equipment, but the Division's instrumentation was improved by procurement of a well counter and development of an alpha spectrometer, a polonium air monitor, and an improved fixed monitoring system for the BGRR.

Waste Disposal and Reclamation

For the past 3½ years, all but the lowest level liquid and solid radioactive wastes have been packaged in 10-ton concrete vaults and stored at the waste control area on site. This spring, arrangements were made to ship the accumulation of 240 vaults to Oak Ridge for burial. The blocks were loaded into freight cars, securely anchored, and transported in a 34-car special train, escorted by five health physicists. Special arrangements for this shipment were necessary, since radiation levels at the surface of some of the blocks were >200 mr/hr.

In addition to the concrete vaults, 75 tubes containing old-type spent reactor fuel elements have been in storage for some time. By using special facilities constructed for the purpose at the reclamation building, the elements were pushed out of 60 of the tubes into shipping containers and were forwarded to Savannah River for processing. The other 15 tubes couldn't be emptied and were returned to storage. This was a difficult operation involving high levels of radiation and contamination.

The shotblasting facility installed a year ago was thoroughly tested during the fall and has been in routine operation this spring. It has been extremely valuable in handling the steadily increasing volume of decontamination work. A still has been set up for processing contaminated mercury

Table 5
Summary of Liquid Waste Data

	Fiscal 1963	Fiscal 1962
Input to filter beds, gal/day	720,000	612,000
Output from filter beds, gal/day	578,000	537,000
Net loss in filter beds, %	19.5	11.8
Stream above discharge point, gal/day	121,000	450,000
Stream at site boundary, gal/day	661,000	1,053,000
Rainfall, in./mo	3.5	3.6
Activity concentration at input to filter beds, C/cc	1.4×10^{-13}	3.2×10^{-13}
Activity concentration at output from filter beds, C/cc	1.3×10^{-13}	2.4×10^{-13}
Reduction in activity concentration, %	7	25
Activity at input to filter beds, mC/mo	10.6	22.6
Activity at output from filter beds, mC/mo	8.8	15.1

Figures are averages for each fiscal year.

and is turning out ≈ 325 lb/mo of reclaimed mercury of very high purity. These reclamation activities are very profitable, since they save both the cost of replacement and the cost of disposal.

Data relating to the liquid waste system are presented in Table 5. The amount of activity leaving the site in the stream into which the effluent is discharged totaled 97.0 mC during the fiscal year, and the average concentration was 1.1×10^{-7} μ C/cc.

Personnel Monitoring

Activities of the Personnel Monitoring Group continued to expand gradually in step with the growth of the Laboratory staff. Film processing equipment in service for 15 years was replaced, and the darkroom was enlarged and modernized.

The distribution of exposures for the 2504 individuals regularly monitored is shown in Table 6. Despite an increase in the number of exposures >5 rem-equivalent compared to the previous year, the over-all exposure was lower by $\approx 10\%$. All exposures were <3 rem-equivalent per 13-wk period except in the case of one individual at the reactor who received an exposure of 4.8 r to a limited portion of the body. In no case has an individual exceeded the prescribed limit on integrated exposures.

Table 6

Distribution of Exposures of Individuals Receiving Regular Personnel Monitoring Service

Exposure index range*	Calendar 1962	Calendar 1961
0.0-0.4	2330	2187
0.5-0.9	79	106
1.0-1.4	30	28
1.5-1.9	13	20
2.0-2.4	11	14
2.5-2.9	14	6
3.0-3.4	8	9
3.5-3.9	5	11
4.0-4.9	6	15
5.0-5.9	7	2
6.0-6.9	1	0
Total	2504	2398

*Exposure index = $\frac{1}{2}$ of β exposure in rads + γ exposure in r + neutron exposure in rem.

Synchrotron Monitoring and Dosimetry

Continuous operating schedules at both proton synchrotrons were established during the year, and considerable effort has been devoted to training the technical staff required for 21-shift coverage. A detailed training manual has been written, and monitoring and control procedures have been formalized to some degree. However, experimental programs at both the Cosmotron and the AGS are constantly changing, and the efficiency of both machines has continued to improve. Thus, exposure control problems are increasing in number and diversity. The measurement of fast neutron fluxes with moderated indium foils has been reduced to a routine, and numerous data have been accumulated on radiation levels from targets and activated machine components.

Work has been continued on the study of depth-dose patterns, with results similar to those summarized in last year's report. One experiment performed with a very pure beam of 2.9-Bev protons showed a twofold buildup of dose in rads at a depth of 7 in. as compared with the dose measured in air. The dose at the front surface of the phantom was 25% greater than the air dose. However, in most work areas there is no appreciable buildup of dose with depth, and measurements in air are adequate for hazard evaluation.

Area Survey

Background radiation dose rates measured with ionization chambers at two off-site stations averaged 3.9 mr/wk. This was a slight increase over the previous year's value of 3.6 mr/wk. The highest value, 5.0, occurred in June following the spring peak in fallout from the weapons tests in the fall of 1962. The average fallout rate in rain and settled dust was 488 mC/sq. mile/mo as compared with 220 mC last year. The rate varied considerably from month to month, with a minimum value of 138 in July and a maximum of 1120 in April.

The highest radiation level at the site boundary occurred at a point opposite the gamma forest source and averaged 7.40 mr/wk. This may be broken down into three components of 4.73, 1.22, and 1.45 mr/wk due to background, Ar^{41} from the reactor, and the forest source, respectively. Thus, the total addition to background due to Laboratory operations was 2.67 mr/wk, which may be compared with the permissible level of 10 mr/wk.

The iodine released from the reactor stack was not detectable at ground level, but fallout iodine was observed in environmental samples during most of the year at levels comparable with those reported by other nearby stations. The highest I^{131} level in milk was noted in October and amounted to 155 pC/liter.

General Safety

The Radiation Safety Committee was reconstituted as the Laboratory Safety Committee and will henceforth deal with all safety problems including those not involving radiation hazards.

The service aspects of the general safety program have been expanded to include periodic inspections of construction projects both for the Brookhaven Office of the AEC and for the Laboratory. The accident record for calendar year 1962 was about the same as that for 1961; the respective frequency rates were 3.5 and 3.4 per million man-hours. The policy of encouraging safety inspections by departmental personnel is working well; more safety problems are being dealt with effectively at the local level. There has been a gratifying increase in the use of technical consulting services provided by Safety Office personnel.

MECHANICAL ENGINEERING

During the past year the level of mechanical engineering activity at Brookhaven has remained

almost constant. The distribution of personnel among the various departments is shown in Table 7.

The major engineering achievement this year of Division personnel assigned to the Bubble Chamber Group was the completion of fabrication, assembly, and operation of the 80-in. liquid hydrogen bubble chamber. The hydrogen chamber was cooled down and expanded, and on June 2, 1963, tracks from the AGS were photographed with and without the magnetic field.

Other activities of the group have been the operation of the 20-in. liquid hydrogen bubble chamber to obtain 1.2×10^6 pictures and the operation of the 30-in. liquid hydrogen bubble chamber to obtain 0.4×10^6 pictures.

Personnel have been active in developing film-reading equipment for bubble-chamber pictures. A 70-mm reader for the 80-in. bubble chamber has been designed, and a film handling system for the Hermes film readers to handle 1000-ft film reels has been designed and is in production.

Some progress has been made in developing coils and cryostats for working on superconducting magnets using the new hard superconducting materials niobium-zirconium and niobium-tin.

The general physics group has worked on a number of independent projects. Preliminary design has started on a spectrometer system for polarization studies to be used in the HFBR. The system will include three minutes of arc collimation, an angle divider accurate to one second of arc, and a superconducting magnet system.

Fabrication was completed of the major components of six neutron spectrometers for use by the Physics and Chemistry Departments at the HFBR. An almost identical spectrometer was assembled on site for the Puerto Rico Nuclear Center, and another is being assembled for the Weizmann Institute of Science in Israel. Design has been finalized for a new three-crystal spectrometer for inelastic scattering to be utilized at the HFBR.

The first rotor of a new three-rotor slow-neutron chopper system was designed and fabricated. The system will be used for research in solid and liquid state physics, particularly for elastic, quasi-elastic, and inelastic scattering measurements at the HFBR. The finished rotor is vertically shafted and, like the other two, has a diameter of 80 cm. In the system two rotors spin on a horizontal axis and one on a vertical axis at a maximum speed of 250 rev/sec, with a constant phase angle relative to each other. The completed rotor acts as both a

Table 7
Assignment of Mechanical Engineering Division
Personnel as of June 30, 1963

Department	Engineers	Designers and Draftsmen	Secretarial and Clerical
Accelerator			
AGS	21½	20	½
Cosmotron	10	6	—
Central Design	1½	8	1½
Nuclear Engineering	6	20	1
Physics			
Bubble chambers	15	12	—
General design	8	12	—
Reactor	—	2	—
Safety Services	1	—	—
Total	63	80	3

neutron chopper and a rotating collimator and consists of upper and lower high-strength aluminum forging discs with a 5-cm-thick Mg-10% Cd alloy ring in between. The path of neutrons is perpendicular to the rotor axis and travels through a geometry comprising some hydrogenous material and a central steel ring and then through the Mg-Cd ring, which has three equally spaced slits. The design of one of the horizontally shafted rotors has been completed. This rotor will be constructed from a Mg-Cd alloy forging and will have three slits of the same dimensions as those in the vertical rotor.

The combined three-rotor system will be capable of producing short bursts of monochromatic neutrons at the sample with wavelengths $\lambda_0 = 3.5 \text{ \AA}$ and longer, depending upon the speed of rotation of the rotors. The scattered spectrum will be analyzed by the time-of-flight method in which a burst of neutrons of the order of several microseconds' duration is produced and the time required for the neutrons to reach a detector some 10 meters distant is measured electronically. An elaborate system of spin testing has been set up on the Laboratory site, and all three rotors will be spin-tested before final installation at the HFBR.

The drive system, specifically designed and fabricated for the slow-neutron chopper, consists of three frequency modulated ac drive motors, a motor-generator set, and control equipment for operation, regulation, and synchronization of the drive motors. The design criterion for speed regu-

lation is to maintain speed to $\pm 0.25\%$ from 3600 to 15,000 rpm, and in addition to provide synchronism within a phase angle of 0.1% .

A high current particle lens is being developed to focus a beam of charged particles by means of a high magnetic field. This device will use a cylinder made of separate insulated conductors with the same current passing through them all. Thus a focusing field varying directly with radius will be produced to focus charged particles traveling along the axis of the cylinder. To obtain this high field and at the same time minimize multiple scattering and absorption, it is necessary to construct the lens of a material capable of carrying a high current density and having a low atomic number. Lithium metal has been chosen for this purpose. At $\approx 20^\circ\text{K}$ the electrical resistivity of lithium decreases to a point at which it is feasible to carry off the heat generated by the high currents.

Tests for electrical resistivity have been made on samples of lithium of various purities. An attempt was made to correlate electrical resistivity and certain impurities. The impurities varied so widely that the correlation could not be made. A source of high-purity (99.997%) lithium has been found, and this material is due shortly. The lens is to be constructed of the best material available to date (99.88% pure). A second version of the lens which will allow the use of lithium or sodium is in the design stage. The hydrogen cryostat in which the lens will operate has been designed and is now being manufactured. An investigation of the possible use of temperatures $< 20^\circ\text{K}$ is also being made. These lower temperatures would be employed if the lens were to be constructed of sodium.

The ever-increasing quantity of 35-mm stereoview photographs of spark-chamber tracks has indicated the urgent need for a machine that will automatically reduce the coordinates of these tracks to data stored on magnetic tape. In tape form they are readily assimilated by the IBM digital computer. Design of the spark-chamber film reader was initiated in June 1962. Final assembly is scheduled for the early part of July 1963.

The muon reprojection system is utilized to reproduce on a 34×34 -in. precision glass screen a space view of the muon experiment one-fifth the actual size. In addition, the unit also provides a means of rapidly digitizing x and y coordinates to aid in the final computation. An interesting feature of the design is the incorporation of a photosensitive device that automatically stops the specially con-

structed 70-mm film transport systems and relatively positions the varying spark-chamber images on the reprojector viewing screen.

