BROOKHAVEN NATIONAL LABORATORY

Annual Report

July 1, 1956

Associated Universities, Inc.

under contract with the

United States Atomic Energy Commission

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Associated Universities, Inc.

Upton, New York

Brookhaven National Laboratory is operated under a contract between the United States Atomic Energy Commission and Associated Universities, Inc. This, the seventh in a series of unclassified Annual Reports, gives an account of the progress of the Laboratory during the period July 1, 1955 - June 30, 1956, and its plans for the future. It is submitted under the terms of Contract No. AT-30-2-GEN-16 between Associated Universities, Inc., and the Atomic Energy Commission.

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465 *Altus*

Construction area of the Alternating Gradient Synchrotron. Circular trench will accommodate housing for magnet assembly. To its right is the service building. At lower right is the Cosmotron building with size of magnet indicated on its roof. Dike erected to trap external Cosmotron beam can be seen at lower left.

Introduction

This annual report of Brookhaven National Laboratory describes its program and activities for the fiscal year 1956. The progress and trends of the research program are presented along 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 in the quarterly scientific progress reports and other special reports of the Laboratory. Hence the activities of the Laboratory's service organizations are treated more fully in this report, whereas research activities are covered in summary. (A list of all publications may be found in Appendix A, and the record of publications since 1946 is shown in Figure 2.)

In this introductory section may be found a general summary of the Laboratory's activities. More detailed information is given in the following sections of this report.

PRESENT RESEARCH FACILITIES

The Laboratory's Cosmotron, a 3-Bev proton-synchrotron, and the nuclear reactor continue to support the major fraction of the research effort.

Except for a two-month shutdown for repairs and the usual regularly scheduled periods of preventive maintenance, the Cosmotron has been operated for research purposes on a 24-hr, 5-day schedule. It now provides a circulating beam of 10^{11} protons per pulse at energies up to 3 Bev. Thirty to 40% of this circulating beam can be deflected out of the vacuum chamber and focused on a target of less than 1.5-in. diameter at a distance of 50 ft. Beams of π -mesons and K -mesons, homogeneous in momentum, are also available for experiments.

The shutdown referred to above was occasioned by the development of loose field coils in the generator that supplies the magnet current. It was found necessary to rewind one coil and to realign the shaft of the motor generator-flywheel system. Also during this period, a dike composed of 40,000 yards of gravel taken from the trench for the Alternating Gradient Synchrotron was erected to trap the intense external beam. This dike effectively

protects outlying areas from objectionable levels of scattered radiation.

In spite of the 24-hour operating schedule, research priorities have had to be continued. The demands of many university scientists, as well as of the Brookhaven scientists, exceed the capacity of this machine. Over 100 physicists, including 70 from universities, have been engaged in devising and carrying out experiments at the Cosmotron and in analyzing photographs, emulsions, or other data obtained. Since the Bevatron at Berkeley is the only other high energy accelerator operating in the billion electron volt range, this situation is expected to persist at least for a few years. The Laboratory is continuing to exert every effort to meet demands through more efficient operation and use of the machine. To take advantage of the great usefulness of the new and powerful external beam, however, a large amount of supplemental apparatus and heavy shielding is needed. Consequently, a serious shortage of floor space in the vicinity of these beams has developed. Additional space is required to permit the operation of the Cosmotron for one experiment while others are being set up. Plans for a major extension of the present building, including increases in the existing shielding and provision for revisions in the machine operation setup, together with budget estimates, have been submitted to the AEC. These additions will greatly increase the research usefulness of this machine, as well as permit more efficient operation in meeting demands for its beams.

The development of bubble chambers for studies of high energy interactions has proved significant. These chambers are replacing both conventional cloud chambers and emulsions. A small hydrogen bubble chamber is now available, and a large one, $20 \times 9 \times 10$ in., is under construction and will be provided with a magnetic field of 15,000 to 20,000 gauss. To meet the increasing use of liquid hydrogen, a new liquifier is being installed that will deliver up to 50 liters per hour.

The Brookhaven research reactor operated smoothly throughout the year, with only a few shutdowns for minor causes. The facilities at the reactor have been used to capacity in supporting research projects from all the disciplines at the Laboratory, as well as from 14 other organizations which have members of their staffs on assignment

at the reactor. These institutions include universities, industrial corporations, and government agencies. About 1250 shipments of materials irradiated in the reactor have been made to hospitals, universities, industrial organizations, and government agencies. Neutron fluxes of up to 4 or 5×10^{12} neutrons/cm² are available at the center of the pile, and about a dozen neutron spectrometers are in almost continuous use. Laboratory, office, and shop space has been crowded. Increasing demands for space and flux have necessitated continued efforts to stretch the research facilities beyond their originally designed capacity.

Studies have been continued on the proposal to replace the present natural uranium fuel elements with new enriched fuel elements. These studies indicate that a five-fold increase in neutron flux should be realized with the new elements, accompanied by a reduction in operating costs because of more efficient cooling. An order for 300 new fuel element assemblies has been placed. The first units received will be substituted for those now in the central core position and direct evaluation studies of their effect upon the reactor's characteristics undertaken.

The 60-in. cyclotron has had a remarkably good performance record throughout the past year. External beams of protons, deuterons, and alpha-particles have been available at energies of about 10, 20, and 40 Mev, respectively. By means of radio-frequency bunching, bursts of deuterons 3 millimicroseconds in width and 10 milliamperes in peak intensity are being evaluated for use in time-of-flight experiments. It has been necessary to operate this cyclotron an average of about 15 hours a day, 5 days per week, to satisfy the demands for time at this machine.

External focused beams of protons at 2.5 Mev are available for neutron-producing reactions from the 18-in. cyclotron, which has also had a satisfactory performance record for the past year. Additional space is required for the neutron research program in order to eliminate effects due to scattered radiation and at the same time provide adequate shielding. This fact, coupled with the radiation hazards arising from the external beam of the Cosmotron, has made removal of the 18-in. cyclotron from its present temporary location in the test shack practically mandatory. An addition to the cyclotron-Van de Graaff building to house this machine has been authorized, and design and construction will begin in fiscal 1957.

Experience with the electrostatic generator which provides protons at 3 to 3.5 Mev was not as favorable as that with the 60-in. cyclotron.

Evaporation of aluminum inside the accelerating tube decreased the maximum voltage obtainable to about 2.5 Mev. A collaborative effort between this Laboratory and the High Voltage Corporation has resulted in a new tube design in which more rugged materials than aluminum are used in regions of high interelectrode fields. One of these new composite electrode tubes was installed in April. High intensity beams have been accelerated up to 3.7 Mev. Performance to date has been entirely satisfactory, which indicates a substantial improvement in the design of accelerating tubes for these machines. While demand for use of the electrostatic generator diminished at times during the academic year, the demand by visiting scientists, combined with that of the Laboratory staff, required operation of this machine on a 2-shift basis, 5 days per week, throughout the summer period.

CONSTRUCTION PROGRAM

The Alternating Gradient Synchrotron, Project AGS, is now well into its construction phase. The construction area is shown in the aerial photograph which serves as frontispiece. The circular trench that will accommodate the concrete housing for the magnet assembly can be seen, as well as the partially completed AGS service building. The piles to support the magnet assembly, although not visible, have been driven. The AGS service building should be completed and ready for occupancy by late fall. Solicitation for bids on the foundation for the injector building, the half-mile concrete tunnel to house the magnet assembly, and the foundation for the target building will go out early in July.

Ground was broken for the new Medical Research Center on June 26. An architect's rendering of this new structure is shown in Figure 3. The design layout is based solely on functional requirements. There are five basic sectors: 1) a research laboratory with flexible division for biochemistry, medical physics, physiology, microbiology, pathology, and animal quarters; 2) a research hospital with four 12-bed nursing units, together with facilities for occupational and physical therapy; 3) a medical reactor housed in a building nearly free-standing but connected to the research laboratory; 4) an industrial medicine wing which will be the outpatient department for Brookhaven personnel; and 5) central facilities including library, conference room, administrative offices, kitchen and shop. A single-level plan has been chosen, and

ASSOCIATED UNIVERSITIES, INC.

ORGANIZATION CHART

Figure 1.

Table 1
Organizational Expenditures - Fiscal 1954, 1955, 1956
(Includes Operating, Services to Fixed Assets, and Work for Others. Direct Costs of A.G.S. and Other Fixed Assets Are Not Included, see Table 3)

		Salaries, Wages, Insurance									Man-Years		
		Staff	Consultants & Temporary Employees	Travel	Material & Supplies	Research & Development Subcontracts	Special Power	Miscellaneous (Net)	Total Organizational Costs	% of Total			
											Scientific (Incl. Guests)	Others	Total
Physics & Chemistry Research	1956	1,951,118	88,882	81,998	464,265	7,054	64,491	(13)	2,657,795	22.4	199.5	146.5	346.0
	1955	1,734,418	74,767	53,330	388,452	24,193	38,337	(753)	2,312,744	21.6	181.5	134.0	315.5
	1954	1,639,590	89,936	55,487	351,713	81,350	47,075	(4,122)	2,261,029	22.7	163.5	129.5	293.0
Biology, Medicine & Biophysics Research	1956	1,125,070	38,319	40,884	213,772	8,214	—	(15,626)	1,410,633	11.9	81.0	149.5	230.5
	1955	1,036,260	46,240	30,702	216,930	11,101	—	(6,899)	1,334,334	12.5	85.5	147.5	233.0
	1954	916,503	38,373	30,344	204,575	68,516	—	(7,937)	1,250,374	12.5	79.0	132.5	211.5
Engineering Research	1956	914,145	20,629	43,093	383,957	190,602	—	(276)	1,552,150	13.1	77.5	82.5	160.0
	1955	780,197	16,362	23,777	305,769	112,154	—	(2,658)	1,235,601	11.5	67.5	71.0	138.5
	1954	703,359	18,553	23,211	256,585	33,194	—	(918)	1,033,984	10.4	61.5	70.0	131.5
Radiation Protection	1956	237,004	1,768	2,141	34,268	—	—	(14,358)	260,823	2.2	14.0	35.0	49.0
	1955	220,567	1,201	947	41,532	—	—	(13,298)	250,949	2.4	13.5	32.5	46.0
	1954	202,092	492	1,720	33,116	—	—	(11,422)	225,998	2.3	16.5	28.0	44.5
Supporting Scientific & Technical Services	1956	1,579,781	6,705	15,066	256,976	—	470,945	(244,127)	2,085,346	17.5	29.0	257.5	286.5
	1955	1,485,085	8,298	8,236	239,298	—	427,389	(175,040)	1,993,266	18.6	31.0	255.5	286.5
	1954	1,372,695	6,142	10,016	218,219	—	374,103	(122,273)	1,856,902	18.7	31.5	239.5	271.0
Security & Plant Protection	1956	448,685	—	392	10,541	—	—	(35)	459,583	3.9	—	86.0	86.0
	1955	460,006	—	1,569	5,764	—	—	—	467,339	4.4	—	95.5	95.5
	1954	494,362	—	1,058	4,421	—	—	—	499,841	5.0	—	105.0	105.0
Miscellaneous (including Lighting, T & T, Heating Fuels, Special Maintenance, etc.)	1956	—	—	1,127	86,541	—	—	683,808	771,476	6.5	—	—	—
	1955	—	—	1,394	72,923	—	—	518,672	592,989	5.5	—	—	—
	1954	—	—	—	54,226	—	—	441,653	495,879	5.0	—	—	—
General and Administrative	1956	2,222,434	10,798	58,524	243,278	—	—	(147,497)	2,387,537	20.1	5.5	424.5	430.0
	1955	2,027,971	7,520	57,133	262,029	—	—	(146,149)	2,208,504	20.6	5.0	406.5	411.5
	1954	2,014,723	8,066	15,141	222,495	—	—	(116,612)	2,143,813	21.5	5.5	412.0	417.5
Laboratory Total	1956	8,478,237	167,101	243,225	1,693,598	205,870	535,436	261,876	11,585,343	97.6	406.5	1,181.5	1,588.0
	1955	7,744,504	154,388	177,088	1,532,697	147,448	465,726	173,875	10,395,726	97.1	384.0	1,142.5	1,526.5
	1954	7,343,324	161,562	136,977	1,345,350	183,060	421,178	178,369	9,769,820	98.1	357.5	1,116.5	1,474.0
AUI Administration	1956	—	—	—	—	—	—	150,000	150,000	1.3	—	—	—
	1955	—	—	—	—	—	—	161,400	161,400	1.5	—	—	—
	1954	—	—	—	—	—	—	150,000	150,000	1.5	—	—	—
Total AUI and BNL	1956	8,478,237	167,101	243,225	1,693,598	205,870	535,436	411,876	11,735,343	98.9	406.5	1,181.5	1,588.0
	1955	7,744,504	154,388	177,088	1,532,697	147,448	465,726	335,275	10,557,126	98.6	384.0	1,142.5	1,526.5
	1954	7,343,324	161,562	136,977	1,345,350	183,060	421,178	328,369	9,919,820	99.6	357.5	1,116.5	1,474.0
Work for Others, Direct Costs Only	1956	70,853	10,582	5,809	41,496	—	—	—	128,740	1.1	6.0	8.5	14.5
	1955	43,296	65	1,367	48,785	53,010	—	—	146,523	1.4	2.0	6.0	8.0
	1954	12,184	—	373	24,253	—	—	—	36,810	.4	2.0	2.5	4.5
Grand Total	1956	8,549,090	177,683	249,034	1,735,094	205,870	535,436	411,876	11,864,083*	100.0	412.5	1,190.0	1,602.5
	1955	7,787,800	154,453	178,455	1,581,482	200,458	465,726	335,275	10,703,649**	100.0	386.0	1,148.5	1,534.5
	1954	7,355,508	161,562	137,350	1,369,603	183,060	421,178	328,369	9,956,630†	100.0	359.5	1,119.0	1,478.5

Note: Certain adjustments have been made in 1954 and 1955 costs as previously reported in order to make them comparable to 1956 cost-reporting procedures.

*\$291,410 of this total was distributed to Fixed Assets and as services to Work for Others.

**\$252,910 of this total was distributed to Fixed Assets and as services to Work for Others.

†\$218,978 of this total was distributed to Fixed Assets and as services to Work for Others.

Figure 2.

each sector has been located appropriately with respect to the others from the functional point of view.

One distinctive feature is found in the four circular nursing units of the research hospital. Each consists of twelve single bedrooms in a radial layout with the nurse's station at the center. The scheme permits the nurse on duty to have direct observation and control of each patient and reduces to a minimum distances from the nurse's station to patients. Another distinctive feature is the Medical Research Reactor (see Figures 4 and 5). The core will consist of highly enriched uranium-aluminum alloy, aluminum-clad fuel elements contained in a 2-ft-diameter aluminum tank. A dry graphite reflector will be placed around the tank. The core will be cooled by natural water flowing up between the fuel elements, and the reflector, by moving filtered air through cooling passages in the graphite. The experimental holes all terminate in the graphite reflector. The shutters which will start and stop the neutron beams used for treating patients, and for experimental purposes, will be located within the shield. A neutron flux of 10^{10} to 10^{11} neutrons/cm² will be available for therapy and for experiments from a core flux of 10^{13} neutrons/cm².

Ground was also broken in June 1956 for a new engineering works area, 10,000 ft², that will pro-

vide a high-ceilinged building for the development and testing of such large equipments as the experimental loops used in the feasibility studies of new reactor designs.

The construction and installation was completed of equipment needed to increase the steam capacity of the Laboratory's central heating plant to take care of the AGS complex and other requirements. This system now serves the whole central area of the Laboratory except for those temporary barracks that still have individual units.

Major construction over the next two years will include, in addition to the AGS facilities and the Medical Research Center, a new physics building approximately 51,000 ft², an engineering building 44,000 ft², housing for the reclamation facility and hot laundry 7500 ft², and a 5800-ft² addition to the cyclotron-Van de Graaff building to house the 18-in. cyclotron. Budget requests for these new facilities have been approved by Congress. Detailed design and construction will begin in fiscal 1957. These plans are in line with the philosophy of gradually providing permanent facilities, both for general Laboratory requirements and for functions that are specific to Brookhaven and its work. The new Medical Research Center, besides providing permanent quarters for the medical group will, by its location in the central area, facilitate more active cooperation between this group and the

Successy vision
 Figure 3. Architect's rendering of Medical Research Center.

MRR
 Figure 4. Model of Medical Research Reactor.

Figure 5. Cross section of core of Medical Research Reactor with shields and shutters.

biologists, chemists, physicists, and engineers – a cooperation that has already proved characteristic of medical research here, in spite of the handicap of remote location. Similarly, the physics building will for the first time bring under one roof physicists now scattered in various temporary structures, and thus provide for quicker and more complete interchange of ideas, as well as better administrative efficiency. The engineering building will similarly provide housing for the increasing staff of the Nuclear Engineering Department, now crowded into a temporary and badly deteriorated structure formerly used by the Army as the Enlisted Men's Service Club.

Many minor construction projects were also completed during this report period. These are listed under "Architectural Planning" in the Administration and Operations section of this report. Among the more significant of these is the hydrogen liquifier laboratory in which the liquifier, now nearly completed, should be in operation within the next two months. The program of restoration of both permanent and semipermanent buildings initiated last year has been continued.

Structural weaknesses in many of the wooden buildings which the Laboratory plans to use over the next few years have required correction. As the temporary wooden buildings become older, maintenance requirements increase and will have to be met in order to preserve the buildings until more permanent structures become available.

MAJOR RESEARCH PROJECTS

LIQUID METAL FUEL REACTOR

The use of a liquid metal as a reactor fuel has been under investigation at Brookhaven for several years. These studies have been fundamental in character in order to determine the feasibility of developing components that could be later coordinated into a complete reactor system. The results have been encouraging. During the past year, the Liquid Metal Fuel Reactor (LMFR) has been added to the official list of reactors which are being developed by the Atomic Energy Commission. The Commission is now negotiating a prime contract with the Babcock and Wilcox Company,

first to study the scope, preliminary design, and required research and development, then to undertake the detailed engineering design and construction, and possibly the operation of an LMFR experiment. The chief advantages of such a reactor for power purposes can be summarized as follows. The liquid metal fuel can be circulated for direct heat transfer and can be processed continuously. High fuel temperatures give high thermal efficiencies without excessive pressures and the containment problems resulting therefrom. An accompanying liquid metal breeder blanket can also be continuously processed and should provide as much fissionable material as is consumed. Continuous processing and replenishing of fuel should keep fuel costs low and eliminate shutdowns for fuel replacements. The reactor structure itself can be relatively simple and economical.

The work of the past year on fuel processing has reinforced the belief that the volatile fission products can be removed from a liquid fuel consisting of uranium dissolved in molten bismuth by a physical degassing process, and that a large and important fraction of the nonvolatile fission products can be extracted into a fused salt. Measurable progress has also been made in scaling up some of these processes from the laboratory toward the plant stage. Breeder blanket development work has resulted in a promising technique for obtaining fluid slurries of thorium bismuthide in molten bismuth. Graphite for use as the moderator should be impervious to the bismuth-uranium fuel. Samples from commercial sources have proved satisfactory in this respect. Studies of the effect of irradiation on graphite in the presence of such substances as uranium, bismuth, zirconium, magnesium, and fission products have been undertaken. In the search for a satisfactory container material, valuable information has been obtained on the behavior of a variety of steels in contact with the uranium-bismuth fuel. By use of zirconium as an additive, these experiments have indicated that inhibition of corrosion is due to the formation of a zirconium nitride film and that the higher the activity of nitrogen in the steel, the more corrosion resistant the steel is. Further experiments seeking the best container material are under way. A number of exponential studies on assemblies of bismuth rods, graphite stringers, and uranium-235 foils have been planned for the purpose of obtaining the data required to establish the core parameters for the LMFR experiment. These will be carried out at the new critical assembly facilities being provided for this work. Theoretical studies have been completed on cores

consisting of uranium dissolved and suspended in other low-melting metals. Earlier calculations on breeders for the LMFR have been refined by carrying out multigroup computations and have yielded results consistent with previous ones. Estimates of control rod effectiveness in the Laboratory's preliminary design of the LMFR experiment (see Figure 6) have been completed. All these results will be used in establishing the final design of this experiment.

ALTERNATING GRADIENT SYNCHROTRON

This accelerator is expected to provide beams of protons of 25 to 30-Bev energy. It employs the strong-focusing principle. The design is in its final stage and it is expected that orders for most major components will be placed during the next fiscal year. Experimental tests of the dynamic behavior of strong-focusing synchrotrons have been completed during the past year by means of the Electron Analogue. In this machine, beams of electrons are guided in orbits 45 ft in diameter by strong-focusing systems of electrostatic rather than magnetic lenses. Three aspects of AGS operation can be studied: the locations, widths, and strengths of resonances; the feasibility of phase-transition passage of the beam without undue loss; and the effects of nonlinear fields. All these phenomena were successfully investigated during the past year and the Electron Analogue was placed on standby in June until future problems arise that require its reactivation. In general, the resonance patterns found have confirmed earlier predictions. Conditions giving rise to unacceptable beam losses have been determined. The feasibility of passing the electron beam through the phase transition smoothly has been established. Techniques have been determined by which half the injected beam can be passed smoothly through the phase transition to an energy corresponding to several phase oscillations beyond the transition point. AGS phase-oscillation conditions were simulated in the analogue in order to determine both the feasibility of maintaining beam stability and the conditions required therefor. Results of all these studies with the Electron Analogue have more than justified its cost by confirming the practicability of the Alternating Gradient Synchrotron and by establishing many of its design features on an experimental basis.

Magnet model investigations have been continued throughout the year. On the basis of these measurements and calculations, an optimum cross section and design for the final magnet has been determined. The usable aperture within

- ① REACTOR
- ② CONTROL ROD DRIVES
- ③ DEGASSERS
- ④ URANIUM BISMUTH FUEL PUMPS
- ⑤ FUEL-AIR INTERMEDIATE COOLER
- ⑥ AIR-AIR FINAL COOLER
- ⑦ STACK
- ⑧ DUMP TANKS
- ⑨ FUEL PROCESS CELL
- ⑩ GENERAL VENTILATING FAN ROOM

Figure 6. Proposed Liquid Metal Fuel Reactor Experiment.

which the beam orbits must be magnetically contained is about $7 \times 2\frac{1}{2}$ in., an area less than $1/800$ th of the scaled-up ($10\times$) aperture of the 3-Bev Cosmotron. This is due, of course, to the application of the "strong focusing" principle discovered independently here in 1952 that makes the Alternating Gradient Synchrotron economically feasible. The particular magnet steel to be used and the method of fabricating the magnets have not yet been determined. Studies are being continued with the cooperation of the research laboratories of several steel firms. The approximate characteristics of the magnet power system have been determined.