A fast-neutron chopper is currently being designed and constructed to evaluate the effects of gamma rays resulting from the capture of neutrons into resonant states of the nucleus. The design involved the determination of stresses and vibrations of a high-speed, high-density alloy composite rotor. A unique feature of the chopper rotor is an interchangeable collimator for additional versatility in the forthcoming fast-neutron chopper experiments at the HFBR.

The central design group has been mainly engaged in supporting the design effort of the general physics group.

Division personnel located in the Nuclear Engineering Department have been supplying engineering services to the majority of that department's programs.

In the area of experimental reactor physics, the major effort has been on the HFBR Mark II engineering mock-up, equipment for the new addition to the Critical Assembly Facility (fuel vault and containers), and the UO_2 -Th lattice assembly (fuel storage tank, modification of lattice frame assembly, shipping cask, fuel baskets, shielding, and supporting equipment).

In connection with radiation source development and radiation chemistry research the following services were supplied: design and development of standardized cobalt sources for irradiation at Savannah River; design and supervision of construction of a Co^{60} food irradiator to be installed in Florida for the Agriculture Division of the University of Florida; engineering services on the High Intensity Radiation Development Laboratory which was completed in June 1963; and design of an in-pile circulating gas loop for a variety of chemonuclear experiments.

In liquid-metal heat transfer and corrosion testing, work has been done on the boiling-potassium heat transfer facility under construction. Revisions are being made to the NaK liquid-phase heat transfer facility in preparation for the installation of a new test section in fiscal 1964. Rebuilding of the mercury liquid-phase heat transfer facility was completed in April 1963. Work in the liquid-metal corrosion testing area consisted of the design of a natural circulation, boiling-sodium loop to operate at temperatures up to 2200°F . This loop will be in operation during the summer of 1963.

Also, design and procurement for a pumped boiling-sodium loop is under way.

Supporting engineering for the settled bed reactor project includes the design of a 1000-gal/min water facility to test the hydraulic performance of small settled beds. The effort on the missile propulsion system involved the design and procurement of an air-storage and control system for a rotating fluid bed test as well as the design of a higher-speed rotating bed.

Some Division personnel are members of the HFBR project staff, which is responsible to the AEC for technical administration and many engineering services.

The Mechanical Engineering Division is represented on one of the committees of the American Nuclear Society (ANS-7 Reactor Components Standards Committee).

At the AGS, the major effort has been to support the operation of the machine with design and fabrication of new equipment.

To correct the vertical oscillations due to 12th harmonics in the magnetic field structure of the AGS, 96 radial field kicker coils have been added.

The mechanical services group at the AGS has been supervising the operation and maintenance of equipment of the utility type at the accelerator. In addition, instrumentation for the 80-in. bubble-chamber cooling tower and associated equipment has been completed, and the tower is now in operation. A preliminary design for the AGS experimental area cooling tower system was completed and turned over to the Stone and Webster Engineering Corporation for final design and procurement. The final phases of assembly were supervised at Brookhaven, and the plant was placed in operation. To service the new Southwest Experimental Area the main well-water lines were relocated, and a 1-Mw cooling tower system was designed for use with experimental equipment.

The Division's extensive work at the AGS is further described in the section on High Energy Accelerators.

The effort of Division members at the Cosmotron has also been in support of the use of the accelerator for experiments.

A breech-loading target ram has been tested and installed in the south straight section to speed up target changes for work in radiochemistry. With this device the target is inserted into a pneumatic tube and then automatically moved through the air lock and positioned at any preset radius.

Upon a signal from the control room the target is automatically withdrawn through the air lock and delivered to the breech end of the pneumatic tube.

An assembly of five flip targets has been designed to insert jump targets into the beam path for external beam extraction. This device will permit remote selection of target thickness when beam energy is changed and will replace existing manually changed targets.

To handle heavy equipment adjacent to the magnet without removing shielding, a 1½-ton circular crane was installed inside the main Cosmotron shield to cover 80% of the ring's circumference. A lightweight fixture for removing the Cosmotron vacuum chamber and a fixture for reblanketing the chamber inside the concrete shield have been designed. A new vacuum-system control center has been designed which will consolidate all controls and indicators on an illuminated map.

The experimental operations group has supported experiments being performed at the Cosmotron. In addition, design has been completed and procurement started for a new water system for the main magnet and experimental magnets. This will remove the present limitation of the evaporative coolers and reduce the consumption of well water.

A member of this group has supervised the construction of a machine shop and laboratory addition to the Cosmotron. This will provide a larger design room and more engineering offices.

The design, fabrication, and operation of all hydrogen targets at the accelerators has been the responsibility of the Cosmotron cryogenics group. They also supervise the handling and delivery of liquid hydrogen on the Laboratory site.

A deuterium separation plant to make deuterium from special heavy water of low tritium content was installed and placed in operation.

MACHINE SHOPS

The services provided by the Central Shops Division fall into three general categories: on-site fabrication, fabrication by vendors, and inspection and quality control. In addition, management of the Laboratory-wide machine tool organization and replacement program and the small tool standards program is the responsibility of the Division.

The facilities of the Division provided more productive man-hours in fiscal 1963 than in any

Table 8
Contributions to Machine Shops Workload

	% Man-hours		
	Fiscal 1963	Fiscal 1962	Fiscal 1961
Accelerators			
AGS	11.2	8.4	8.6
Cosmotron	8.4	15.7	14.3
Biology	2.0	2.6	3.1
Chemistry	3.0	3.3	3.4
Instrumentation and			
Health Physics	1.3	0.9	0.7
Medical	2.5	3.2	3.1
Nuclear Engineering	33.0	28.6	33.3
Physics	32.9	29.7	25.1
Reactor	3.6	4.5	6.6
Miscellaneous	2.1	3.1	1.8
	100.0	100.0	100.0

prior year. An increase in personnel resulted in a 16% increase in the number of productive man-hours over the previous fiscal year to a total of 138,448 for this year. Table 8 indicates the distribution of this time among the scientific departments. About two-thirds of all the work was performed for the Nuclear Engineering and Physics Departments, with the AGS and the Cosmotron collectively contributing another 20% of the work load. Work processed through intralaboratory requisitions accounted for 86.2% of the total, the remaining 13.8% representing jobs performed on a short-order basis. The average monthly backlog reached an all-time high of 18,419 hr, divided ≈ 70 to 30 between the machining sections and the sheet metal and welding sections.

Contracting of fabrication work to vendors has become an essential facet of Division operations in order to meet delivery schedules, control on-site backlog, and program work for fabrication in the most economical manner. The importance of this activity to the Division and the Laboratory at large is reflected in the addition of an administrative officer to the Division staff to assume responsibility for vendor fabrication work, vendor facility surveys, and vendor performance evaluation. The facilities of 59 vendors were surveyed and appraised, and 51 were found adequate for BNL work. Procedures were established for evaluating vendor performance, and the continuing program of review and evaluation will provide up-to-date

delivery and quality performance data derived from actual experience with BNL work. Close collaboration is being maintained with the Purchasing Division in the performance of these functions. During the year a total of 235 jobs, valued at $\approx \$80,000$, were processed under subcontracts with BNL.

During the latter half of the year the Inspection and Quality Control Section handled 2262 jobs. The demand for inspection services has increased steadily, and a number of pieces of equipment were procured during the year which will extend the capabilities of the section to perform these services. In particular, it is now possible to measure tension and compression forces and to obtain greater accuracy in angular measurements.

Two organizational changes were effected during the year. The position of Assistant Division Head was created with responsibility for all line operations of the Division's fabrication facilities, and a Production Planning and Inventory Control Section was established with responsibility for all preliminary processing of work and inventory control for capital equipment and small tools.

The purchase of three new machines made it possible to grind tools faster and more accurately, and a procedure was established for immediate exchange of worn tools for freshly ground tools.

About \$138,000 was spent for new shop equipment for the Laboratory during the year. Of this amount, about \$82,500 was used for machine tool replacements and additions in the Division, and the remaining \$55,500 was used for equipment for the 10 staff shops of the scientific departments. In addition, a number of machine tools were acquired from government surplus. The original acquisition value of these surplus tools was about \$134,000.

The major pieces of equipment procured for the Division included a 54-in. Bullard vertical turret lathe, a Bertsch initial bending roll capable of handling $\frac{7}{8}$ -in. mild steel plate 6½ ft wide, a Jones and Lamson 30-in. optical comparator, a 60-in. Allis-Chalmers rotary table, and a Pratt & Whitney Model B Tape-O-Matic drill. The latter is the first numerically controlled machine tool to be purchased by the Laboratory and represents a major step forward in a concerted effort to modernize facilities and improve operating efficiencies.

Several of the 2069 jobs worked on during the year were of particular interest. For example, the first production run of 125 cobalt source assemblies – for which the prototype was developed

during fiscal year 1962 – was completed in special, clean-room facilities under strict inspection and quality control; prototype control rods demanding the holding of extremely close tolerances during the welding operation were fabricated for the HFBR; a set of collimators were constructed for mu-meson proton experiments by utilizing surplus naval gun barrels; an atomic beam apparatus was fabricated; a stainless steel fluid-irradiator was constructed for the Medical Department to be shown at the 1964 World's Fair; control panels, two sets of plastic piston rings, and an insertion fixture were fabricated for the 80-in. bubble chamber as well as stainless steel bellows-and-shoe assemblies requiring very precise welding and close control of distortion due to welding. The bellows-and-shoe assemblies entailed a great deal of experimental and development work in fabrication and were undoubtedly among the most difficult jobs ever completed by the Division. The major part of a complete AGS beam extraction assembly was completed during the year, with fabrication split between vendors and Division facilities.

Work was also done for Rensselaer Polytechnic Institute, Massachusetts Institute of Technology, Columbia University, Argonne National Laboratory, New York University, the University of Illinois, the University of Rochester, the Weizmann Institute of Science (Israel), the General Electric Company, the Lummus Company, the Puerto Rico Nuclear Center, and the Naval Ordnance Laboratory.

TECHNICAL INFORMATION

With the possible exception of the Classified Library, all the Laboratory's technical information activities falling within the scope of the Information Division again showed a marked increase. In spite of a 3600-sq-ft extension, completed in 1960, space is again a problem in the Research Library. This is due mainly to the steady growth of the book and report collections, which must keep pace with the diversified demands of the Laboratory's research program. Of particular note is the recent rapid expansion of the Library's collection in the field of mathematics, a natural outcome of the increasing use of computer techniques in all areas of research. A significant increase in service by the Reference Section is noted in the acquisition of non-AEC reports and in the preparation of bibliographies.

The demand for the translation services provided by the Library has also continued to increase. Although the translations from the Russian scientific literature still predominate, requests involving other European languages are becoming more frequent. The translated proceedings of several important Russian conferences required by Brookhaven scientists have been made available to the atomic energy project through the cooperation of the Division of Technical Information of the AEC.

Because of the increased number of reports provided by the AEC's Division of Technical Information in microcopy form, the Library has acquired an additional microcard reader, a microcard printer, and a microfilm reader-printer. Other equipment recently installed includes a copying machine for the rapid reproduction of book and journal pages and several banks of open-shelf files for document storage.

Preliminary studies have begun on the adoption of a data processing system for the maintenance of library records. The programming of such records has been completed, and it is anticipated that lists of the Laboratory's journal holdings by subject, department, and vendor will be available.

After several years at a fairly steady level, the current workload at the Classified Library reflects a moderate rise in the Laboratory's involvement in certain areas of classified research. Most of this increase can be attributed to projects within the Nuclear Engineering Department concerned with the technology of advanced reactor systems; many of these projects have implications for the space propulsion programs being conducted elsewhere. During the year 953 classified reports were accessioned, as compared with 700 in the previous year. The annual inventory, conducted in March 1963, showed holdings of 14,918 classified research and development reports, of which 8108 are secret. In the previous year the total was 14,269 items. No classified formal reports were published by the Laboratory during the past year. In order to keep to the minimum the Laboratory's classified holdings, the services of two representatives of the AEC's Declassification Branch were obtained to review classified correspondence, with the result that 230 items were declassified. It is hoped that another visit by a declassification team can be made soon and will lead to a further reduction of the classified files.

The number of scientific manuscripts originating from Brookhaven-supported research and pub-

lished in the form of journal articles and Laboratory reports continues to increase. During the year 959 such documents (including published abstracts of speeches) have been reviewed and processed by the Information Division, as compared with 710 in the previous year, 708 in fiscal 1961, and 607 in fiscal 1960. With the increasing use of such research facilities as the AGS and Cosmotron for experiments, and the anticipated completion of the HFBR, a further increase in the volume of scientific publications emanating from the Laboratory is to be expected.

Seventy-six BNL formal reports were processed by the Division and given the appropriate distribution. Most of these reports are edited and otherwise prepared for publication by the Division's Editorial Section, which works closely with the Photography and Graphic Arts Division in ensuring that the Laboratory's technical publications meet the highest possible standards in format, style, and accuracy.

The Laboratory's expanding output of technical information was also reflected in the activities of the BNL Patent Office, which is responsible for the review and clearance for patent of all scientific manuscripts. The number of documents requiring such clearance showed an abrupt increase of $\approx 18\%$ when compared with the average for recent years. It is notable that no proportional increase occurred in the numbers of preliminary invention reports and records of invention; these remained well within the general range of the past several years. The sudden change in patent clearance activity is probably associated with the completion of the initial studies in high energy physics at the AGS coupled with the normal growth in the other fields of fundamental research.

Table 9 summarizes the activities of the BNL Patent Office during fiscal 1963 and the two preceding years.

During November and December 1962, a member of the Information Division served as Director

Table 9			
	Fiscal year		
	1963	1962	1961
Patent clearances	909	768	760
Preliminary invention reports	45	40	40
Records of invention	20	19	29
Patent applications	12	7	10

of the Technical Information Center at the AEC's Atoms at Work Exhibit in Bangkok, Thailand. The Center was open to Thai scientists, educators, and science students during the entire period of the Exhibit. Its primary purpose was to acquaint them with the scientific literature in atomic energy and related fields and to assist them in locating specific sources of technical information.

PHOTOGRAPHY AND GRAPHIC ARTS

The workload in the Photography and Graphic Arts Division has continued to increase significantly. During fiscal 1963 the staff of the Division was increased from 46 to 52 persons. The production figures for the past three years are shown in Table 10 for the Photography Group and in Table 11 for the Graphic Arts Group.

The great increase in the production figures for photostat-Xerox copies results from the acquisition of an automated Xerox machine and the consequent ease of obtaining copies by this means. The number of Ozalid prints produced during this fis-

Table 10			
	Fiscal year		
	1963	1962	1961
Photographs	12,937	11,062	8,758
Photomicrographs	2,290	2,768	2,167
Lantern slides	15,423	10,371	9,271
Prints	58,275	52,212	44,300
Photostat-Xerox copies	185,804	46,291	31,928
Ozalid prints	140,981	506,128	597,205
Film processed, ft	2,289,985	1,409,730	1,453,018
Charts and graphs drawn	6,164	3,982	3,581

Table 11			
	Fiscal year		
	1963	1962	1961
Offset impressions	13,709,625	11,207,710	10,294,755
Mimeo impressions	1,721,044	2,283,530	1,769,058
Ektalith impressions	2,008,140	—	—
Sheets collated and bound	6,773,150	3,363,100	2,819,350
Reports and booklets, copies produced	75,905*	100,725	92,745

*The decrease from 1962 to 1963 reflects the purchase of the Visitors' Day booklet.

cal year is markedly less than in the past as a result of the introduction of the Ektalith process in the Graphic Arts Group for facsimile reproduction of preprints and similar material. One Ozalid machine was transferred to the Mechanical Engineering Division, and the other machine is used principally for the reproduction of drawings on a self-service basis. The processing of film exposed at the bubble chambers and spark chambers used in the high energy research programs has increased at a rate substantially greater than a comparison of the year-end totals in Table 10 would indicate. For example, the average amount of film processed during the first four months was $\approx 22,000$ ft/month. As the chambers and the AGS settled down to longer periods of continuous operation, the amount of film exposed and processed increased and during the last eight months averaged $\approx 270,000$ ft/month.

A second film processing machine was installed and put into operation during the last quarter of the year, and the first machine was modified to improve its operation. In spite of some difficulties experienced in getting the new machine into full-scale operation, it has been possible to accommodate the increased workload of film processing. When the 80-in. bubble chamber is put into operation early in fiscal 1964, the average monthly production is expected to exceed that for the last eight months by 65%.

Investigations of film characteristics continue to be carried out, particularly those relating to the use of film for bubble-chamber and spark-chamber pictures. The microdensitometer acquired last year has been particularly valuable in these investigations. A small processor was developed to handle film test strips at the chamber site. Such test strips are used to monitor the operation of bubble chambers.

A half-hour motion picture depicting the AGS and the high energy physics program was produced under contract with various professional organizations and under the direction of Photography Group personnel. This motion picture, titled "Of Man and Matter," is available on loan

from the Information Division. Several short films were produced, and considerable use was made of high-speed motion picture photography. Typical assignments were a time-lapse study of slime mold plasmodia, a demonstration of the production of phosphate glass for the incorporation of radioactive waste, and high-speed photography of the motion of targets used in the AGS and of the motion of particles suspended in a gas stream.

During the year the Ektalith offset printing process was put into full-scale operation. The equipment for this process, which provides rapid, inexpensive, good-quality facsimile reproduction, was added to the facilities of the Graphic Arts Group to meet the increasing demand for preprints of papers submitted for publication and copies of reports, memoranda, and similar material. Since this process can provide from clean typewritten material reproductions of higher quality than those obtained from stencils or Ozalid masters, it has replaced mimeographing and Ozalid to a considerable extent.

The increasing use of the Ektalith process made it necessary to acquire a camera to be used exclusively in this work, since the only other camera was needed in the other offset printing operations. Another major piece of equipment acquired for the Graphic Arts Group was a quadder and twin turret camera to modernize the older Fotosetter.

Approximately half of the 29% increase in production occurred in the area of technical report publication. Some of the larger reports produced are listed below.

	Pages	Total impressions
<i>Angular Distributions in Neutron-Induced Reactions</i> , BNL 400, Second Edition (in 2 volumes)	868	2,604,000
<i>Proceedings of the Brookhaven Conference on Neutron Thermalization</i> , BNL 719 (C-32) (in 4 volumes)	1666	1,544,700
<i>Brookhaven Symposia in Biology No. 15, Enzyme Models and Enzyme Structure</i> , BNL 738 (C-34)	350	1,575,000
<i>Proceedings of 1962 High-Temperature Liquid-Metal Heat Transfer Technology Meeting</i> , BNL 756 (C-35)	410	502,250

Administration and Operations

The management operations reviewed in this section have been carried out in a manner designed to facilitate and encourage the research activities of the Laboratory's scientific staff.

PERSONNEL

Scientific Staff and Students

After a year of relatively little net change in the number of scientists holding appointments at Brookhaven, significant increases were recorded last year. As shown in Table 1, the regular staff increased by 10% during the 12 months ending May 31, 1963. The net addition of 33 individuals is the largest such increase since fiscal 1949. Turnover also continued to be noteworthy; 61 scientists were appointed to the staff, and 28 terminated.

While the number of salaried Junior Research Associates (thesis students) decreased, the number of salaried visitors as of May 31 reached an all-time high. Half of the over-all increase is attributable to the net increase in the number of post-doctoral Research Associates. Turnover in this category remained characteristically high because of the limited term of these appointments. During the year, 60 scientists began appointments as Research Associates, and 56 terminated or transferred. Of the latter, 17 were promoted to the regular staff.

The number of nonsalaried visitors holding appointments at the Laboratory continued to increase. For the second successive year, students accounted for nearly two-thirds of the net increase.

May 31, instead of June 30, was used in Table 1 to exclude from the statistics the large number of

Table 1
Scientific Staff and Students on May 31, 1962 and 1963

	Regular staff		Visitors			
			Salaried		Nonsalaried	
	1963	1962	1963	1962	1963	1962
By appointment category						
Staff						
Senior Scientist	57	52	1	1	20	9
Scientist	120	112	5	0	121	115
Associate Scientist	130	107	9	10	122	119
Assistant Scientist	62	65	11	6	77	93
Research Associate	—	—	80	76	39	29
Students						
Junior Research Associate	—	—	5	10	75	57
Research Assistant	—	—	0	0	62	57
Total	369	336	111	103	516*	479**
By academic degree						
Ph.D. or M.D.	248	204	103	92	338	317
Master	50	55	5	9	81	73
Bachelor	66	72	3	2	90	82
No degree	5	5	0	0	7	7

*57 of these appointees were at BNL on a full-time basis as of May 31, 1963.

**65 of these appointees were at BNL on a full-time basis as of May 31, 1962.

Table 2

Classification of Visiting Scientists and Students Participating in BNL Program
for One Month or More, June 1, 1962 - May 31, 1963

	Guests and salaried visitors							
	More than 3 months		Less than 3 months		1962 Summer program		Total	
	Salaried	Guest	Salaried	Guest	Salaried	Guest	Individuals	Institutions
University staff	24	30	3	35	58	43	193	98
Thesis students	12	20	1	22	2	3	60	23
Student Research Assistants	1	17	0	5	99	31	153	69
Subtotal	37	67	4	62	159	77	406	138 different
Industry	0	6	0	5	0	5	16	11
Other institutions	16	55	5	16	19	14	125	64
Total	53	128	9	83	178	96	547	213 different

visitors at Brookhaven only during the summer. The 12-month period ending May 31 was used in Table 2 to include participants in only one summer program.

Table 2 lists the numbers of visiting scientists (exclusive of salaried Research Associates) and students who participated at the Laboratory for a cumulative period of one month or more during the year. The total of 547 visitors from 213 institutions establishes another new high in Brookhaven's history. This compares with 503 visitors from 185 institutions during the previous year. In addition to those included in Table 2, 198 scientists and students worked at Brookhaven for less than one month.

Data pertaining to the employment of consultants is listed in Table 3. The use of these specialists, as measured by man-days of service, increased to the highest level since 1950.

Summer Program for 1963

Arrangements have been made for 306 visiting scientists and students to work at Brookhaven during the summer of 1963. Of this number, 156 are staff members from colleges, universities, industrial organizations, and other institutions; and 150 are students.

Special groups include approximately 40 participants in a super high energy study at the Accelerator Department, 10 Health Physics Fellows, and 102 students in the Laboratory's twelfth annual summer student program.

Labor Relations

The major event in the field of labor relations turned out to be the negotiation of the labor contract between Associated Universities, Inc., and the Directly Affiliated Local Union No. 24426, AFL-CIO, which represents the Maintenance, Machine Shop, Warehousing, and Firefighting groups, totaling ≈ 525 employees. Negotiations began in October 1962 and were broken off in January 1963 because of the inability of the parties to agree to a modification of the subcontracting clause in the contract.

This clause originated in the 1961-62 contract and specifically protected the Laboratory's right to subcontract work but protected the bargaining unit against layoffs directly resulting from this subcontracting. The layoff protection did not apply to subcontracting due to Davis-Bacon Act requirements. The AEC requested that the clause be modified because as written the clause might im-

Table 3

Consultants' Services

	Fiscal year		
	1963	1962	1961
Total contracts in effect June 30	88	88	79
No. of consultants used	60	59	35
No. of man-days of service	761	577	372

pair the ability of the AEC to comply with the government regulations relating to the assignment of work to private industry.

The Union's position was that in 1960-61 they had bargained for the layoff protection in exchange for specifying the Laboratory's right to subcontract and that the modification required by the AEC was a potential threat to their job security. The efforts of the Federal Mediation and Conciliation Service proved unsuccessful, and the Atomic Energy Labor-Management Relations Panel assumed jurisdiction of the dispute in January 1963.