A foundation design for the support of the magnet units has been adopted on the basis of data from test borings, load tests, subterranean temperature observations, and stress analyses. The injector system will consist of an 800-kv Cockcroft-Walton accelerator as a preinjector, followed by a modified version of the conventional Berkeley linear accelerator. Modifications introduced include the substitution of a single copper-clad steel tank for the conventional radio-frequency cavity of light construction enclosed in a heavy vacuum

tank, newly designed drift tubes, and the replacement of grid focusing by alternating gradient focusing inside the drift tubes. These modifications should improve such factors as mechanical rigidity, power consumption, and focusing effectiveness. The design of the rf cavity has undergone one major change, the substitution of water cooling for the previously proposed air cooling of the ferrite core. Work is progressing on the design of the vacuum chamber and a system of Evapor-ion pumps has been adopted on the basis of simplicity and speed. The over-all progress in both the design and construction phases of the AGS Project has been encouraging. Barring unforeseen delays, the AGS should be ready for operational tests by about 1960, as previously estimated.

PROJECT COLOMBO

The proposal for the establishment of a regional nuclear and training center in Asia, to which this country would make a major contribution, was first made known to the world in a speech in Sin-

gapore by John B. Hollister, Director of the International Cooperation Administration (ICA), on October 20, 1955. Mr. Hollister was speaking as United States representative to the Ministerial Meeting of the Consultative Committee for Economic Development in South and Southeast Asia, otherwise known as the Colombo Plan.

Although the U.S. proposal was a very general one and did not give much indication of the size, scope, or location of the center, it was received with great interest by the Asian countries of the Colombo Plan. In early 1956, therefore, the U.S. Government decided to initiate a detailed study which would assist in drawing up plans for the installation, operation, and administration of the proposed center. In seeking a suitable agency to conduct such a study, the following criteria were obviously desirable: a) research and training experience in the various nonmilitary aspects of nuclear science and technology; b) experience in the administration of research projects of a cooperative or regional nature, and c) a private rather than government affiliation so that the necessary consultations with the representatives of the Asian countries could be conducted in a private and autonomous rather than an official atmosphere.

With the above criteria in mind, ICA requested Brookhaven National Laboratory to undertake the study. The Laboratory accepted the assignment on March 2, subject to the approval of AEC and the transfer of funds from ICA to AEC in the amount necessary to defray the cost of the work. Accordingly, a memorandum of agreement between ICA and AEC was signed on April 6. The cost of the entire project was estimated at \$240,000, and this figure was set as a ceiling.

In the meantime, Marvin Fox, Chairman of the Reactor Department, was appointed Leader of Project Colombo, as it was named locally, with Dennis Puleston, Head of the Technical Information Division, as Deputy Project Leader. To staff the project, specialists in the various scientific disciplines were sought, as well as a political scientist well-versed in Far Eastern affairs and an expert in industrial nuclear power. Solomon H. Chafkin joined the group from the International Cooperation Administration, John F. Hogerton from the Vitro Corporation, Horace Smith from the Department of State, Ralph Strom from the AEC, Harold B. Tukey from Michigan State University, Amry Vandenbosch from the University of Kentucky, and Frederick C. Vonderlage from the Oak Ridge National Laboratory. All were assigned to the Laboratory by their institutions to serve, as individuals, for the duration of the study.

From the Laboratory staff, Victor P. Bond (M.D.), G.J. Dienes, Norman Elliott, and H.H. Smith also joined the group.

The plans for the study called for an integrated professional team to be sent on an extended tour of the various Asian countries involved. Concurrently, the remainder of the project staff was to explore sources of information in this country and in general prepare for the reporting phase of the project when the entire staff was reunited. A firm of architect-engineers, the Ralph M. Parsons Company, was engaged to prepare architectural ideas for the center, with preliminary layout plans and schematic drawings of the various buildings, together with rough construction cost estimates.

The ten-man field group, accompanied by an aide loaned by the ICA, departed on its tour on April 6, and during the following ten weeks visited fourteen Asian countries within the Colombo Plan—Pakistan, India, Nepal, Ceylon, Burma, Thailand, Malayan Federation, Singapore, Indonesia, South Vietnam, Laos, Cambodia, the Philippines and Japan. Discussions were held with government officials, scientists, and educators in each country with the ultimate objective of learning what type of nuclear center could best serve their needs and interests.

Since the Department of State had already decided, and publicly stated, that the center would be established in the Philippines, the question of site selection by the Brookhaven group was confined to that country. The most desirable location, it was soon found, was a 91-hectare triangle within the campus of the University of the Philippines. The allocation of this area for the center was greatly facilitated by the cooperative spirit and enthusiasm of many Philippine government officials, including President Magsaysay, who took a great personal interest in the proposed center.

On June 25, most of the members of the project staff assembled at Brookhaven to discuss plans for writing the necessary reports. All efforts are now bent toward preparation of the study report, which is to be submitted to ICA in preliminary form by August 15. The comments of many scientists and administrators from the Laboratory staff have been solicited in finalizing the Brookhaven concept for the center.

RESEARCH ACTIVITIES

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

central theme the development and exploitation of nuclear science and technology. It can be broadly described under four major headings:

- 1) fundamental studies of atomic nuclei, the particles which constitute them, and the forces involved in their structure;
- 2) studies of the physical, chemical, and biological effects of radiation;
- 3) the use of nuclear tools, such as neutrons, charged particles, gamma-rays, and isotopic tracers, in all branches of scientific research; and
- 4) research and development, not necessarily of a nuclear nature, directed at the specific problems of atomic energy development.

The status of the research activities and the important developments of the year in each department can be found in more detail in the separate departmental sections of this report.

FUNDAMENTAL STUDIES OF NUCLEI

Studies seeking to throw light on how the particles making up the nuclei of atoms are held together are carried out in the Physics, Cosmotron, and Chemistry Departments. These studies make use of probes to disturb the nuclei, and various techniques to determine the resulting events. The probes range from protons at 3 billion electron volts of energy from the Cosmotron, to neutrons of fractions of an electron volt of energy from the reactor. The work at high energy has excited most attention and enlisted the active collaboration of scientists from a number of universities. This is doubtless due to the as yet little understood array of mesons and hyperons that are produced at these high energies. All these particles are very transitory in existence, with mean lives ranging from millionths to tens of billionths of seconds. The meson masses are intermediate between those of the electron and the proton; the hyperon masses are slightly greater than those of the proton or neutron. Considerable attention has been given in the past year to the conditions under which these transitory particles are produced, and to their number, characteristics, and modes of decay in an attempt to learn more about the role they play in nuclear structures.

In an effort to gain very basic information, studies have been continued on the interaction of high energy protons on protons and on neutrons, i.e., studies of the interaction of nucleons on nucleons. These studies have in general confirmed those described in the last Annual Report. They support the concept that the pions produced in these simple interactions result from the almost immediate de-

cay of excited states of one or both nucleons. The experimental data, although rather incomplete, suggest that these excited states are resonant isobaric states, in which both the isotopic and mechanical spins equal $3/2$.

One of the first of the heavy K -mesons discovered in cosmic rays was an uncharged particle designated as theta, which decays into two pions with a mean life of 10^{-10} sec. The rigid application of charge conjugation, a concept closely related to the existence of antiparticles, predicted that another form of the neutral theta-meson should exist which would decay into three particles with a considerably longer mean life. Experimental confirmation of the existence of this particle was obtained by a group from Columbia University working with a Brookhaven physicist. Analysis of some 8000 cloud-chamber photographs revealed 23 events in which neutral particles were found that decayed into three particles with a mean life much greater than 10^{-10} sec.

Emulsion studies at Berkeley, California, showed that two of the K group of the strange mesons had the same masses within a very small error, although they decayed in two different modes. A group from Princeton University, working with the Cosmotron, has shown that the mean lives for these two particles are also the same within 8%. Another group of experimenters from the Massachusetts Institute of Technology has sought any difference that might exist in the manner in which these particles are scattered, but has found none. Results of both these experiments, together with the one at Berkeley, indicate that in this case one is dealing with a single particle that has two different modes of decay. This presents an enigma not yet adequately explained by theory.

Considerable evidence was presented in the last Annual Report to the effect that the production of a hyperon always occurred simultaneously with the production of one of the heavy K -mesons, a phenomenon discovered at Brookhaven and called associated production. This phenomenon occurs in the interaction of negative pions of energies of 1 Bev or above with protons or neutrons. Efforts to produce hyperons and heavy mesons by means of interactions of protons with protons have been unsuccessful in the 3-Bev range of energy, which suggests that associated production occurs by the interaction of negative pions only. The energy threshold for the production of negative K -particles by protons on nuclei such as beryllium has been found to be near 1.8 Bev, a value that is consistent with the concept of associated production on the basis that a positive K -meson must be pro-

Figure 7. The experimental area at the end of the electrostatic generator. A beam of protons or deuterons is directed down any one of the pipes. Different pipes are used for different experiments.

Figure 8. The experimental area for the beam from the 60-in. cyclotron.

duced simultaneously. The threshold for positive K -meson production was found to be lower, at 1.2 Bev, a value predicted on energy considerations if production is associated with that of a hyperon also. The cross section for associated production by protons on various nuclei reaches a maximum cross section per nucleon for nuclei around beryllium or carbon. The variation of this cross section with mass number is consistent with production by direct nucleon-nucleon interaction, together with production by an intermediate pion excited by incident protons in the same nucleus. Further investigations on the phenomena of associated production are under way by groups from several different universities.

Physicists study the interactions of nucleons on nucleons and mesons on nucleons, the products of these reactions, and the properties and behavior of the unstable particles (mesons and hyperons), while radiochemists investigate the nuclear fragments (nuclides) produced by the bombardment of complex nuclei with high energy particles. Emphasis in these latter studies has shifted from surveys of the over-all yield of different nuclides to more specific studies of particular processes. The availability of the external proton beam from the Cosmotron has made possible the absolute measurement of a reaction cross section which can then be used for beam monitoring in the circulating beam. The reaction $C^{12}(p,pn)C^{11}$ has been chosen for this purpose. A value of 28 ± 2 millibarns has been obtained for proton energies between 2 and 3 Bev. This value is about 25% higher than that obtained in earlier, less accurate measurements. The energy dependence of the cross section of p,pn reactions upon target mass number has been determined for C^{12} , N^{14} , F^{19} , Cu^{65} , Mo^{100} , Ce^{142} , and Ta^{181} . Except for Ce^{142} , the cross section for each of these reactions was found to be nearly constant for proton energies between 0.4 and 3.0 Bev. For Ce^{142} , the cross section decreases by about a factor of 2 when the proton energy is increased from 0.4 to 1.0 Bev. The near constancy of these cross sections with energy (except that of Ce^{142}) can be interpreted by a pure knock-on mechanism, i.e., the direct ejection of a neutron by an incident proton. The cross section variations at one energy, from nuclide to nuclide, do not exhibit the type of regularity to be expected from such a mechanism. These variations, in the case of heavy nuclides, may be indicative of differences in neutron densities near the nuclear surface and may be connected with nuclear shell structure.