In March 1963 the Union Negotiation Committee unanimously rejected the Panel's recommendation and called for a strike effective at 0001 hours on April 15, 1963. However, agreement was

reached with a slight modification in form of the Panel's recommendation, and the contract was signed on April 11, 1963, just prior to the strike deadline.

The final agreement provided that if bargaining unit members were to be laid off as the result of a subcontract issued in compliance with an AEC directive to the Laboratory the Union would be given 60 days' notice of such layoff and within the 60-day period may give 30 days' notice of termination of the contract. The three-year contract is effective January 1, 1963, and provides a rate increase of 3.5% as of that date, a rate increase of 2.35% in January 1964, and 2.9% in January of 1965.

There were no contract negotiations within the year with the Long Island Guards Union with which there is a two-year agreement terminating in February 1964, nor with the Oil Chemical and Atomic Workers group, as the contract negotiated with that group in 1962 has an indefinite expiration date.

Employment

During fiscal 1963 a total of 608 employees were hired, including 403 on the nonscientific staff and 205 on the scientific and professional staff. With 291 separations, this gave a net increase of 317 employees and brought the total population of the Laboratory up to 2910, excluding temporary appointees, research collaborators, and guests. In comparison with the June 30, 1962, figure of 2593 employees, the Laboratory continues to show a rapid rate of growth (see Table 4).

The most pressing needs during the year were for electrical engineers and physicists to participate in the design, development, construction, and operation of the accelerators and bubble chambers.

The supply of highly trained technicians, i.e., graduates of two-year technical schools, has improved somewhat during the past year. This is particularly true in the electronics field where continuing recruiting efforts are beginning to show results.

Group Insurance Plans

Effective May 1, 1963, several changes were incorporated into the Group Medical Insurance Plan. A new surgical schedule was adopted increasing maximum allowances from \$300 to \$450. This new schedule provides more realistic allowances in relation to the current cost of surgical

Table 4
Employment Statistics*

	Fiscal 1963		Fiscal 1962	
Scientific staff	477		439	
Professional staff	297		256	
Nonscientific staff	2136		1898	
Total	2910		2593	

Turnover data	Number	Annual rate (%)	Number	Annual rate (%)
<u>Accessions</u>				
Scientific staff	127	28	93	21
Professional staff	78	28	62	26
Nonscientific staff	403	20	317	17
Total	608	22	472	19
<u>Separations</u>				
Scientific staff	89	19	91	21
Professional staff	37	13	23	10
Nonscientific staff	165	8	153	8
Total	291	11	267	11
<u>Net Accessions</u>				
Scientific staff	38	0.8	2	0.1
Professional staff	41	14.8	39	16.5
Nonscientific staff	238	11.8	164	9.0
Total	317	11.5	205	8.2

*Figures do not include 95 temporary summer non-student employees. Guests and temporary student employees are included in Table 2.

procedures. An allowance for in-hospital doctors' visits was added to the Group Medical Plan for retired employees. A change in Major Medical Insurance benefits was made limiting dependent coverage for out-of-hospital treatment by a psychiatrist to 50% of reasonable expenses after the deductible. New booklets incorporating the changes were distributed to all employees.

During the year 14 employees retired; the total number of retired employees is now 103.

Ten-year service pins were awarded to 51 employees. These awards now total 882.

Personnel Policies

The sick-leave accrual system was revised to provide accrual at the rate of $1\frac{1}{2}$ days each month instead of 18 days at the employee's annual anniversary date.

The vacation accrual for all hourly and wage employees with 15 or more years of service was increased to $1\frac{3}{4}$ days a month. Other less significant changes in policies were also effected.

ARCHITECTURAL PLANNING

The following major building projects, with a total value of slightly more than \$22,000,000, were initiated, under construction, or completed during fiscal 1963.

- High Intensity Radiation Development Laboratory
- High Flux Beam Research Reactor
- Chemistry Building
- Instrumentation and Health Physics Building
- Cosmotron laboratory addition

The contracts for architect-engineer and construction work were held by the AEC and administered by its Brookhaven Office. BNL was represented by the Architectural Planning Division, which provided the liaison required from early planning through construction.

Engineering has been essentially completed and construction will begin during the coming summer on three additional major projects costing $\approx$ \$7,700,000.

- Physics and Mathematics addition to the Physics Building
- Controlled Environment Laboratory
- Water treatment plant

Contracts for the latter project will be held by Associated Universities, Inc., and administered at BNL by the Architectural Planning Division.

Also scheduled to begin in fiscal 1964, contingent on congressional approval, are a steam plant

addition, a low background counting facility for the Medical Research Center, and a tandem Van de Graaff accelerator facility. The cost of these projects is currently estimated at \$13,250,000. Preparation and development of the technical and planning information for these projects are currently under way.

Smaller projects initiated or undertaken during fiscal 1963 amounted to \$1,200,000 under the General Plant Projects program. There were almost 100 of these minor additions to, or modifications of, research and supporting staff facilities, many of which presented special engineering problems and required considerable engineering effort. The general plant projects exceeding \$50,000 were a building addition to house the Hough-Powell flying-spot digitizer system; a bubble-chamber staging-area building; water supply well No. 7; a facility for large animals; an addition to the underground steam distribution system; a modification of the cyclotron building required for the installation of a new electron accelerator; and the conversion by Plant Maintenance personnel of two ex-Army barracks into a modern dormitory for women. As in past years, the Architectural Planning Division worked closely with the Plant Maintenance Division to coordinate many of these projects.

The *BNL Master Plan*, which discusses the Laboratory's present and future buildings and site plans, was reissued during the year. This plan, which has an estimated useful life of 5 years, is the third in the 15-year history of the Laboratory. It establishes a general pattern of development against which specific construction projects may be examined when the time comes to proceed with them. As part of the development of this plan, a comprehensive review was made, not only of the necessary research facilities and supporting services, but also of utilities and service functions. In connection with the latter, qualified engineering firms were called upon to review and make recommendations for such services as water supply and treatment, steam generation and distribution, and sanitary sewage treatment.

The Architectural Planning Division, during the first part of 1963, prepared the facilities section (buildings) of the budget request for fiscal 1965. This involved site locations, preliminary building plans, cost estimates, and descriptive brochures for the projects listed below (total estimated cost of almost \$29,000,000).

Administrative Services Center
 Lecture Hall-Cafeteria
 Technical Photography and Graphic Arts Building
 Central Shops Building
 Supply and Materiel Building
 Hot Laboratory addition
 AGS Service Building addition
 High-Pressure Gamma Radiation Loop Facility
 Animal laboratories
 AGS North Experimental Building
 Nuclear Engineering Building, Phase II
 Site utilities (extension)

PLANT MAINTENANCE

The responsibilities of the Plant Maintenance Division include the maintenance and operation of all Laboratory utilities; the maintenance of all buildings, grounds, heavy equipment, and automotive vehicles; and the provision of Laboratory services including the Hot Laundry, telephones, mail distribution, housing, cafeteria operation, and automotive or commercial carrier travel arrangements. These routine responsibilities of the Division continue to increase with the growth of the Laboratory. The specialized aspects such as facility modification projects, major maintenance programs, plant engineering, special staff services, and research support functions also have increased correspondingly.

During the past year the Plant Maintenance Division has initiated and substantially completed 227 major maintenance projects and/or facility modification projects totaling slightly less than \$1,000,000. These projects were funded from the General Plant Projects and the Special Maintenance programs. They were engineered and supervised by the Division, with various contracting firms and some Division personnel accomplishing the work. A partial list of accomplishments includes the restoration of 2 buildings for women's residences; the repair and refurbishing of 12 chemistry and metallurgy laboratory areas; refurbishing of 4 Army barracks buildings for continued use as office-laboratory space; renovation of 2 metal-working shops; air-conditioning installations and changes; improvement of lighting, heating, and plumbing in various buildings; and interior and exterior painting, waterproofing, and roof repair of 18 buildings.

A very large portion of the Division's effort continues to be expended in direct support of the scientific research programs. Increasing use was made of the various skills of craftsmen within the

Division, such as electricians, steam fitters, plumbers, carpenters, model makers, and riggers, in setting-up and connecting experimental equipment and apparatus.

The Laboratory's role as host to more than 125 scientific seminars, conferences, and meetings annually is supported by the Division's Special Staff Services Group, which takes care of the transportation and travel arrangements, housing, and other accommodations required by the participants, who come from all parts of the world. While the increase in the number of such functions over the past few years has not been great, there continues to be a marked increase in the number of participants.

Continued use was made during the year of the services of consulting engineers in the examination of such problems as water treatment in cooling towers, heat exchangers, and sewage treatment.

The utilization of man power and distribution of costs within the Plant Maintenance Division for fiscal 1962 and 1963 are analyzed in Tables 5 and 6.

SECURITY AND PLANT PROTECTION

The Security and Plant Protection Division continued to perform its assigned functions during fiscal 1963.

Although the scope of the security function at the Laboratory has contracted substantially since Brookhaven's early days, the Laboratory continues nevertheless to maintain an extremely active AEC security clearance program. At the end of fiscal 1963, ≈ 1000 Laboratory employees and affiliates had active "Q" clearances and ≈ 300 had active "L" clearances. These clearances are required not only in connection with the classified work at the Laboratory but also to enable Brookhaven scientific and technical personnel to have full access, when necessary, to restricted data, both at the Laboratory and at other laboratories and institutions.

The physical growth of the Laboratory and the expansion of its research program have necessitated ever-increasing emphasis upon the Laboratory's plant protection program. The increase in this aspect of the Division's functions has been accomplished through the adaptation of industrial plant protection techniques and practices to the specialized requirements of Brookhaven.

The Fire Group maintained its excellent record in meeting potentially dangerous fire situations at

Table 5
Manpower Utilization

Type of work	Fiscal 1963		Fiscal 1962	
	Productive man-years	Percent of total work	Productive man-years	Percent of total work
Maintenance, repairs, and utilities operations	125	35	86	28
Major maintenance programs	15	4	9	3
Facility improvements	7	2	13	4
Research program support	81	23	79	27
Building janitor services	64	18	54	18
Decontamination	5	1	—	—
Hot Laundry operation	7	2	14	5
Conferences and miscellaneous services	5	1	—	—
Telephone and telegraph services	12	4	14	7
Transportation, housing, and mail services	32	10	18	8
Total	353	100	287	100

Detailed comparisons between fiscal 1962 and fiscal 1963 are not possible because of revisions in categories.

Table 6
Costs of Supplies, Materials, and Contracts

	Fiscal 1963	Fiscal 1962
Maintenance and utilities materials	\$ 306,826	\$ 265,717
Major maintenance materials and contracts	612,605	383,421
Facility improvement materials	351,751	339,017
Building janitor supplies	55,433	39,825
Decontamination	474	—
Hot Laundry	19,571	17,481
Fuel oil	305,336	306,114
Electricity	1,310,260	1,047,375
Gasoline	24,834	21,752
Telephone, teletype, and mail	319,793	295,176
Housing and cafeteria	75,000	71,867
Total	\$3,381,883	\$2,787,745

Detailed comparisons between fiscal 1962 and fiscal 1963 are not possible because of revisions in categories.

the Laboratory. An active fire-inspection and fire-prevention program has been instituted as 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 gratifying results. During the fiscal year, fire-fighting equipment has been increased and modernized, and mutual-aid fire-fighting agreements with nearby communities have been renewed. Training of the regular fire

fighters, as well as the auxiliary and volunteer fire fighters, has been accelerated.

Fortunately, there were no major fires on site during fiscal 1963; responses to fire alarms, however, continue to increase in proportion to the Laboratory's growth:

	1963	1962	1961
Responses on site	209	165	132
Responses off site	7	7	5
Investigations	70	49	34
Total	286	221	171

BUSINESS MANAGEMENT

During the past year the Business Office has handled an increased volume of business as shown by the following tabulation.