The formations of the nuclides F^{18} and Na^{24} from Al, Cu, Ag, Ta, Au, Pb, and U have been

measured for protons at 1, 2, and 3 Bev. The cross sections for Na^{24} are higher than those for F^{18} by factors of 2 to 5, but show the same general dependence on energy and target mass number. Two different mechanisms for the formation of F^{18} and Na^{24} are indicated, one predominating in the light element targets and the other in the heavy elements. For the light elements, F^{18} and Na^{24} are presumably produced mostly by conventional spallation mechanism, i.e., a knock-on cascade leading in about 10^{-21} sec to an excited nucleus from which nucleons, deuterons, alpha-particles, etc. are evaporated in perhaps 10^{-14} sec to form the final product. The observed cross sections for the production of F^{18} and Na^{24} from heavy elements presumably cannot be explained in terms of such a process. A fragmentation process is suggested, namely, the breakup of a nucleus into two or more large fragments in a time that is short compared with the time required for the distribution of energy throughout the nucleus. It is suggested that such a fragmentation process may be the result of a local hot spot in a nucleus created by successive scattering collisions of a pion inside the nucleus which lead to the breaking of several nucleon-nucleon bonds in a small region.

The researches using probes of much lower energy than those from the Cosmotron are primarily concerned with the energy level structure of nuclei. When charged particles such as deuterons or protons from low energy accelerators or neutrons or gamma-rays interact with a nucleus, new nuclear energy states are produced which, in general, are unstable. The unstable state may decay into a stable state in a very short time by the emission of a particle or gamma radiation, or it may take a measurable time for the stable state to be formed. In the latter case, the intermediate unstable state is designated as radioactive, and a time characteristic of the decay is called the mean life of the unstable configuration. Studies of the modes of decay of the radioactive nucleus, with respect to the number and energy of the particles and gamma-rays emitted, and the mean life of the decay lead to information on the energy level structure of the nucleus. On the other hand, when the intermediate nucleus resulting from an interaction reverts to a stable configuration in a time too short to be measured with existing techniques, the interaction products have to be studied simultaneously with the interaction process. Numerous studies of both types have been carried out during the past year. New and improved techniques have given more detailed information about the complex energy level structure of nuclei. An electronic coincidence

analyzer has been developed that has made it possible to measure mean lives as short as 3×10^{-11} sec. The mean lives of positrons and several nuclides have been determined with this instrument. The study of energy levels involved in gamma radiations requires high precision and good resolution in the determination of gamma-ray energies. An intermediate image pair spectrometer having both high energy resolution and high transmission has been designed and constructed. This device indirectly determines gamma-ray energy by measuring the energies of the electron and positron into which the gamma is converted when these two particles have the same energy. Equipped with a gamma-electron coincidence facility, it has been used in the investigation of a number of radioactive nuclides.

Neutrons from the research reactor have also been used as probes. Interactions of neutrons in the energy range from thermal energies to several kilovolts have been studied with the fast chopper, together with time-of-flight techniques. Reduction of gamma-ray background by a modification of this chopper has permitted the use of fast scintillation detectors. A xenon scintillation counter has

been used to confirm the constancy of the number of neutrons released per fission for plutonium-239 over the energy range from thermal up to 0.3 electron volts. Measurements have been made in the kilovolt region of the neutron resonances and their widths for 16 nuclides ranging from silver to uranium. The measurement of 12 resonances for U^{235} has been completed during the past year. From the fission widths of these resonances, it is possible to deduce information concerning the variation in the probability of fission from resonance to resonance. Measurements of potential scattering cross sections for a large number of heavy nuclei are being obtained by averaging over the resonances in the range of kilovolt energy neutrons. These measurements, when completed, should give useful information about the variation of nuclear radius with atomic weight.

Studies of neutron interactions at energies higher than those available from the reactor have been carried out at the 18-in. and 60-in. cyclotrons. The neutrons are obtained from bombardments of target nuclei by protons or deuterons. Both elastic and inelastic neutron scattering from iron and carbon have been investigated at the 18-in. cyclo-

✓ Figure 9. Neutron spectrometer mounted at an experimental hole through the shield of the reactor. The diffraction pattern of a beam of neutrons from the reactor reveals the distribution of atoms and magnetic centers in solids.

tron for incident neutron energies of about 1.6 Mev.

EFFECTS OF RADIATION

The effects produced by the irradiation of materials and of organisms are important in themselves; in addition, the study of these effects frequently reveals characteristics of materials or throws light on the internal processes of organisms. A few of the results of studies of this character, made in nearly all the disciplines at the Laboratory, will be cited here.

The technique for the determination of the concentration of lattice defects in graphite by means of the transmission of long wavelength neutrons was mentioned in the last Annual Report. This technique has been applied to other types of solids of low neutron absorption. In the case of alpha-aluminum oxide which had been irradiated for four months at room temperature, an effect on the transmission only one-sixth that predicted by theory was found. To eliminate the annealing effect suspected in this substance and others to be examined, the crystal spectrometer used has been rebuilt to increase the detectable neutron intensity and to provide for the examination of specimens at low temperatures.

Other techniques used in studying the effects of irradiation on solids include changes in x-ray diffraction patterns, in optical absorption bands, in ultrasonic attenuation and elastic constants, in resistivity, and in chemical reactivity. The changes in chemical reactivity in solids are effected by ionization or by means of displaced atoms. Solid state polymerizations induced by gamma-rays have been found to proceed via a free radical mechanism without any local melting. X-ray diffraction studies are under way in an attempt to elucidate the mechanism involved. Changes in chemical reactivity due to displaced atoms have also been studied. In particular, the oxidation rate of graphite in the temperature range of 250° to 400°C was found to be increased markedly by prior reactor irradiation. This effect may be regarded as catalytic in the sense that the displaced atoms are not oxidized preferentially, but apparently facilitate the over-all oxidation. Ionizing radiation (gamma-rays only) increased the rate of oxidation in unirradiated graphite, but by a very much smaller factor. This smaller effect is doubtless due directly to the ionization of oxygen molecules. Neutron irradiation lowered the activation energy for the reaction by about 28%.

Reactions induced by radiations in aqueous solution are brought about by formation in the

water of the molecular decomposition products H_2 and H_2O_2 , and the free radicals H and OH , which react with whatever solutes are available. The aim of studies in this field is to obtain a consistent description of all observed reactions in terms of their initiation by these common sources of activation, the yields of which (in terms of number of molecules or radicals produced per unit of energy input) should be the same in all dilute aqueous solutions for a given radiation. The yield of the molecules produced has been found in general to increase, and the yield of radical reactions to decrease, as the quality of radiation changes in the direction of greater ionization density or linear energy transfer (i.e., greater release of energy per unit distance along the track of the fast particle which is actually transferring energy to the irradiated medium for the case of the radiation in question, with correspondingly higher initial concentration of radicals along the track). During the past year, studies have been continued with radiations covering the whole range of available ionization densities in order to establish the molecular and radical yields in sulfuric acid solution. Results of these studies are discussed under the heading "Chemical Effects of Radiation" in the Chemistry section of this report.

It is becoming increasingly apparent that perhaps the most profound effects of ionizing radiations on living tissue are produced in the nucleus of the cell, and specifically on the genetic structure contained within the nucleus. In fruit flies it has been found that sensitivity to radiation-induced mutation varies strikingly during the development of the egg. The cells (ovarial oocytes) can be divided into three categories with respect to their stage of development at the time of irradiation: Class A, more advanced; Class B, less advanced; and Class C, the earliest stage. Cells of Class A show a high rate of dominant lethal mutation and of X-chromosome loss and recessive lethal mutation, whereas cells of Class B show lower rates of all three types of mutation. The difference in sensitivity can be correlated with cytological differences between the two groups of cells. In group A cells the nuclear membrane has broken down and the chromosomes are maximally condensed, whereas the relatively diffuse chromosomes of group B cells lie in a typical nucleus. Cells of Class C (which include those at the earliest stage of development when irradiated) contain few or no induced dominant lethal mutations and X-chromosome losses, but the frequency of sex-linked recessive lethal mutations is not significantly different from that found in cells of Class B. Perhaps the probability

of breakage is low or the probability of restitution high in chromosomes of Class C cells. If such were the case, dominant lethal mutations and X-chromosome losses would not be produced, but subtler types of genetic change such as recessive lethals would still occur. Although gross chromosome aberrations are quickly eliminated from the germ tract, the more subtle recessive lethal mutations are not, a fact which suggests that this class of mutations should be studied in populations of higher animals exposed to radiation.

The cooperative program designed to produce useful mutations in agriculturally important plants and trees continued to expand. An additional facility for the irradiation of seeds with neutrons has been completed at the reactor. Seventeen projects are under way with Canadian institutions. Cooperative projects have been started with scientists in Australia, Italy, Mexico, Pakistan, Peru, the Philippines, Rumania, Thailand, and Venezuela. It is likely that foreign cooperation will increase considerably during the coming year. Reports coming in from cooperating institutions have given a much better basis for neutron dosage estimation. A number of different investigators have reported finding mutations in wheat, oats, barley, rice, and peanuts which were resistant to specific diseases. Other important characteristics observed in mutants include earliness, winter hardiness, stiff straw, and dwarfing. Most of these results are less than a year old and field trials must be carried out before their ultimate value can be determined. The effective use of radiation-induced mutations will increase as understanding of basic radiobiological processes is expanded. Considerable emphasis is being put on projects seeking to elucidate these processes.

Somatic mutations involving flower color produced by irradiation with either gamma-rays or x-rays have been previously reported, in particular, a high rate of change from white to red in carnations and a much lower rate of change from red to white. This difference suggested that other than pure genetic factors were involved. The fact that the outer layers of the plant had a genetic constitution different from that of the underlying layers suggested that an injury phenomenon might have been observed rather than a true mutation. Studies of the stem apex at various intervals after irradiation revealed selective destruction of the outer layers followed by regeneration of a new apex from the deep-seated cells. The new apex was genetically homogenous with that of the underlying tissues and therefore produced red flowers instead of the white ones characteristic of the outer tissues.

The much fewer changes from red to white could not have been produced in this manner and must, therefore, be considered as true mutations.

It is well known that following a large dose of radiation an animal is very susceptible to infection, apparently because the body is unable to produce antibodies. At Brookhaven, attention has been directed to the role of the eosinophil cells (a type of white cell found in blood) in this connection, since they are known to be related to allergic reactions, parasitic infections, and foreign-body reactions. Experiments in mice have led to the following conclusions: There is a close correlation between the accumulation of eosinophils at the site of antigen inoculation and the production of antibody. The increase in eosinophils appears to occur only when antibody is formed and in organs or tissues forming the antibody. Both antibody formation and eosinophil accumulation are inhibited by massive doses of cortisone or whole-body irradiation if given immediately prior to the antigen injection. If the irradiation is given 12 to 24 hours after the antigen injection, neither is prevented. The radiosensitive stage of antibody formation appears to be the period in which eosinophils are accumulated. During the radioresistant phase, they have already accumulated and are apparently resistant to the effects of irradiation.

One of the organs most sensitive to radiation in the bodies of mammals is the intestine, and many acute deaths have been attributed to failure of this organ. An investigation using hamsters and mice indicates that the effect of the radiation is to block the production of viable new cells in the intestinal epithelium. It has also been found that there is a small region in and around the mouth of rats and mice the irradiation of which, with relatively small doses, will lead to the death of the animal. Further investigation of these effects is under way.

Mice receiving whole-body irradiation of 525 roentgens of x-ray at 8 weeks of age died on the average at about 12 months of age, whereas the controls lived about 18 months. Death apparently resulted from the same causes in both cases. It appears that x-irradiation of this type increases the normal rate of aging, at least in mice.

As was reported last year, the Medical Department at Brookhaven has been investigating the application of neutron capture therapy, and in particular its use in the treatment of the malignant brain tumor, glioblastoma multiforme. In this procedure, the tumor area is exposed to a beam of slow neutrons following an intravenous injection of a boron-10 salt solution. The interaction of neu-

trons with boron-10 atoms results in an alpha-particle and a lithium recoil atom of short range but sufficient energy to prove lethal to tumor cells. The results of the treatment of 19 patients have been encouraging, as previously reported. Certain problems, however, were indicated which required further study to permit the development of successful procedures. The investigation of these problems has been intensive this past year. Experiments on swine have indicated that the radiation dermatitis developed in some patients may be attributable to the boron-10 neutron interaction rather than to any other effects produced by the neutrons. In experiments on mice, the relative biological effectiveness of the radiation resulting from the neutron-boron interaction was found to be 1.7 compared with cobalt-60 gamma radiation, and 1.1 compared with 250-kvp x-irradiation. Boron injection plus neutron irradiation has also been studied in mice with brain tumors in an effort to determine the viability of such tumors after treatment. The tumor masses from mice so treated were transplanted into normal mice and mortality data collected. The mortality in this group was 30%, as compared with a mortality of 90% in a control group, the tumors of which had been transplanted from mice that had received neutron irradiation but no boron. In an effort to improve the concentration of boron in tumor masses, pentaborate solutions and tetraborate solutions were injected into mice. The ratio of the boron in the tumor to boron in the brain was 6.5 for the pentaborate solution, as compared with 3.5 for the tetraborate solution. The studies of neutron capture therapy will be greatly facilitated when the reactor to be installed in the new Medical Research Center becomes available.

Studies have also been continued on the effects of radiation on enzymes in their physiological environments. For example, plasma, red blood cells, and brains of rats were lyophilized and exposed to cobalt-60 gamma radiation. The sizes of the radiosensitive targets were estimated from the rates of inactivation of the acetylcholinesterase in each tissue. A striking difference was found between the sensitive volume of brain and that of red blood cell acetylcholinesterase, which indicates that these enzymes, which functionally appear almost identical, do have differences in their normal environments.

USE OF NUCLEAR TOOLS

The nuclear tools of research have been used extensively throughout the Laboratory during the

past year. Studies of the arrangement of atoms, ions, and magnetic spin systems in solids by means of beams of neutrons from the reactor have been continued. Investigations of the kinetics of chemical reactions, biological processes in plants and animals, human metabolism, and medical diagnosis have been pursued with radioisotopes used as tracers. A few of these numerous studies from different fields will be mentioned here.

Research has continued on the scattering of long wavelength neutrons by crystalline materials. A beam of thermal neutrons from the reactor is intercepted by a slab of beryllium at liquid nitrogen temperature. Only the coldest neutrons with very low energies are transmitted through the slab. These cold neutrons are then allowed to strike a solid crystalline material, and the energy distribution of the resulting scattered neutrons is determined with the aid of a slow chopper and time-of-flight measurements. Since the energy of the incident cold neutrons is negligible compared to that which they receive from the lattice vibrations of the crystal, their scattered energies are a direct result of the lattice vibrations. Studies of this type have been made of a single crystal of aluminum and of polycrystalline vanadium. These studies provide tests of the various models of interatomic forces and the resulting frequency distribution of the lattice vibrations. The fact that the experimental results do not agree with previously proposed models and theories indicates the need for more detailed information as a basis for improved theory. A new experimental arrangement has been designed and is being constructed that will increase by a factor of 25 the number of cold neutrons available for these experiments.

A number of neutron diffraction investigations have been completed in efforts to relate magnetic properties to the arrangement of atoms in crystals. These are described in more detail in later sections of this report. Physicists working with antiferromagnetic cobalt oxide have shown that the diffuse diffraction peaks due to magnetic spins reach a maximum intensity and minimum width at the Curie temperature, in agreement with Van Hove's theory. Neutron diffraction studies on Fe_3Al indicate that the magnetic moments of the iron atoms depend on the nature of the nearest neighboring atoms. For those atoms surrounded by other iron atoms as nearest neighbors the magnetic moment is double that of the iron atoms surrounded by 50% aluminum and 50% iron atoms as nearest neighbors. Chemists have studied manganese ferrite, lead nitrate, and three polymorphic forms of manganous sulfide. Results found with

three different preparations of the simple ferrite were consistent with the Néel model of ferrimagnetism and with the measured saturation moment. The study on manganous sulfide was directed toward an experimental verification of some of the implications of indirect exchange mechanisms for antiferromagnetic structures. Results obtained for the three polymorphic forms of this material have been satisfactorily correlated with an indirect exchange mechanism.

A technique has been developed whereby evidence can be obtained as to the origin of fragments of pottery made between the second century B.C. and the second century A.D. This information is of archaeological interest in tracing ancient commerce. By means of neutron irradiation in the reactor, an induced radioactivity is produced in such fragments which is dominated by that arising from sodium-24 and manganese-56. The ratio of these activities is constant within approximately 20% for fragments that are known to have originated in the same region and differs by as much as a factor of 4 for fragments originating from different regions.

In the growth and metabolism of cells it has been thought that deoxyribose nucleic acid (DNA) is responsible for the transmission of hereditary characters and that each hereditary character (gene) is represented by a different form of DNA. If so, the DNA is capable of self-duplication from its precursors during the process of cell division. The theory postulates further that DNA in some way forms ribose nucleic acid (RNA) which then diffuses out into the cytoplasm of the cell, where it in turn is capable of synthesizing the enzymes which regulate the growth and metabolism of the cell. In attempts to obtain verification of phases of this general picture, applications of the autoradiographic technique have been undertaken. The nucleic acids are radioactively tagged by allowing living material to grow on various isotopically labeled precursors. Various labeled substances are removed from tissue sections until only the tagged nucleic acid remains. The sections are then exposed to photographic emulsion. The autoradiographs obtained are observed under a microscope and sites of activity are correlated with various cellular structures. Information on the rate of synthesis can be obtained by counting the silver grains over a particular structure. So far attention has been focused on the extraction procedures, and it appears possible to remove labeled substances in such a way that only RNA and DNA, or only DNA itself, remain in the tissue. Isotopic phosphorus in the form of phosphate ions has been in-

corporated into the DNA of onion root nuclei. Other nucleic acid precursors such as adenine, orotic acid, and thymidine labeled with carbon-14 or tritium, are being studied. Substances labeled with tritium show particular promise because the resolution which can be obtained with this isotope is higher than that obtainable with others because of the very short range of its emitted beta-particle.

Another application of the radioautographic technique involves the use of astatine-211 produced by bombarding bismuth with the beam of the 60-in. Cyclotron. Astatine-211 has a half-life of 7.5 years and emits alpha-particles with energies of 5.9 to 7.4 Mev. From the tracks of these alpha-particles, its precise intracellular location can be determined by radioautographic techniques. Procedures by which astatine can be incorporated into gamma globulin, albumin, and fibrinogen have been successfully developed. Autoradiographic techniques should make possible the precise location within tissue of a number of biologically important macromolecules. If humans produce antibodies to their own tumors, the detection of such antibodies and studies of their tissue specificity should become a major field of cancer research. Such antibodies, indeed, might serve as vehicles for carrying short-lived isotopes to tumors where they might deliver lethal amounts of radiation.

Radioactive isotopes have been used in investigations of a number of human diseases. Studies of rheumatoid arthritis have been undertaken. Diseases of connective tissue are known to be accompanied by changes in the concentration of such substances as collagen, glycoproteins, and mucopolysaccharides in areas in which the disease is active. Tracer studies of the functions of these substances in the organization of normal and pathological connective tissues are being pursued. Tracer experiments in children and in rats with nephrotic syndrome have given results in accord with the concept that there is an impairment in the ability of the liver to remove lipides from the blood stream. The reason for the fall in blood pressure in many hypertensive patients placed on a low sodium diet is not yet known. Studies of these patients with sodium and potassium tracers indicated the desirability of concomitantly observing the role of magnesium in this connection. Radioactive magnesium-28 is now available in low specific activity for this work. More emphasis has been placed on the immediate effects of salt restriction. A population of rats has been rendered hypertensive by a high salt intake. The effect of salt on the chemical composition and physiological func-

tion of the arterioles and aortas of these rats is under way.

Parkinson's disease exhibits symptoms indicative of injury to the central nervous system. In many instances the cause of the disease is a virus infection; however, in certain instances there has been a clear association with poisoning by heavy metals, among them manganese. Studies on the metabolism of radiomanganese-56 have been initiated in both patients and animals. More insight is being sought into the normal transport mechanism for manganese and into the variations produced in manganese metabolism by disease. Present investigations are aimed at correlating the effectiveness of drugs used in the control of tremor in Parkinson's disease with their effects on the glucose metabolism of brain and the distribution of manganese.

Experiments on diabetic and nondiabetic patients using carbon-14-labeled acetates have shown no indication of a significant net formation of glucose from fat and none that the hexosemonophosphate shunt was abnormally active in diabetics. An attempt is being made to design a convenient diagnostic test for hyperactivity of the thyroid using iodine-132 which can be carried out by a physician within six hours. Nine patients with polycythemia vera (a blood disease in which there is an excess of red blood cells) have been treated with radioactive phosphorus-32, administered as phosphate, in an attempt to correlate the incidence of thrombosis with changes in the number of circulating platelets and red cells. A successful procedure has been developed for labeling *Trichinella spiralis* larvae with carbon-14 during incubation. If isotopic tracer techniques can be adapted to studies of the life history of such parasites, new avenues of research will be open of major importance in those underdeveloped areas of the world in which parasitic diseases are prevalent.

RELATED RESEARCH AND DEVELOPMENT

Research and development in areas which are not in themselves nuclear but which are vital to the development of the atomic energy program are carried out primarily by the engineering departments. Many of these studies are directly related to reactor components and the design of reactor systems; these include problems in metallurgy, in the chemical processing of reactor fuels, in the determination of appropriate container materials, and in heat transfer associated with the development of liquid metal fuel reactors. The progress made during the past year has already been described under the heading, "Major Research Projects." It has resulted in the addition of

the LMFR to the official list of reactors being developed by the Atomic Energy Commission.

An investigation has been under way for several years of a method of processing natural uranium fuel elements by fluorination in an interhalogen solution to fluoride compounds and subsequent extraction of the uranium in the form of hexafluoride by distillation. Bromine trifluoride and bromine pentafluoride have been used as the fluorinating agents. The efforts of the past year have been devoted to the construction of a continuous dissolver pilot plant capable of handling five pounds of fuel per hour. This plant should be ready for test operation next fall.

Work on the problem of ultimate waste disposal has been directed toward the development of a ball kiln unit for calcining bulk metals in the wastes, such as aluminum and zirconium, to their stable oxides; the leaching of soluble fission products from those oxides; and the development of electrodeionization cells for removal of bulk anion nitrates, fluorides, etc. from waste solutions. The purpose of these processes is the fixation of the fission products in stable solids and this work is,

Figure 10. Pilot plant for continuous removal of waste products from irradiated uranium by means of fluoridation.

therefore, in direct continuity with previous work on adsorption and fixation in montmorillonite clay. Progress has been made toward all three objectives in bench-scale experiments.

Progress has also been made in the treatment of aqueous wastes from fuel processing plants to produce a molten salt product by use of the auger-driven calciner described in the last Annual Report. A decontamination factor of about 1000 with a volume reduction factor of about 3 has been realized in test runs.