	Fiscal 1963	Fiscal 1962
Number of procurement transactions	36,582	32,600
Value of procurement transactions	\$24,900,000	\$17,000,000
Number of receiving actions	42,697	38,500
Number of stores issues	149,255	133,000
Value of inventory turnover	\$ 2,935,300	\$ 2,410,000

In addition, excess serviceable equipment representing a cost avoidance of $\approx$ \$5,043,159 has been acquired. The AEC has advised the Laboratory that it is now the largest user of government surplus in the East.

The above increase in business resulted in a change of personnel levels as indicated below.

	Staff	Clerical	Fiscal 1963 total	Fiscal 1962 total
Business Office	3	2	5	5½
Purchasing Division	17	14	31	28
Supply and Materiel Division	10	70	80	68
Total	30	86	116	101½

The addition of an Assistant to the Business Manager, an Assistant Purchasing Manager, and an Assistant Materials Manager has provided smoother operation and a more realistic span of control.

Fiscal 1963 has been a challenging year in which many ambitious programs were begun. These efforts have already produced tangible results. For example, the purchasing cycle was streamlined to provide better integration of forms and eliminate recording of repetitive data; a single numbering system was instituted for requisitions, purchase orders, and receiving reports; adaptation was made to mechanization of commitment reporting and vendor performance control; and signature authorization requirements on requisitions and purchase orders were broadened. In summary, these procedures have resulted in greater efficiency of service and a reduced time interval from requisition to receipt of material.

The establishment of a Purchasing Services Center, featuring a central purchase-order file, has proved to be a definite asset to the Purchasing

Division and to the scientific departments as well. Other services rendered by this group include traffic control, order expediting, statistical reporting, and mail distribution.

The negotiations of contract renewals for such items as cafeteria services, gas stations, insurance, and special gases have proved economically beneficial; for example, the negotiations for liquid hydrogen resulted in an annual saving of \$200,000 at the present consumption rate.

The Supply and Materiel Division has developed a mechanized inventory management program which provides for automatic computation of economical re-order quantities, inventory trend analysis, early prediction of stock shortages, and adequate stocking at a minimum cost to the Laboratory. To expedite processing and reporting, the main stockroom is being prepared for acceptance of a "check-out" issue system that utilizes pre-punched cards. The Division is also conducting an examination of its organization and procedures to improve service; procedural changes in the receiving function have reduced the processing time from an average of 3 to 4 days to 24 hr.

CONFERENCES, PUBLIC INFORMATION, AND EDUCATION

Because of a change in schedule, both the third and the fourth George B. Pegram Lectures were held during fiscal 1962 (October 1961 and June 1962, respectively). Therefore no lecture in the annual public series can be reported for the past year. The fifth in the series will be given in August 1963 by Dr. J. Robert Oppenheimer, under the general title "Niels Bohr and His Times."

Ten formal conferences were held at the Laboratory during fiscal 1963. Among these were the High Energy Linear Accelerator Conference, August 20-24; the ninth Conference on Reaction Mechanisms, September 5-8; the Rapid Data Processing Conference, September 20-21; the Symposium on Chemistry in Medicine, March 28-29; the High Temperature Fuels Committee Meeting, May 15-17; and the sixteenth Brookhaven Biology Symposium, titled "Meristems and Differentiation," June 3-5.

In addition to these conferences, the Laboratory served as host for the following meetings: the Future Computer Requirements of AEC Laboratories, July 23-27; the High Energy Accelerator Meeting between CERN and BNL personnel,

September 10-14; the semiannual meeting of the Bio-Medical Program Directors of the AEC, November 26-27; a symposium for Suffolk County science teachers, December 1; the European Nuclear Energy Agency High Flux Reactor Meeting, March 18-20; and a Summer Study on Super High Energy Accelerators, from June 10 through July 19.

The thirteenth annual Visitors' Day for the general public, held on October 20, was attended by 8166 individuals. The ninth High School Visitors' Day was held on October 27 and was attended by 4371 juniors and seniors representing 226 high schools. The fifth College Visitors' Day, held on October 26, was attended by 1622 students from 106 colleges. On February 11, the Laboratory held its seventh Science Youth Day in observance of the anniversary of Thomas Alva Edison's birthday. It was attended by 226 selected high school students and editors of high school papers, representing 31 Suffolk County schools. The program offered a variety of talks on a great many research projects at the Laboratory, such as the use of microbeams in the study of cosmic-ray effects, the effects of radiation on plants, gene structure and function, chemical effects of radiation, techniques and applications of modern crystallography, nuclear reactions induced by high energy protons, the use of radioisotopes in clinical medicine, experimental cancer therapy, investigations in leukemia, energy from red giant stars, and measurements at ultralow temperatures with oriented nuclei and polarized neutrons.

During the year the following foreign groups visited the Laboratory: 46 mechanical engineering students from the École Nationale Supérieure de Nantes, July 11; 9 members of the German Study Mission in Research Planning, September 26-27; 10 members of the German Radiological Study Team, October 10; 11 engineering physics students from the University of Toronto, October 18; and 6 members of the USSR Delegation to the United Nations, December 11. In addition, 207 professional, governmental, and industrial representatives from foreign countries visited for short periods during the year. Most of these visits were suggested by the AEC.

The Laboratory arranged 1-day visits for 9 National Science Foundation teachers-in-training seminars, totaling 325 individuals. In all, 34 professional and student groups totaling 1485 individuals visited the Laboratory.

The Public Information Office continued to experience an increased demand from students and teachers for assistance in preparing science projects and programs and term papers. Many requests for information in elementary nuclear science were also received from the lay public. Most of these inquiries can be met satisfactorily by mailing the appropriate literature from the large stock of pamphlets and information sheets now available, but some require more personalized attention. The Laboratory also continued to provide speakers for neighboring civic, educational, and semi-professional audiences; 30 staff members responded to such requests during the past year.

Appendix A

PUBLICATIONS, JULY 1, 1962 – JUNE 30, 1963

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, 1962. BNL 742 (AS-16).
Progress Reports, Nuclear Engineering Department:
January 1 – April 30, 1962. BNL 731 (S-61).
May 1 – August 31, 1962. BNL 759 (S-62).
September 1 – December 31, 1962. BNL 782 (S-63).
Conference Reports:
Brookhaven Symposia in Biology No. 15. *Enzyme Models and Enzyme Structure*. BNL 738 (C-34).
High Energy Accelerator Papers From USSR. BNL 767 (C-36).
Proceedings of the Brookhaven Conference on Neutron Thermalization: Vol. I, *The Scattering Law*; Vol. II, *Neutron Spectra in Lattices and Infinite Media*; Vol. III, *Experimental Aspects of Transient and Asymptotic Phenomena*; Vol. IV, *Theoretical Aspects of Transient and Asymptotic Phenomena*. BNL 719 (C-32).
Process Radiation Development Program Summaries, Third Annual Contractors Meeting, Brookhaven National Laboratory, April 22-23, 1963. BNL 790 (C-37).
Brookhaven Lecture Series:
6. *High Energy Accelerators*, ERNEST COURANT. BNL 747 (T-273).
8. *The History of Cosmic Rays and Meteorites*, OLIVER A. SCHAEFFER. BNL 779 (T-295).
16. *Fundamental Studies of Radiation Damage in Graphite*, DONALD G. SCHWEITZER. BNL 745 (T-270).
17. *The Role of the Cell Nucleus in Determining Radiosensitivity*, ARNOLD H. SPARROW. BNL 766 (T-287).
24. *The Use and Misuse of the Atmosphere*, MAYNARD E. SMITH. BNL 784 (T-298).
High-Temperature Liquid-Metal Technology Review:
Vol. 1, No. 1, February 1963. BNL 788 (PR-1).
Vol. 1, No. 2, April 1963. BNL 801 (PR-2).
Vol. 1, No. 3, June 1963. BNL 814 (PR-3).
Weekly Bulletin 15, No. 52; 16, No. 1-51.
Weekly Selected Reading List 15, No. 16-52; 16, No. 1-14.

*Also included are those listings from the last annual report [BNL 742 (AS-16)] for which complete reference information was not then available.

Miscellaneous:

- Bibliography of Technical Publications and Reports of the Radiation Division, Brookhaven National Laboratory, 1951-1962 Inclusive*, D.S. BALLANTINE AND L.E. KOPP. BNL 789 (L-338).
Experimental Program Requirements for a 300 to 1000-Bev Accelerator and Design Study for a 300 to 1000-Bev Accelerator. BNL 772 (T-290).
High-Pressure Gamma Loop for Brookhaven National Laboratory. BNL 796 (T-305).

STAFF PUBLICATIONS AND ABSTRACTS

Accelerator Department

- ADAMS, R.R. – See PLOTKIN, M.; SPIRO, J.
BALZARINI, D. Cerenkov and scintillation properties of Plexiglas UVT and UVA. Informal Report BNL 6865.
BARTON, M.Q. Coherent effects in the Cosmotron. (A) Presented at Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963.
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- SALANT, E.O. - See FICKINGER, W.J.; PICKUP, E.
- SAMIOS, N.P. - See BERTANZA, L.; CONNOLLY, P.L.; LEITNER, J.
- SANDWEISS, J. - See BACHMAN, A.; BALTAY, C.; FERBEL, T.; STONEHILL, D.L.; TAFT, H.D.
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Dec. 1962	BNL 778 (T-294)
Jan. 1963	BNL 783 (T-297)
Feb. 1963	BNL 786 (T-299)
Mar. 1963	BNL 793 (T-302)
Apr. 1963	BNL 798 (T-306)
May 1963	BNL 803 (T-308)
June 1963	BNL 813 (T-314)

Appendix B

OFFICERS AND SCIENTIFIC AND PROFESSIONAL STAFF

Maurice Goldhaber, *Director*
 Clarke Williams, *Deputy Director*
 Charles E. Falk, *Associate Director*
 R. Christian Anderson, *Assistant Director*
 G. Norris Glasoe, *Assistant Director*
 Samuel M. Tucker, *Assistant Director*

G. Kenneth Green, *Chairman*, Accelerator Department
 Howard J. Curtis, *Chairman*, Biology Department
 Richard W. Dodson, *Chairman*, Chemistry Department
 Horner Kuper, *Chairman*, Instrumentation and Health Physics Department
 Victor P. Bond, *Chairman*, Medical Department
 Warren E. Winsche, *Chairman*, Nuclear Engineering Department
 George H. Vineyard, *Chairman*, Physics Department
 John W. Calkin, *Head*, Applied Mathematics Division
 Irving J. Polk, *Head*, Mechanical Engineering Division
 Robert W. Powell, *Head*, Reactor Division

J. Georges Peter, *Director*, Architectural Planning
 H. Russell Cort, *Budget Officer*
 William J. Catacosinos, *Business Manager*
 Lewis R. Burchill, *Controller*
 Dennis Puleston, *Information Officer*
 Charles F. Dunbar, *Legal Counsel*
 Joseph S. Washburne, *Personnel Manager*
 Edward J. Burke, *Security Officer*

Accelerator Department

G. Kenneth Green, *Chairman*
 Roger R. Adams
 David A. Barge
 Mark Q. Barton
 Gerald W. Bennett
 David Berley
 Richard A. Beth
 John W. Bittner
 John P. Blewett
 M. Hildred Blewett
 Hugh N. Brown
 William T. Chu
 (*postdoctoral appointment*)
 Theodore N. Constant*
 James G. Cottingham
 Ray R. Crittenden
 Gordon T. Danby
 Donald A. Davis
 Bernard L.C. de Sereville
 (*assigned from*
Commissariat à l'Énergie Atomique,
Saclay, France)
 Edward W. Dexter
 Emory G. Egler

Arthur J. Enright
 Arnold V. Feltman
 Theodore Fishman
 Eric B. Forsyth
 Robert S. Frankel
 Hyota Fujita*
 (*on leave from Mitsubishi Atomic Power*
Industries, Inc., Japan)
 John J. Gabusi
 William Gefers
 Salvatore T. Giordano
 (*on leave to Yale Univ.*)
 Joseph W. Glenn, III
 Jack Gordon*
 Richard J. Gran*
 Allen S. Grossman
 Harald Hahn
 Henry J. Halama
 John L. Harris
 Elias H. Hochman
 Robert S. Hulliger
 John W. Jackson
 Kurt Jellett
 Ralph R. Kassner
 John T. Keane
 Robert A. Larson
 Lawrence B. Leipuner

Gerald S. Levine
 Isador J. Livant
 Walter Livant
 Anthony J. Longano
 Robert A. Loper
 Edward A. MacDougall
 Alfred W. Maschke
 Lowell McLean
 Walter W. Merkle
 William Michaelson
 William H. Moore
 Gerry H. Morgan
 Albert C. Nerenberg
 Rudolf F. Nissen*
 Eileen C. O'Donnell
 Leslie W. Oleksiuk
 Richard J. Orgass
 Arthur N. Otis, Jr.
 Jean-Louis Pellegrin
 Martin Plotkin
 Eugene C. Raka
 Raymond H. Rheume
 Everett J. Rutan
 Eleftherios J. Sacharidis
 (*postdoctoral appointment*)
 William B. Samson
 Albert J. Schoenemann

*Terminated before July 1, 1963.