Work on the production of special radioisotopes for the use of research workers, particularly in the medical field, has continued. A simple milking system for the separation of yttrium-90 from its long-lived strontium parent has been devised. A good yield of magnesium-28 has been obtained by the bombardment of a mixture of lithium-6 and magnesium-26 with neutrons from the reactor, the magnesium-28 being produced from magnesium-26 by tritons released in the neutron bombardment of lithium-6. A number of shipments of this material have been made to various research institutions during the past year. Improvements in the production of fluorine-18 by a similar process have resulted in an eightfold increase in specific activity over that guaranteed previously. The wet distillation process for the production of iodine-133 reported last year has been successfully scaled up to the 1-curie level.

Research progress in the general field of nuclear energy requires continual provision of more highly sensitive and faster devices for the detection and measurement of radiation. Work has continued along these lines and is described in a later section under the heading of "Instrumentation." The multichannel time sorting instrument for neutron time-of-flight measurements described in last year's report has proved to be a great time saver in the accumulation of data on the fission resonance widths of fissionable nuclei and other similar experiments. The Instrumentation Department has also undertaken to build a high capacity digital electronic computer based on the design of the Maniac II at Los Alamos. Memory capacity will be several times larger than that of most present computers and the operating speed high by current standards.

Nearly all investigations of the chemical and biological effects of radiation depend for their interpretation on an accurate knowledge of the average energy lost by the radiation per pair of ions produced in air. The accuracy of the accepted value of this constant has been questionable. Measurements have been completed at both this

and several other laboratories during the past year. The results are in agreement and it is probable that the formerly accepted value of 32.5 electron volts will be replaced by one close to 34.0 electron volts. This constant is also of fundamental importance in radiation dosimetry in the field of medicine.

PERSONNEL

The number of people on the Laboratory payroll as of June 30, 1956 was 1598, exclusive of temporary appointees, a net increase of 65 for the fiscal year. The ratio of nonscientists to scientists rose from 3.7 to 3.8.

The growth of the scientific staff from July 1949 to July 1956 is shown in Figure 11. The actual number of man-months of work performed by the scientific staff is plotted for each month. The graph is, therefore, an indication of scientific services rendered and also represents the average number of scientists working at the Laboratory full time each month. Salaried visitors include scientists and engineers on leave from their own institutions, graduate students doing doctoral investigations while on leave from their graduate schools, postdoctoral research associates on one-year appointments, and temporary appointees whose services are in some measure requested by Brookhaven. Guests include scientists and engineers who participate in the Brookhaven program but receive no remuneration from the Laboratory. The services of consultants are not included in the graph. During the fiscal year 1956, over 21 man-months of service were rendered by these consultants.

For the ninth successive year, the number of scientific visitors who worked at the Laboratory for one month or more increased. Of a total of 403 man-years of scientific effort in the report period, not including the summer student program, 124 man-years were contributed by salaried visitors, guests, research associates, and consultants. Of these 124 man-years, half were provided by guests and research collaborators who received no remuneration from the Laboratory for their work here. The continuing increase in the number of visiting staff making use of the facilities and opportunities available at Brookhaven is gratifying.

During the past year there has been a large increase in the number of visiting scientists and engineers from other countries, 60 individuals having worked here for periods of weeks to a year. They have come from 21 different nations and from all 6 continents. Most of them were seeking

Figure 11.

additional experience in nuclear techniques directly related to the "Atoms for Peace" programs of their governments.

The formal summer program for students initiated in 1952 has been continued. The circulation of announcements for the summer of 1956 resulted in about 400 applications from 115 different colleges. Eighty-five appointments have been accepted by 44 undergraduates and 41 graduate students, representing 49 different educational institutions. About 100 faculty members from 50 different universities are also planning to work here during the coming summer. Including 14 Radiological Physics Fellows and 20 additional graduate students who will be brought to the Laboratory by faculty members to work as their research assistants, there will be an influx of about 225 additional workers this summer.

APPOINTMENT POLICY FOR THE SCIENTIFIC STAFF

During the past year the Laboratory has carefully reviewed the appointment policy for the scientific staff. Certain modifications in the light of experience were recommended to and adopted by the Board of Trustees. These modifications were minor in the sense that they did not change the basic concepts and objectives of the older

policy. The following statements set forth briefly the present appointment policy for the scientific staff.

THE CONCEPT OF A ROTATING STAFF

From the beginning Brookhaven National Laboratory was designed to be national in the broadest sense of the word; for this reason it is essential to make available the Laboratory's facilities and scientific and technical information to a much broader group of scientists than can be present on its staff at any one time, not only to give this broader group the opportunity to do useful work at the Laboratory but also to enable its members to carry to other institutions the specialized knowledge and skills acquired here. Since this requires a substantial rotation of scientists between this and other institutions, only a portion of the staff should be permanent. Rotation, especially of the younger scientists, is advantageous to the Laboratory, to science as a whole, and to the individuals concerned, since it provides an opportunity for the individual to develop and to broaden his interests by working at more than one institution.

In furtherance of the above objectives, the Laboratory 1) provides flexible appointments (a few months to two or three years) for visiting scientists from universities or other institutions; 2) provides appointments for graduate students working on their doctoral theses; and 3) offers nonstaff research

appointments, akin to postdoctoral fellowships and limited in tenure, to promising individuals not associated with other institutions who are initiating a career in independent research.

In order still further to enhance the rotation of young scientists with differing training and experience and to permit an adequate selection process while at the same time protecting the interests of the individual, term appointments are used in the more junior classifications of the Brookhaven staff proper, and a limit is set to the permissible tenure in those classifications. This procedure is modeled closely on those used in many leading universities. With such an understanding, failure to reappoint an individual after a few years at the Laboratory need reflect in no way upon his competence but may well result from the lack of an opening in a higher rank and from the requirement that other, younger men be given the opportunities that he has just had.

The rotating staff, therefore, consists both of visiting scientists and of scientists on the regular staff holding appointments of limited terms.

THE REGULAR SCIENTIFIC STAFF

Titles assigned to the regular Brookhaven scientific staff are as follows: Senior Scientist, Scientist, Associate Scientist, Assistant Scientist, and Junior Scientist. All initial appointments to the regular staff are limited in term to one, two, or three years. It is obvious that continuity in the various programs demands the presence of a continuing staff, particularly of the senior scientists. For this reason, and also to provide security for its most able staff, the Laboratory awards appointments with permanent tenure to selected individuals with the rank of Scientist or Senior Scientist whose scientific contributions have proved exceptionally significant to Brookhaven's program. These appointments are permanent to the extent that is possible within the terms of the AEC contract.

Continuity is also desirable in many activities requiring special skills, such as the design and operation of special equipment, the execution of certain service functions, etc. Consequently indefinite appointments, not subject to a term limitation, may be given to selected individuals who have served the Laboratory in such activities for at least two years as an Associate Scientist or one year as a Scientist. Such appointments carry no implication of permanent tenure.

All appointments other than permanent and indefinite ones are for specific terms of one, two, or three years, and a limit is set to the permissible tenure in each rank.

THE VISITING STAFF

The visiting staff is wholly rotating in character. Scientists and engineers who leave their home institutions primarily to assist in advancing the Laboratory's own program may be given appointments to the Laboratory staff up to one year in duration or even longer, with mutual agreement between the individual, his home institution, and the Laboratory. Their titles are similar to those of staff scientists, prefixed by the word "Visiting." They may receive stipends comparable to those offered by their home institutions, or consistent with the services to be rendered.

Scientists who come to Brookhaven during vacations or on sabbatical or special leaves from their home institutions to carry out primarily their own research projects (which have been approved in advance by the Laboratory and require facilities not available at their home institutions), and scientists who come primarily to gain additional experience in nuclear techniques by participating in Brookhaven's own research projects do not, in general, receive remuneration from the Laboratory. Their salaries are usually provided by their home institutions, by research grants, by fellowships, or by project money provided their home institution by some external agency. There are two types of nonsalaried appointments. 1) The Laboratory, in certain cases, may defray a portion of additional expenses such as travel, lodging, and/or subsistence. Since, in most of these cases, collaboration with members of the Laboratory staff is involved, the title Research Collaborator is used. 2) In cases in which the visiting scientist is fully supported by his home or other institution, appropriate Laboratory staff titles are used, prefixed by "Guest."

In order to provide opportunities for supplementing and broadening the experience of young scientists, the Laboratory offers special nonstaff appointments for competent scientists and engineers who have recently received their doctoral degrees. Appointments to these positions of Postdoctoral Research Associate are for a term of one year from their effective date and are renewable for one additional year. At the expiration of his appointment as a Research Associate, the individual is, in general, expected to find employment at another institution. He is, however, eligible for appointment to the regular Brookhaven Staff in competition with candidates from other institutions.

Appointments as Junior Research Associate are offered to qualified graduate students who

come to the Laboratory endorsed by their graduate schools to undertake doctoral investigations under the guidance of regular, or in some cases of visiting, staff members. Appointments are for terms not exceeding one year and may be renewed only on the basis of merit. Such appointments may include stipends comparable to those of predoctoral fellowships.

A limited number of summer appointments as Research Assistant are offered on a competitive basis to graduate students and to undergraduate students who have completed at least two years of college training. Similar appointments may be offered at any time to qualified students seeking work at Brookhaven to fulfill the requirements of their field training periods.

EDUCATIONAL AND TRAINING PROGRAMS

Since its establishment one of the main objectives of this Laboratory has been to afford opportunities for students, scientists, and engineers to gain additional experience and training in nuclear techniques. Certain programs have become well established. All of them have been based primarily on the thesis that the most effective training can be obtained through active participation in Brookhaven's research and development activities rather than through courses of the formal academic type. A brief description of four well-established programs follows.

- 1) **Program for Scientists and Engineers from Other Institutions:** Hundreds of scientists and engineers from universities, industries, and government agencies have come to Brookhaven to gain experience with nuclear techniques applicable in their fields of interest. As individuals they have joined in the research and development activities as members of Brookhaven's staff. They have worked here for varying periods and gained additional training to varying degrees, depending upon their previous experience. During this report year, about 125 such scientists and engineers from about 70 different institutions have participated in the Laboratory's activities for periods of one month to a year, primarily for training purposes.
- 2) **Program for Graduate Students Qualified for Doctoral Investigations:** This program offers qualified graduate students an opportunity to undertake doctoral investigations with facilities and techniques available here

that are not available at their home institutions. After suitable endorsement by his graduate school and the selection of a thesis project, both appropriate to the Laboratory's program and acceptable to the professor in charge of his thesis, the student comes to Brookhaven to carry out his investigation under the immediate guidance of a Brookhaven staff member or of a visiting scientist from his university. He returns to his institution to present and defend his thesis when it is completed. In all, 107 graduate students from 24 different universities have been appointed in this program. Of these, 67 have completed their theses and been awarded doctoral degrees by their home institutions and 40 are still here.

- 3) **Program for AEC Radiological Physics Fellows:** After taking an academic year of formal course work at the University of Rochester, these Fellows come to Brookhaven in groups for a nine-week period of field experience in the Division of Health Physics during which they participate in all phases of the Division's activities. Since the start of this program in the summer of 1949 and including the summer of 1956, 105 Radiological Physics Fellows and 4 scientists from other countries will have received the training that this program affords.
- 4) **Program for Undergraduate and Graduate Students:** This program, which started informally in the early years of the Laboratory, was first formally organized for the summer of 1952. The students work as research assistants at Brookhaven for a period of 2½ months during the summer. Appointments are awarded on a competitive basis to graduate students and to undergraduate students who have completed at least two years of college work. The objective is to give the students an opportunity to experience life and work in a nuclear research center in close association with mature scientists, in the expectation that they will return to their formal education with a more realistic appreciation of what a career in nuclear energy research and engineering both demands and can offer. About 100 undergraduate and graduate students, roughly evenly divided, now receive this training each summer. Including the summer of 1956, about 500 students will have participated in this program from approximately 100 different colleges and universities. Similar appointments have been used by several un-

dergraduates as the field period required by cooperative courses at their universities.