Edward E. Shelton
 Lyle W. Smith
 Anastasios Soukas
 Julius Spiro
 Colin D. Stewart
 Clifford E. Swartz*
 Arthur Tranis
 Clarence M. Turner
 Arie van Steenberg
 Robert J. Warkentien
 Theodore F. Zipf

Applied Mathematics Division

John W. Calkin, *Head*
 John A. Altson
 Barry S. Arbeit
 William J. Beard
 David R. Beaucage
 William Bouris
 John R. Cannon
 John E. Denes
 Jerry M. Friedman
 Kurt Fuchel
 Evelyn Gottesfeld
 Sidney Heller
 Stanley Kaplan
 Mary Anne Kelley*
 Arlene S. Larsen
 Leslie L. Lawrence
 Alvin A. Legerlotz
 Joel H. Malament
 Robert B. Marr
 John P. Milazzo
 Noboru Nakanishi
 Irene Nicodemus
 Larry S. Padwa
 Ilse Perlman
 Joel D. Pincus
 Marc Platt
 George Rabinowitz
 Dysart A. Ravenhall
 Nechemiah Reiss
 Stuart S. Rideout
 Jerome A.G. Russell*
 (on leave to Lawrence Radiation Laboratory)
 Carole J. Sawner
 Yoshio Shimamoto
 Morris M. Strongson
 Bette E. Sullivan
 Joyce L. Tichler*
 Roger N. Van Norton
 Betty Weneser
 Annette L. Woodbury
 Lourdes Zavitsas

Biology Department

Howard J. Curtis, *Chairman*
 Jean Aitchison
 Etsuo Amano

Barbara G. Barnes
 (assigned from U.S. Public Health Service)
 Frederick R. Becherer
 Arnold M. Becker
 John Berech, Jr.
 John A. Bergeron
 Clara A. Bjerknes
 Francesco Bresciani
 (on leave from Univ. of Naples, Italy)
 Robert W. Briggs
 (postdoctoral appointment)
 John R. Broich
 John A.M. Brown*
 Nicholas C. Combatti
 Gerard M. Courtin
 Cathryn T. Crowley*
 D. Roy Davies
 (on leave from
 United Kingdom Atomic Energy Authority,
 Harwell, England)
 Milislav Demerec
 Grace M. Donnelly
 (postdoctoral appointment)
 Julius M. Elias
 Frieda M. Englberger
 William R. Evans
 (postdoctoral appointment)
 David L. Filmer
 (postdoctoral appointment)
 Suzanne M. Gaddone*
 Walter J. Geisbusch
 Barbara Goolnick*
 Anne D. Gounaris*
 (postdoctoral appointment)
 Lewis J. Greene
 Kenneth L. Grist
 Elmer B. Hadley
 (postdoctoral appointment)
 Robert E. Heiner
 (postdoctoral appointment)
 William S. Hillman
 C.H.W. Hirs
 H. Robert Horton
 (postdoctoral appointment)
 James R. Innes
 Alexandra H. Jahn
 Yashwant Karkhanis
 (postdoctoral appointment)
 Shams-Ul-Islam Khan*
 (assigned from
 Department of Agriculture, Canada)
 J. Raymond Klein
 Daniel E. Koshland, Jr.
 Marian E. Koshland
 Charles C. Kuehnert
 (postdoctoral appointment)
 Sanford A. Lacks
 H. George Latham, Jr.
 Eugene P. Lazzari*
 (postdoctoral appointment)
 Harvard Lyman
 (on leave from Brooklyn College)

Richard B. Middleton
 (postdoctoral appointment)
 Jerome P. Miksche
 Lee N. Miller*
 Grace H. Moffat
 (graduate student from New York Univ.)
 Samuel M. Mozersky
 (assigned from National Inst. of Health)
 Archie Murdock
 (postdoctoral appointment)
 Leslie F. Nims
 Gursaran W. Notani
 (assigned from Rockefeller Inst.)
 John M. Olson
 Jan K. Oosting
 Mary E. Owen
 (postdoctoral appointment)
 Carmie A. Perrotta
 (assigned from Yale Univ.)
 Andrew E. Petracco
 (graduate student from Yale Univ.)
 Eleanor Pitti
 Bernard Pivo
 Thomas H. Plummer, Jr.
 (assigned from American Cancer Society)
 Virginia Pond
 Herbert Posner
 (postdoctoral appointment)
 Wolf Prenskey
 (postdoctoral appointment)
 Henry Quastler
 Allan Rebuck
 Nicholas Rigopoulos
 John J. Rusnica
 Kenneth E. Sanderson
 (postdoctoral appointment)
 Louis C.R. Sarda*
 (assigned from
 Univ. of Sciences, Marseilles, France)
 Gideon W. Schaeffer*
 (assigned from
 U.S. Public Health Service)
 Lloyd A. Schairer
 Patricia J. Schroeder*
 Janet S.D. Scott
 (postdoctoral appointment)
 Kenneth Scott
 (postdoctoral appointment)
 Donald Shaver*
 (postdoctoral appointment)
 Robert M. Smillie
 Harold H. Smith
 Arnold H. Sparrow
 Elizabeth Stanton
 Robert Steele
 Peter A. Stewart*
 (on leave from Emory Univ.)
 David H. Strumeyer*
 (postdoctoral appointment)
 Christiaan Sybesma*
 (postdoctoral appointment)
 Austin L. Taylor*
 (postdoctoral appointment)

*Terminated before July 1, 1963.

Keith H. Thompson
 John J. Tilley, Jr.
 Jack van't Hof
(postdoctoral appointment)
 Richard H. Wagner
(postdoctoral appointment)
 Donald E. Wimber*
 Doris R. Wimber*
 Marilyn F. Wolfsberg
(assigned from U.S. Public Health Service)
 Robert Woodley
 George M. Woodwell
 Ruth V. Wright
 Geoffrey Zubay
 Sylvia E. Zvingilas*

Chemistry Department

Richard W. Dodson, *Chairman*
 Hans-Joachim Ache
(postdoctoral appointment)
 Augustine O. Allen
 Desire J. Apers*
*(on leave from Inst. Interuniversitaire des
 Sciences Nucléaires, Belgium)*
 Elizabeth W. Baker
 Werner H. Baur
*(on leave from
 Univ. of Göttingen, West Germany)*
 Benon H. Bielski
 Jacob Bigeleisen
*(on leave to
 Swiss Federal Inst. of Technology, Zurich)*
 George W. Black, Jr.*
 Fulvio Cacace*
(on leave from Univ. of Rome, Italy)
 Raymond J. Campion
(postdoctoral appointment)
 Thomas C. Castorina*
(assigned from Picatinny Arsenal)
 Joseph C.Y. Chen
(postdoctoral appointment)
 Lung-Wen Chiao*
(postdoctoral appointment)
 David R. Christman
 Yung Yee Chu
 James C. Cobb
 Kenneth E. Collins
(postdoctoral appointment)
 Philip Coppens*
(postdoctoral appointment)
 Lester M. Corliss
 William C. Corning*
(graduate student from Univ. of Rochester)
 James B. Cumming
 Gidon Czapski*
(postdoctoral appointment)
 Eileen P. D'Arcy
 Raymond Davis, Jr.
 Hartmut Diebler*
(postdoctoral appointment)

Bodo Diehn
(graduate student from Univ. of Kansas)
 Paul F. Donovan
*(assigned from
 Bell Telephone Laboratories, Inc.)*
 Israel Dostrovsky
*(on leave from
 Weizmann Inst. of Science, Israel)*
 Guenther Dulz
(postdoctoral appointment)
 Florence T. Dunn
 Stanton Ehrenson
 Norman Elliott
 Eena-Mai Franz
 Simon Freed
 Gerhart Friedlander
 Lewis Friedman
 Raymond Goldberg
 George A. Gregoriou
(postdoctoral appointment)
 James R. Grover
 Masayuki Hamada*
*(on leave from
 Radiation Center of Osaka Prefecture,
 Japan)*
 William C. Hamilton
 Garman Harbottle
 Julius M. Hastings
 Karl H. Heinzinger
(postdoctoral appointment)
 Jerome Hudis
 Andries Hummel
*(on leave from Ministry of Education,
 Arts, and Sciences, Netherlands)*
 James A. Ibers
 Adolph P. Irsa
 Karin Karlstrom
(assigned from Columbia Univ.)
 Seymour Katcoff
 Ann M. Kistner*
(graduate student from Columbia Univ.)
 Fritz S. Klein
*(on leave from
 Weizmann Inst. of Science, Israel)*
 Pak Sang Leung
(graduate student from Columbia Univ.)
 George H. Megrue
(postdoctoral appointment)
 Sandro Meloni
(on leave from Univ. of Pavia, Italy)
 James P. Mollenauer
(postdoctoral appointment)
 Gordon G. Moore*
(postdoctoral appointment)
 Thomas F. Moran
(postdoctoral appointment)
 Robert T. Mullen*
(postdoctoral appointment)
 Elinor F. Norton
 Lars Borje Ostman
(postdoctoral appointment)
 Catherine T. Paul

*Terminated before July 1, 1963.

Morris L. Perlman
 Norbert T. Porile
 Arthur M. Poskanzer
 Neil Purdie
(postdoctoral appointment)
 Srinivasan Raman
(postdoctoral appointment)
 Carol S. Redvanly
 Paul L. Reeder
(postdoctoral appointment)
 Bruno Reitzner*
(assigned from Picatinny Arsenal)
 Louis P. Remsberg, Jr.
(postdoctoral appointment)
 J. Keith Rowley
 William Robinson
 Edward V. Sayre
 Oliver A. Schaeffer
 Harold A. Schwarz
 William A. Seddon
(postdoctoral appointment)
 Stanley Seltzer
 Kohji Shimaoka
(postdoctoral appointment)
 Frederick J. Silkworth, Jr.
 Morris Slavin
 Marvin J. Stern*
(postdoctoral appointment)
 Gerhard Stocklin
(postdoctoral appointment)
 Raymond W. Stoenner
 Norman Sutin
 Shigeo Tanaka
(on leave from Univ. of Tokyo, Japan)
 Anthony J. Tench*
(postdoctoral appointment)
 Sydney O. Thompson
 Richard B. Timmons
(postdoctoral appointment)
 W. Alexander Van Hook*
(postdoctoral appointment)
 Helge T. Von Koch*
(postdoctoral appointment)
 Jesse M. Wampler
(postdoctoral appointment)
 Freddie H. Watson, Jr.
 Ralph E. Weston, Jr.
 Ronald Withnell
 Alfred P. Wolf
 Max Wolfsberg
 Armin Wyttenbach*
(postdoctoral appointment)
 Ursula Zahn
*(assigned from
 Univ. of Munich, West Germany)*
 Andreas A. Zavitsas
(postdoctoral appointment)

Instrumentation and Health Physics Department

Horner Kuper, *Chairman*

Frank R. Berry
 Robert M. Brown
 Roger D. Caldwell*
 Arland L. Carsten*
 Robert J. Champagne
 Robert L. Chase
 David O. Clark
 Lester A. Cohen
 Jerome Constant
 Frederick P. Cowan
 Carl H. Distenfeld
 Jack C. Faust
 Joachim Fischer
 Charles F. Foelix
 John A. Frizzola
 Lee Gemmell
 John S. Handloser*
 William J. Hartin
 William A. Higinbotham
 Andrew P. Hull
 John F. Jacobs
 Robert J. King
 Jorge Llacer
 Robert O. McClintock
 Charles B. Meinhold
 Gabriel L. Miller*
 Constance M. Nagle
 Anthony Nappi
 Casimir Z. Nawrocki
 Arcadio M. Niell*
 James P. Palmer
 Howard R. Pate
 Smith G. Pearsall
 Paulo P. Petry*
*(on leave from
 Univ. of Rio Grande do Sul, Brazil)*
 Leigh F. Phillips
 David W. Potter
 Veljko Radeka
(postdoctoral appointment)
 Seymour Rankowitz
 Gilbert S. Raynor
 Edwin J. Rogers
 Martin J. Rosenblum
(on leave to CERN, Geneva, Switzerland)
 Claire L. Safford*
 George E. Schwender
 Stanley I. Silverman
 Irving A. Singer
 Maynard E. Smith
 Robert J. Spinrad
 Raymond W. Stong
 Luis Tepper
*(on leave from
 Atomic Energy Commission, Israel)*
 John A. Vanlandingham*
 Sanford E. Wagner
 Gaylord N. Wall
 John B.S. Waugh
 Stanley Wood

*Terminated before July 1, 1963.