In addition to the above training-by-participation programs, the Laboratory has from time to time responded to requests for organized courses in specialized fields involving subject material and laboratory techniques not then available at universities. Typical of these programs have been the following: Defense Against Atomic Attack, a five-week course given for 15 civilian defense officials from the northeastern states; Radiation Hazards and Protection, a five-day course given for 92 safety engineers and other representatives of 42 casualty insurance companies; Reactor Science and Technology, a concentrated six-week course given to four naval officers and four civilian engineers; Reactor Science and Technology, a course meeting one day a week over a 14-month period for a group of engineers from public utilities in southern New England and the vicinity of New York City; four annual seminars in Nuclear Science for different groups of Naval Reserve Research Officers; and an Institute in Nuclear Science and Engineering planned for the summer of 1956, described below.

Summer Institute in Nuclear Science and Engineering: During the spring, the Laboratory has been preparing to give a Summer Institute in Nuclear Science and Engineering for 30 professors from 22 different engineering schools in 14 states and Puerto Rico. This institute is being sponsored by the American Society for Engineering Education, the National Science Foundation, the Atomic Energy Commission, and Associated Universities, Inc., and will extend over an eight-week period beginning on July 2. It will present the basic theory and technology essential to reactor development in the form of a course suitable for incorporation into the curricula of engineering schools for students preparing for careers in the general field of nuclear engineering. Laboratory experiments of the type that give a basic insight into the problems of reactor design and technology and can be introduced into engineering schools at a reasonable cost have also been included. For this purpose a series of about 70 lectures has been outlined covering the whole field of reactor science and technology; a subcritical graphite assembly and neutron spectrometer have been constructed; and research equipments developed in studies of heat transfer, corrosion, and other metallurgical and liquid metal problems have been modified for lab-

oratory experiments. Experiments have also been designed using the sigma pile, the research reactor, and the criticality experiment setup. The curriculum content will be integrated by a reactor symposium to be held at the end of the course which will consist of detailed lectures on the several current AEC demonstration power reactor projects, given by experts directly connected with each project, and followed by discussion periods.

Additional training activities of a less extensive character have been a regular part of the program of the Health Physics Division for the past few years. Last year more than 130 individuals came to the Laboratory for periods of days or weeks to obtain specific information on the calibration and use of radiation measuring instruments, proper procedures for protection against and control of radiation hazards, and radioactive waste disposal. Most of them are engaged in work on AEC contracts or subcontracts that involve the handling and disposal of radioactive materials. Because of their relatively brief stay at the Laboratory, these persons have been statistically considered as visitors rather than as participants in any of the training programs mentioned above; however, their number and the attention they require are not inconsiderable.

CONFERENCES AND PUBLIC INFORMATION

Four organized conferences were held at the Laboratory during the past year: 1) Information Meeting on the Liquid Metal Fuel Reactor, November 21 and 22, attended by 170 individuals representing 125 industrial companies; 2) Medical Conference on a Critique of Present Knowledge and Investigation of the Effects of Radiation Upon the Central Nervous System, March 15 and 16, attended by 23 physicians representing 14 different medical centers; 3) Biology Symposium on Genetics in Plant Breeding, Ninth Annual Brookhaven Biology Symposium, May 21 to 23, attended by 190 representatives from 64 different institutions; and 4) Nuclear Energy and the Life Sciences, Fourth Annual Naval Reserve Nuclear Sciences Seminar, held at the request of the Third Naval District, June 3 to 17, attended by 75 officers of the Naval Research Reserve.

At the request of the State Department, the Laboratory arranged one-day guided tours for Junior Foreign Service Officers, to enable them to become acquainted with the facilities and

program of a nuclear energy research center prior to their first foreign assignments. Seven of these tours were given during the year to 130 Junior Officers.

The Laboratory was host to 44 different professional groups including 1861 individuals during the year. On the annual Student Visitor's Day, October 14, special tours, demonstrations, and exhibits were provided for 3900 students. This was followed on October 15 by the Annual Visitor's Day, attended by about 2700 persons.

The activities of the Public Information Office have continued at about the same level; however, requests for visual aid material in the form of exhibits, pictures, and films have increased considerably. Staff members have also responded to numerous requests for talks to lay and semiprofessional groups.

BUSINESS AND ADMINISTRATION

The organization of the Laboratory as of August 1956 is given in Figure 1. A number of changes in the administrative staff have taken place during the past year.

Dr. R.A. Patterson, one of the early members of the Director's staff, reached retirement age on December 31, 1955. At that time he relinquished his responsibilities for university liaison and scientific personnel. Dr. R. Christian Anderson was transferred from the Chemistry Department to the Director's Staff to assume these duties. Dr. Patterson has been retained on the staff as Assistant Director on special assignments.

Mr. L.R. Swart, Director of Personnel, resigned in March to accept a position in industry. Mr. Julius Hannoeh, who replaced Mr. Swart, also resigned for other employment in May. Mr. E.A. Macy has been appointed as Head of the Personnel Division.

Mr. S.M. Tucker, who has been Director of the Naval Research Laboratory for the past two years, has been appointed Assistant to the Director.

Mr. William H. Fields Jr. is now Associate Director for Administration. In this capacity he will have administrative responsibility for the Division of Personnel as well as for the Divisions of Security, Plant Management, Supply and Material, and Purchasing.

The Laboratory's active inventory showed a further slight drop during the year, reaching a new low point of \$261,000 on June 30. Investment in active inventory at the end of the year represented approximately 3.8 months' average use as com-

pared to 6.5 months' two years ago. It is believed that the Laboratory has about reached the leveling-off point with respect to its inventory investment.

Two important phases in the Laboratory's program of more effective management described in the last Annual Report have been completed. A property catalogue has been compiled and issued during the year, and capital equipment items are now under punch card control.

While the number of purchase orders written showed a small decline, the total dollar volume increased over that of the preceding year. This increase was approximately \$800,000, due largely to procurements for the Alternating Gradient Synchrotron and Liquid Metal Fuel Reactor projects.

FINANCE

As in the past, the Laboratory was financed by three Atomic Energy Commission Divisions: the Reactor Development Division, the Research Division, and the Biology and Medicine Division. The three divisions each separately finance the research activities pertinent to their areas of responsibility. Since research requires supporting scientific tools such as the reactor, as well as electronic instrumentation, machine shop, and other technical services, together with administration and maintenance operations, it is necessary for the Laboratory to budget and operate on a functional basis. The operating costs of the Laboratory for the past three years are shown in Figure 12, both by the major programs supporting the work and by major categories of expenditures. Labor costs, as will be noted, continue to absorb the major proportion of all operating expenditures, 73.5%. Nonprogram costs include work done by Laboratory organizational units for the construction of plant and equipment, work undertaken for other government agencies, and special work for the Commission not included under the normal Laboratory budget.

Table 1, which will be found on the reverse side of the organizational chart, shows detailed operating expenditures on a broad organizational basis, exclusive of direct costs of the Alternating Gradient Synchrotron and other fixed assets. The total operating cost for FY 1956 was \$11,864,083, an increase of 10.8% over the previous fiscal year. Included in this sum was \$233,253 (an increase of about 18% over FY 1955) for work done for others, and \$186,898 (a decrease of about 7.5%

COST DISTRIBUTION BY PROGRAMS

FISCAL YEAR	PHYSICAL SCIENCES	REACTOR DEVELOPMENT	LIFE SCIENCES	OTHER	TOTAL COST
1956	52.3 %	21.8 %	22.4 %	3.5 %	11,864,083
1955	54.4 %	18.0 %	23.9 %	3.7 %	10,703,649
1954	56.5 %	17.4 %	23.5 %	2.6 %	9,956,630

MAJOR CATEGORIES OF EXPENDITURES

FISCAL YEAR	SALARIES AND WAGES	MATERIALS, TRAVEL, SUB-CONTRACTS	SPECIAL POWER	MISCELLANEOUS	TOTAL COST
1956	73.5 %	18.5 %	4.5 %	3.5 %	11,864,083
1955	74.2 %	18.3 %	4.7 %	2.8 %	10,703,649
1954	75.5 %	17.0 %	4.5 %	3.0 %	9,956,630

Figure 12.

Table 2
Capital Equipment Expenditures and Commitments

	FY 1956		FY 1955		FY 1954	
	\$	%	\$	%	\$	%
Scientific & Hospital	582,430	80.5	401,494	75.4	318,011	70.8
Automotive & Heavy Mobile	40,894	5.6	36,056	6.8	55,925	12.4
Office Machines & Furniture	35,348	4.9	23,588	4.4	25,734	5.7
Shop Equipment	49,843	6.9	39,116	7.4	26,517	5.9
Miscellaneous	15,298	2.1	32,183	6.0	23,184	5.2
Expenditures & Commitments, Total	723,813	100.0	532,437	100.0	449,371	100.0
Proceeds from Sales	(18,773)		(21,770)		(56,369)	
Expenditures & Commitments, Net	705,040		510,667		393,002	

Table 3
Costs Incurred for Fixed Assets
(Including Charges from Organizational Units, See Table 1)

	1956			1955			1954		
		Man-Years			Man-Years			Man-Years	
	Costs	Sci.	Others	Costs	Sci.	Others	Costs	Sci.	Others
Alternating Gradient Synchrotron									
Direct									
Salaries, Wages, Insurance	492,460	23.5	47.5	417,880	24.5	45.0	146,291	10.5	13.0
Materials, Construction, etc.	1,871,898			610,958			181,589		
Subtotal Direct	2,364,358			1,028,838			327,880		
Charges from Organizational Units	117,697			138,764			106,895		
Total	2,482,055			1,167,602			434,775		
Other, Including Medical Research Center Reactor									
Direct									
Salaries, Wages, Insurance	10,565	1.0	0.5						
Materials, Construction, etc.	937,560			657,694			660,520		
Subtotal Direct	948,125			657,694			660,520		
Charges from Organizational Units	69,201			63,318			99,313		
Total	1,017,326			721,012			759,833		

from FY 1955) for work done by organizational units for plant and equipment. Table 2 gives the capital equipment expenditures and commitments for the past three fiscal years.

A summary of expenditures for fixed assets (plant and equipment) for the past three fiscal years is given in Table 3. The costs of the Alternating Gradient Synchrotron are separated from

those of other items. Included in this table are both the costs of services provided by the Laboratory organizational units (see Table 1) and all the capital equipment expenditures listed in Table 2, as well as the direct costs for construction.

Direct costs of research units increased over the previous fiscal period by \$686,000 (13.6%) while total operating costs increased \$1,160,000 (10.8%). Direct research cost this past year represented 48.2% of total operating expenditures, which compares with 46.9% for the preceding year. On the other hand, a decline in the proportionate costs is noted for organizational units providing support-

ing scientific and technical services. In FY 1956 these services accounted for 18.0% of total costs as compared to 19.3% in FY 1955. This reflects, we believe, a continuing and increasing efficiency on the part of these services.

During the past year significant upward tendencies have been encountered in most of the costs of operating a laboratory - salary and wage rates, equipments, materials, and services. Salaries and wages increased an average of about 6%. The other increases range widely from 5% to 60%. Very few items declined in cost. There is no indication as yet of any leveling out of this rising trend.