Anthony H. Yonda, Jr.
 Hans R. Zulliger*

Mechanical Engineering Division

Irving J. Polk, *Head*
 Richard W. Aichroth
 Joseph E. Allinger
 John G. Androulakis
 Robert D. Baldwin, Jr.
 Joseph A. Bamberger
 Paul Bezler
 Thomas J. Blair
 Donald P. Brown
 Robert H. Browne
 Vernon J. Buchanan
 Leonard N. Chimienti
 Anthony Coppola*
 Henry O. Courtney
 Rudolph Damm
 Jack E. Detweiler
 Basil De Vito
 Julius J. Diener
 Carlo Ferraro, Jr.
 Carl R. Flatau
 Edward H. Foster
 Donald W. Gardner
 Robert J. Gibbs
 Jules B. Godel
 Carl L. Goodzeit
 Charles L. Gould
 Philip E. Greenberg
 John J. Gries
 Melvin E. Griffing
 John J. Grisoli
 Eugene E. Halik
 Jaromir Hanush*
 Charles R. Hedberg
 John J. Hennessy
 Rudolph S. Hodor
 Kenneth C. Hoffman
 John N. Hopping, Jr.
 Hendrik Houtsager
 Donald W. Huszagh
 Jack E. Jensen
 Michael B. Karelitz
 David A. Kassner
 Andrew Kevey
 John T. Koehler
 Calman Lasky
 Boris M. Lomonosoff
 Joseph Lypecky
 Stanley J. Majeski
 Paul Mandel
 John G. Marinuzzi
 Robert J. McCracken
 Anthony P. Meade
 Kurt F. Minati
 Shih Chia Mo
 George Nugent
 Joseph M. O'Donnell, Jr.
 Adolph Oltmann
 Frederick O. Pallas

Francis C. Pechar
 Paul A. Pion
 Carl J. Pozgay
 Oliver S. Reading
 Clive E. Reed
 Morris Reich
 Albert P. Schlafke, Jr.
 Joseph C. Schuchman
 Donald B. Sisson
 Gerald C. Soltz*
 Charles Theisen
 Harvey J. Thomas
 Reese D. Thomas
 Helmuth Thorwarth
 William G. Walker
 Irving J. Winters, Jr.
 Henry H. Woelfel
 Donald H. Wright

Medical Department

Victor P. Bond, *Chairman*
 Emil R. Adamik*
 Vicente Alcober
*(on leave from Facultad de Medicina,
 Univ. de Valencia, Spain)*
 John O. Archambeau
 Robert B. Aronson
 John L. Bateman
(assigned from National Inst. of Health)
 Donald C. Borg
 Salvador R. Bozzo
(on leave from Univ. of Chile)
 Amos A. Britton
(on leave from Univ. of Bogotá, Colombia)
 Bernard J. Bryant
 Wenceslao Calvo*
*(on leave from Facultad de Medicina,
 Univ. de Valencia, Spain)*
 Donald H. Clifford
(on leave from Univ. of Minnesota)
 Stanton H. Cohn
 Spencer L. Commerford
 Robert A. Conard, Jr.
 Hans Cottier
*(on leave from
 Univ. of Bern, Switzerland)*
 George C. Cotzias
 Eugene P. Cronkite
 Janet Cuttner*
*(on leave from
 Mt. Sinai Hospital, New York)*
 Lewis K. Dahl
 Nicholas Delihias
 Ruth M. Drew
 Ralph G. Fairchild
 Ludwig E. Feinendegen
(assigned from EURATOM)
 Theodore M. Fliedner
 Edith M. Forsyth
 Anubha Ghose*
(assigned from Univ. of Cincinnati)

Richard L. Golden*
(*medical associate*)
Ernest A. Gusmano
Richard A. Hammerstrom*
Lawrence V. Hanks
Max W. Hess
Walter L. Hughes
Wen-Shui S. Hwang
John E. Jeseph
(*on leave from Veterans Administration
Hospital, Washington, D.C.*)
Horton A. Johnson
Septimus M. Joubert
(*on leave from
Univ. of Natal, Union of South Africa*)
Hooney C. Kahng
(*medical associate*)
Georg A. Keiser
(*on leave from
Univ. Hospital, Zurich, Switzerland*)
Matina Kesse
(*on leave from
Alexandra Hospital, Greece*)
Henry J. Koch*
(*medical associate*)
Tad Konikowski*
Louis C. Lax
Stuart W. Lippincott*
Robert A. Love
George C. Mather*
(*medical associate*)
Nicholas Odartchenko
Paul S. Papavasiliou
Mildred Pavelec
Edwin A. Popenoe
Kanti R. Rai*
(*medical associate*)
Paul Reilly
Luis Rizo-Patrón
(*on leave from Univ. de San Marcos, Peru*)
James S. Robertson
Charles V. Robinson
Arthur Sakamoto
Eckart Schackow
Lewis M. Schiffer
Brigitte Schultze*
Stephen L. Schwartz
(*medical student from Univ. of Cincinnati*)
Vinod C. Shah
Yukio Shigeta*
(*medical associate*)
Walton W. Shreeve
Clyde R. Sipe
Richard D. Stoner
George M. Tisljar-Lentulis
(*medical associate*)
Edgar A. Tonna
Cornelius J. van der Merwe*
(*assigned from Atomic Energy Board,
Union of South Africa*)

Donald D. Van Slyke
Melvin H. Van Woert

Nuclear Engineering Department

Warren E. Winsche, *Chairman*
George Adler
Leonard B. Adler*
Sidney J. Altschuler
(*graduate student from Columbia Univ.*)
Eigil Andersen
(*assigned from
Kjeller Research Establishment, Norway*)
Arnold L. Aronson
Seymour Aronson
Clemens Auerbach
Elliot H. Auerbach
Allan Auskern
David S. Ballantine
Charles B. Bartlett
Morris Beller
William N. Bishop
Fritz Bloch
John S. Bookless
William Bornstein
Joseph S. Bryner
Albert W. Castleman, Jr.
M. S. Chandrasekharaiah
(*postdoctoral appointment*)
John Chen
Jack Chernick
Chang S. Choi
(*assigned from
Atomic Energy Research Inst., Korea*)
Joe G.Y. Chow
Evelyn A. Cisney
John T. Clarke
Carol H. Collins
(*postdoctoral appointment*)
Peter Colombo
Helen R. Connell
Noel R. Corngold
Anita J. Court
John H. Daane*
Russell N. Dietz
(*graduate student from
Polytechnic Inst. of Brooklyn*)
Robert F. Doering
Roy F. Domish
Kenneth W. Downes
James M. Dwyer
(*postdoctoral appointment*)
Orrington E. Dwyer
James J. Egan
Charles M. Eisenhauer
(*assigned from
National Bureau of Standards*)
Leonard C. Emma
Lester G. Epel
Seymour G. Epstein
René P. Eymery
(*assigned from
Commissariat à l'Énergie Atomique, France*)

Jack Fajer
(*postdoctoral appointment*)
Peter T. Fallon
Joan F. Felberbaum
Stephen W. Feldberg
(*postdoctoral appointment*)
Harmon L. Finston
Albert H. Fleitman
Markley H. Flom
Joseph Forrest
Bernard R. Fox
Leonard Galanter
John D. Garrison
(*on leave from San Diego State College*)
Ajoy K. Ghatak
(*postdoctoral appointment*)
Althea Glines
Donald A. Goellner
Murrey D. Goldberg
Stephen K. Gordon
Leon Green
Margaret W. Greene
David H. Gurinsky
Yuuki Hachiya
(*assigned from
Nippon Electric Co., Ltd., Japan*)
Virginia R. Harris
Loranus P. Hatch
Michael A. Helfant
Robert L. Hellens
Joseph M. Hendrie
John J. Herbst*
(*graduate student from New York Univ.*)
Raymond J. Heus
Frank B. Hill
Manny Hillman
Henry C. Honeck
Frederick L. Horn
Chia-Jung Hsu
(*postdoctoral appointment*)
Robert J. Isler
Richard Johnson
Sheldon Kalish
Otto F. Kammerer
Herbert M. Katz
John J. Kelsch
Akiichi Kigoshi
(*assigned from Tohoku Univ., Japan*)
Mary T. Kinsley
George Kissel
Carl J. Klamut
Walter Kley
(*assigned from EURATOM*)
Paul J. Klotz
Herbert J.C. Kouts
Henry Kramer
Theodore J. Krieger
Otto A. Kuhl
Lawrence E. Kukacka, Jr.
Sam J. LaPlaca
Daniel F. Leahy
Gerald S. Lellouche

*Terminated before July 1, 1963.

Melvin M. Levine
 Stephen Lewkowitz
 Hans R. Lutz*
(assigned from Federal Inst. of Reactor Science, Switzerland)
 Dominic J. Macchia
 Donald R. MacKenzie
 Benjamin Magurno
 Bernard Manowitz
 Michael W. Maresca
 Toshio Masuyama*
(assigned from Japan Atomic Energy Research Inst., Tokai-mura)
 Victoria L. May
 James J. McNicholas
 S. Bradford McRickard
 Donald J. Metz
 Paul A. Michael
 Julius Milau
 Francis T. Miles
(on leave to IAEA, Vienna, Austria)
 Jacobus G. Mohr
(graduate student from New York Univ.)
 Sophie Moore
 Albert C. Muller
 Leonard Newman
 Francis X. Nichik*
 Bruce Nimmo
 Guyon P. Pancer
 Raymond J. Parsick
 James P. Phelps
 Charles E. Porter, Jr.
 James R. Powell, Jr.
 Richard M. Powers
 Thomas F. Prach
 Glenn A. Price
 Jacob Pruzansky
 Surendra N. Purohit*
(postdoctoral appointment)
 Rajiengar Ranganathan*
(graduate student from New York Univ.)
 Chad J. Raseman
 James J. Reilly, Jr.
 Powell Richards
 Francis X. Rizzo
 Ranier Rolle*
(assigned from Atomic Energy Board, Union of South Africa)
 Anthony Romano
 Michael A. Rothbart
 Jerome Sadofsky
 Francis J. Salzano
 Sergio Santiago-Paez
(assigned from Junta de Energía Nuclear, Madrid, Spain)
 César A. Sastre
 Clifford H. Scarlett
 Donald G. Schweitzer
 Balraj Sehgal

Eric Sermet-Chadwick*
(NATO Fellow)
 Charles S. Shapiro
(graduate student from Syracuse Univ.)
 Thomas V. Sheehan
 Louis M. Shotkin
(postdoctoral appointment)
 Richard S. Siegel
(on leave from Bronx High School of Science)
 Robert M. Singer
 Louis M. Slater
 John L. Speirs
 Govindashrama Srikantiah
(postdoctoral appointment)
 Louis G. Stang, Jr.
 John R. Stehn
 Meyer Steinberg
 Gerald Strickland
 John E. Suich*
(graduate student from Massachusetts Inst. of Technology)
 Herbert Susskind
 James W. Sutherland
 Yau C. Tang
(postdoctoral appointment)
 Silvio J. Tassinari
 Paul R. Tichler
 Yoel Tikochinsky*
(graduate student from the Hebrew Univ., Israel)
 Richard J. Tivers
 Walter D. Tucker
 William J. Tunney
 Edwin J. Tuthill
 James O. Tveekrem
 Nazakat Ullah
(postdoctoral appointment)
 John D. Van Norman
 Derek Verdin*
(assigned from United Kingdom Atomic Energy Authority, England)
 Stephen J. Wachtel
 Jean I. Wagner
 Charles H. Waide
 John R. Weeks
 Eugene Weinstock
 Joan Weisenbloom*
 Allen J. Weiss
 Jerome Weiss
 Yehuda Wellwart*
(on leave from Atomic Energy Commission, Israel)
 George G. Weth
 Michael M.R. Williams
(postdoctoral appointment)
 Robert Wilson
 Henry H. Windsor
 Edward Wirsing, Jr.
 Richard H. Wiswall, Jr.
 Wen-Shi Yu
(graduate student from Polytechnic Inst. of Brooklyn)

Carolyn G. Zatto*

Physics Department

George H. Vineyard, *Chairman*
 Fernando Agullo-López*
(on leave from Junta de Energía Nuclear, Madrid, Spain)
 Ian J.R. Aitchison
(postdoctoral appointment)
 David E. Alburger
 Harvey A. Alperin
(assigned from U.S. Naval Ordnance Laboratory)
 Richard Arndt
(postdoctoral appointment)
 Frederick Ayer II
 Trevor C. Bacon
(postdoctoral appointment)
 Charles P. Baker
 Winslow F. Baker
 Virgil E. Barnes
(postdoctoral appointment)
 George E. Barr
(graduate student from Oregon State Univ.)
 John A. Becker
(postdoctoral appointment)
 Mirza A.P. Bég*
(postdoctoral appointment)
 Lewis Berlent
 Brother Austin Bernabei
(graduate student from New York Univ.)
 Jeremy Bernstein*
 Luciano Bertanza*
(on leave from Inst. di Fisica, Univ. di Pisa, Italy)
 Edward J. Bleser
(postdoctoral appointment)
 Martin Blume
 Henri Boutin
(assigned from Picatinny Arsenal)
 Dermot J. Bredin
 Jean-Claude Brisson*
(on leave from Commissariat à l'Énergie Atomique, France)
 P. Jane Brown*
(postdoctoral appointment)
 Gunter Brunhart
(postdoctoral appointment)
 Donald Burd
(graduate student from Columbia Univ.)
 Robert E. Chrien
 James H. Christenson
(graduate student from Princeton Univ.)
 Eugene L. Church
(assigned from Frankford Arsenal)
 Alan R. Clark
(graduate student from Princeton Univ.)
 Jack A. Cockrill
 Victor W. Cohen
 Isaac W. Cole
 George B. Collins

*Terminated before July 1, 1963.

Philip L. Connolly
 Rodney Cool
 Ernest D. Courant
 David E. Cox
 Paul P. Craig
 Bernard B. Culwick
 Arthur C. Damask
(assigned from Frankford Arsenal)
 Horace R. Danner
 Paul C. DeCelles*
(postdoctoral appointment)
 William C. Delaney
 Edward der Mateosian
 Achiel J. Deruytter*
*(assigned from Centre d'Étude
 de l'Énergie Nucléaire, Belgium)*
 Albert N. Diddens*
*(assigned from
 CERN, Geneva, Switzerland)*
 George J. Dienes
 Jean V. Domish
 Frederick R. Eisler
 Guy T. Emery
 Cavd Erginsoy
(on leave from IAEA, Vienna, Austria)
 George Fisher
(graduate student from Univ. of Illinois)
 Kenneth J. Foley
(postdoctoral appointment)
 Hugie L. Foote, Jr.
 William B. Fowler
 Joan F. Franz
 B. Chalmers Frazer
 Joseph L. Friedes
(postdoctoral appointment)
 Tadao Fujii
 Francisco Eiichi Fujita*
*(on leave from Japan Atomic Energy
 Research Inst., Tokai-mura)*
 Maurice Gailloud*
*(assigned from
 Laboratoire de Recherches Nucléaires,
 École Polytechnique, Switzerland)*
 Otis R. Gilliam*
(on leave from Univ. of Connecticut)
 Eli Glazer
 Malcolm Goldberg
 Marvin Goldberg
(graduate student from Syracuse Univ.)
 Gertrude S. Goldhaber
 Samuel A. Goudsmit
 Barton Goz
(graduate student from Syracuse Univ.)
 Edward L. Hart
 Arthur Herschman
(on leave from Worcester Polytechnic Inst.)
 John W. Hess*
(assigned from Picatinny Arsenal)
 Nguyen C. Hien
(assigned from Carnegie Inst. of Technology)

William J. Hilger
 Henry W.K. Hopkins
(postdoctoral appointment)
 John Hornbostel
 Paul V.C. Hough
 James J. Hurst, Jr.
 Hidetsugu Ikegami
(on leave from Tokyo Univ., Japan)
 Joseph Jach
(assigned from Picatinny Arsenal)
 Adeshwar P. Jain
(postdoctoral appointment)
 Edgar W. Jenkins
 Robert A. Johnson
(postdoctoral appointment)
 Jovan V. Jovanovic
(postdoctoral appointment)
 Siegfried Kalbitzer
(postdoctoral appointment)
 Walter R. Kane
 David T. Keating
 Michael A. Kemp*
*(assigned from National Inst. for Research
 in Nuclear Science, England)*
 Stuart H. Kern
 Ottmar C. Kistner
 Joshua K. Kopp
 Saul Krasner
(assigned from Picatinny Arsenal)
 Thaddeus F. Kycia
 Kwan Wu Lai
(postdoctoral appointment)
 Ronald E. Larsen
(assigned from Frankford Arsenal)
 Boran A. Leontic
 Paul W. Levy
 Angela C. Li*
(graduate student from New York Univ.)
 Seymour J. Lindenbaum
 Max Lipsicas
 Demetrios T. Liverios
 George W. London
(graduate student from Univ. of Rochester)
 Robert I. Louttit
*(on leave to Centre d'Études Nucléaires,
 Saclay, France)*
 William A. Love
 James E. Mapes
(assigned from Picatinny Arsenal)
 Harvey Marshak*
 Clyde L. McClelland
*(on leave to
 Arms Control and Disarmament Agency,
 Washington, D.C.)*
 Michael McKeown
 Daniel McSweeney
 Werner A.W. Mehlhop
(assigned from Univ. of California)
 John Mellor
(postdoctoral appointment)
 Jack Menes
(postdoctoral appointment)

Inder S. Mittra*
(on leave from Panjab Univ., India)
 Sergio Monaro
(postdoctoral appointment)
 Giancarlo Moneti*
(on leave from Univ. of Rome, Italy)
 John A. Moore
 Thomas I. Moran
 Thomas W. Morris
 Bernard Mozer
 George T. Mulholland
 Joseph A. Nardi, Jr.
 Robert Nathans
 Kazuyuki Ogawa*
*(assigned from
 Tokyo Shibaura Electric Co., Ltd., Japan)*
 John W. Olness
 Jean Oostens
*(assigned from Inst. Interuniversitaire des
 Sciences Nucléaires, Belgium)*
 Kare Otnes
 Satoshi Ozaki
 Harry Palevsky
 Robert B. Palmer
 Simon Pasternack
(Editor of The Physical Review)
 Jorgen S. Petersen
*(on leave from
 Atomic Energy Commission, Denmark)*
 Peter R. Phillips*
*(assigned from
 Argonne National Laboratory)*
 Robert H. Phillips
 Stanley J. Pickart
*(assigned from
 U.S. Naval Ordnance Laboratory)*
 Albert G. Prodell
 David C. Rahm
 R. Ronald Rau
 A. Lincoln Read
 Kenneth F. Riley
(postdoctoral appointment)
 Robert A. Ristinen
(postdoctoral appointment)
 Donald K. Robinson
 David B. Rosenblatt
(assigned from Frankford Arsenal)
 Joseph H. Rosolowski*
(on leave from General Electric Co.)
 Henry Ruderman
(postdoctoral appointment)
 John J. Russell, Jr.
 Brice M. Rustad
(assigned from Columbia Univ.)
 Eileen Saffron
 Vance L. Sailor
 Edward O. Salant
 Nicholas P. Samios
 James R. Sanford
 Yoshiki Sato
*(on leave from Japan Atomic Energy
 Research Inst., Tokai-mura)*

*Terminated before July 1, 1963.

Robert I. Schermer
 Marcel R. Schmorak*
(postdoctoral appointment)
 Janet C. Schnecke
 Ivan Schroder
(graduate student from Columbia Univ.)
 Arthur Z. Schwarzschild
 Romeo A. Segnan
(postdoctoral appointment)
 Madan L. Sehgal*
(postdoctoral appointment)
 Akinao Shimizu
(assigned from Nippon Atomic Industry Group Co., Ltd., Japan)
 Gen Shirane
 Ralph P. Shutt
 Ian O. Skillicorn*
(postdoctoral appointment)
 Joseph E. Smith
 John H. Sondericker
 Morton M. Sternheim
(postdoctoral appointment)
 Rudolph Sternheimer
 David L. Stonehill
 Richard C. Strand
 Robert Stump
(on leave from Univ. of Kansas)
 Andrew W. Sunyar
 Richard J. Sutter
 Kasuke Takahashi
(postdoctoral appointment)
 Michael J. Tannenbaum
(graduate student from Columbia Univ.)

William M. Thompson
 Alan Thorndike
 Peter D. Townsend
(assigned from Picatinny Arsenal)
 T. Laurence Trueman
(postdoctoral appointment)
 Frank Turkot
 William A. Tuttle
 Issachar Unna
(postdoctoral appointment)
 Hiroaki Uto
(graduate student from Univ. of Pennsylvania)
 John H.M. Van Der Lans
 Joseph B. Vise*
(graduate student from Columbia Univ.)
 Cesare F. Voci
(on leave from Univ. of Padua, Italy)
 Robert L. Warasila
 Ernest K. Warburton
 Neil W. Webre
 Medford S. Webster
 Harvey E. Wegner
 David M. Weigand
 Joseph Wenner
 David H. White
(assigned from Univ. of Pennsylvania)
 Gian Carlo Wick
 Georg Will
(assigned from U.S. Army Signal Corps)
 William J. Willis
 Ernest Windschauer
 Sanford E. Wolf*
(on leave from Brandeis Univ.)
 Estarose Wolfson

Yehuda Wolfson*
(on leave from Weizmann Inst. of Science, Israel)
 Sukeyasu S. Yamamoto
 Taiji Yamanouchi
(assigned from Univ. of Rochester)
 Tsu Yao
(postdoctoral appointment)
 Thomas J. Ypsilantis
 Luke C.L. Yuan
 Bice Zorn*
 Gus T. Zorn*
 Martin S. Zucker*
 Crtomir Zupancic*
(postdoctoral appointment)
 Charles A. Zuroff

Reactor Division

Robert W. Powell, *Head*
 Frederick Allenspach
 Paul Colsmann
 George Demirjian
 Francis A. Dugan
 John J. Floyd
 Gerald C. Kinne
 Paul E. Mamola
 Frederick J. Morse
(graduate student from Rensselaer Polytechnic Inst.)
 Charles L. Osborne
 Jack E. Phillips
 dePuyster G. Pitcher
 Seymour R. Protter
 Walter H. Reed
 Dudley Thompson

*Terminated before July 1, 1963.