BROOKHAVEN NATIONAL LABORATORY

Balance Sheet

	June 30, 1956	June 30, 1955
ASSETS		
Cash	\$ 320,585	\$ 880,868
Accounts Receivable	95,444	82,217
Inventories	336,646	382,790
Advances, Deposits and Prepaid Items	223,209	181,952
Fixed Assets (less reserves of \$21,559,812 at June 30, 1956 and \$19,960,883 at June 30, 1955)	36,248,769	37,930,664
Construction in Progress	4,554,371	1,649,714
Total Assets	\$41,779,024	\$41,108,205
LIABILITIES		
Accounts Payable	910,341	\$ 554,696
Accrued Payroll	78,265	134,924
Atomic Energy Commission	40,790,418	40,418,585
Total Liabilities	\$41,779,024	\$41,108,205

Physical Sciences and Engineering

PHYSICS

The research program in physics continues to be concerned with studies of the structure and fundamental properties of matter. These studies are carried out principally by making observations on the details of interactions between charged particles, neutral particles, or radiation with atomic nuclei or with individual nucleons. The researches reported here extend over a wide range of energy, from the high energy interactions which can be studied with the aid of the protons accelerated to 3 Bev in the Cosmotron down to the very low energies corresponding to the thermal motion of atoms in solid matter. As in previous reports the progress of the research in physics can best be described under the categories of high energy physics, nuclear structure, neutron physics, atomic and molecular structure, and solid state physics.

Most of the research in these various fields is centered around one or more of the major facilities at Brookhaven such as the Cosmotron, the 60-in. cyclotron, the research Van de Graaff accelerator, the 18-in. cyclotron, and the reactor. The researches are conducted by Brookhaven scientists in the Physics, Cosmotron, and Reactor Departments and by guests and visitors from other institutions, in many cases by a collaborative effort between members of these two groups. Most of the equipment used in these researches is provided by Brookhaven, although in some cases a visitor may bring with him special apparatus for his own use.

HIGH ENERGY PHYSICS

The structure of protons and neutrons and the forces associated with them continue to be of great interest to physicists, and the Cosmotron is one of two accelerators having sufficient energy to produce most of the array of unstable particles which reveal the complexities of this new field of physics. These circumstances have resulted during the past year in an active program of high energy research centered about the Cosmotron.

Special attention has been given to the investigation of the phenomena of associated production, observed here three years ago, since the energies available are well suited to this study. Research also continues on the nature of the newly discov-

ered unstable particles. The effectiveness of the Cosmotron for research has been significantly increased by the availability of the high intensity, well-focused, external proton beam, which is now being used a major portion of the running time. In all this work visiting scientists continue to play a major role, frequently working in close association with Brookhaven scientists.

Results of Particular Interest

One of the first of the K -mesons discovered in cosmic rays, now called the θ_1^0 -meson, decays, with a mean life of about 10^{-10} seconds, into two π -mesons. It was predicted by Gell-Mann and Pais that another form of θ^0 should exist which would differ from the original θ_1^0 by having a considerably longer mean life and by decaying into three particles. The prediction of this other form of the θ^0 (called θ_2^0) followed from the rigid application of charge conjugation, a concept closely related to the existence of antiparticles. The proof of the existence of the θ_2^0 -particle was especially important as it would constitute support for a theory of fundamental importance. Consequently, a search for the θ_2^0 was made by a group from Columbia working with a Brookhaven physicist, who set up a large Columbia cloud chamber for this purpose. Some 8000 cloud-chamber photographs were obtained with an arrangement in which a copper target distant 6 meters from the cloud chamber was bombarded by 3-Bev protons from the Cosmotron's external beam. A search of these photographs revealed 23 events which apparently met the requirements for the predicted particle. These particles were found to decay into three particles and, since they traveled 6 meters before decaying, their mean life had to be much greater than 10^{-10} sec. It thus appears that a neutral particle does indeed exist with characteristics which seem to agree well with the predicted ones.

An unanswered question of considerable interest concerns the τ and the θ heavy mesons. The modes of decay of these two particles ($\tau \rightarrow 3\pi$ and $\theta \rightarrow 2\pi$) are such that it is nearly impossible theoretically to see how they can be two modes of decay of the same particle. On the other hand, except for their decay modes, no difference between them has been found. Their masses have been found, from emul-

sion studies at Berkeley, to be identical to within a very small error. Two experiments were performed here in a search for other possible differences but none were found. One of these experiments was a determination by a group from Princeton of the mean lives of the τ - and θ -particles. It was found that, within an uncertainty of $\pm 8\%$, their mean lives were identical. The second experiment, performed by a group from MIT, was arranged to scatter both the τ -mesons and the θ -mesons through a large angle and then to compare the ratio of the number of τ 's to the number of θ 's under these circumstances with the same ratio when these particles are not scattered. Any difference in the nature of τ 's and θ 's might well result in differences in scattering cross section and a consequent change in the relative number of τ 's and θ 's observed. The experiment showed a constant ratio of τ 's to θ 's for both scattered and unscattered particles. Thus the results of these two experiments support the conclusion that the τ and θ are alternate modes of decay of the same particle.

Another group of experiments has produced rather convincing evidence that protons are much less effective than π -mesons of equivalent energy in producing heavy mesons and hyperons via the associated production process. Counter experiments which detected the unstable particles by means of the γ -rays into which they decay and cloud-chamber experiments performed by groups from MIT, Princeton, and Brookhaven are all consistent on this point. In addition, it seems when one looks for hyperons or heavy mesons produced by either p - n or p - p collisions that of the two processes p - p collisions are much less effective. In fact, there is no evidence that p - p collisions in the 3-Bev range can produce any heavy mesons or hyperons. These results suggest that associated production occurs by means of π -mesons. Whether or not this interpretation is correct, the experimental result is surely important to the understanding of the remarkable phenomena of associated production.

The investigation of elastic p - p scattering has continued. Counters were used to extend previous measurements of the proton-proton angular distribution made at 2 Bev and 3 Bev. The distributions appear to be peaked strongly forward and the cross section at 90° is quite small at both energies; these observations indicate that the scattering is primarily due to a diffraction effect arising from the absorption of the incoming wave via meson production.

In collaboration with a group from Harvard University the total cross section for p - p scattering in the range 0.4 to 2.6 Bev was investigated with

Figure 1. Curve A represents the measured total cross section for p - p collisions as a function of proton energy. Curve B represents the measured elastic cross section as a function of proton energy. Curve C is the difference between Curves A and B and represents the inelastic cross section (or cross section for π -meson production) as a function of proton energy.

Figure 2. The points represent experimental determination of relative number of π -mesons produced with different kinetic energies in the center-of-mass system. The solid curve is the experimentally determined cross section for π + p scattering from the $T=3/2$ resonant state. The similarity in shape suggests that mesons are produced via this excited state of the proton.

counters. The results are shown in Figure 1. By subtracting from these total cross sections the elastic scattering cross sections mentioned in the preceding paragraph, a curve is obtained which shows the variation of inelastic cross section (mainly meson production) as a function of energy. These curves are also shown in Figure 1. These data have been interpreted in terms of interactions arising from various isotopic spin states.

In collaboration with members of several universities, the Brookhaven cloud chamber was used to study π -meson production by p - p collisions in the energy range 0.8 to 2.7 Bev. The results are not inconsistent with the assumption that production occurs by exciting one or both nucleons to an intermediate state from which one or both decay by emitting a π -meson.

The production of π -mesons by p - p interactions was also observed by taking the difference between carbon and polyethylene targets inserted in the internal proton beam of the Cosmotron. A counter telescope which included a magnet was used to select the momenta of the π -meson. The results transformed to the center-of-mass system in the form of the relative pion production cross section as a function of pion kinetic energy are shown by points in Figure 2. The solid curve in this figure is the π^+ - p total cross section curve and it is quite obvious that all the present data on π^+ production obtained at the various energies over the range 0.5 to 2.0 Bev are closely related to this curve. A reasonable explanation of this result is in terms of the same excited nucleon model mentioned above whereby one or both nucleons are excited to a resonant isobaric state with $T=J=3/2$ (i.e., the state observed in the π - p scattering), and from which pion emission proceeds by decay of the isobars.

As a test this model was used as a basis for calculating the energy spectra by π -mesons, the ratio of π^+ -meson to π^- -meson production, and the angular correlations for π -meson nucleon pairs using incident proton energies from 0.8 to 3.0 Bev. These calculations show quite good agreement with the existing experimental data, which unfortunately are rather incomplete. The result supports the concept of π -meson production via an excited nuclear state.

Additional studies were made with high energy π^+ - and π^- -mesons. For this the external proton beam was directed against a suitable target such that π -mesons in the forward direction could be observed. Measurements of the pion cross section on hydrogen, both with π^+ and π^- , were completed up to 1.8 Bev. These measurements showed a second maximum in the positive pion

cross section of small amplitude at about 1.35 Bev; on the other hand, no such maximum appears to exist in the negative pion total cross section.

During the latter part of the year, a series of measurements of the interaction between positive and negative pions and various selected nuclei were completed. Measurements were made on lead for both positive and negative pions for the purpose of investigating whether the radial distributions of neutrons and protons were different, as some current nuclear models have suggested. The results of the measurements and the analysis show that no such difference exists of the magnitude predicted by the theory, and they do in fact agree with the assumption that the radial extents of the distributions are the same.

A group from Columbia has used a propane bubble chamber to study interactions of 1.3-Bev π^- -mesons with protons which result in the production of hyperons or heavy mesons. Among the results obtained are:

- 1) Life of the Σ^- -meson, $\tau_\Sigma = (1.4^{+1.6}_{-0.5}) \times 10^{-10}$ sec.
- 2) Three associated production events were observed, which indicate production of a Σ^0 -hyperon. The existence of this particle is now rather well established.
- 3) Hyperon or heavy meson production was observed in 37 cases. Analysis indicated that associated production took place, but in only four cases did both particles decay visibly in the chamber. Apparently both the Λ^0 -hyperon and the θ^0 -meson escaped by some unknown method about two thirds of the time.

Photographic emulsions have been used to determine the energy thresholds for the production of K^- - and K^+ -mesons by protons of various energies on nuclei such as beryllium. The threshold for K^- -particles was found to be near 1.8 Bev. This value is consistent with the concept of associated production on the basis that a K^- -meson must be produced together with a K^+ -meson. The energy threshold for this process for bound nucleons is also 1.80 Bev. The yield of K^- -mesons rises sharply, proton energy being about ten times larger for 3.0-Bev protons than for 2.2-Bev protons. The threshold for production of K^+ -mesons was found to be lower than for that of K^- -mesons and consistent with the value 1.2 Bev predicted by production associated with a hyperon.

The interaction of K^- -mesons in flight yielded a mean free path of 22 ± 4 cm in emulsions, which suggests that these particles interact with emulsion nuclei with a cross section close to the geometrical one. It has been found at Berkeley that the K^+ -

mesons interact with about one-third geometrical cross section.

The cross section for associated production by protons on various nuclei between hydrogen and lead was investigated by observing heavy mesons or hyperons which decay into γ -rays. It was found that the cross section per nucleon reached a maximum value for nuclei around beryllium or carbon. The variation with atomic mass number is consistent with production by direct nucleon-nucleon interaction plus production by means of an intermediate π -meson produced by the incident protons in the same nucleus.

Investigations on the production of heavy mesons and hyperons by protons and π^- -mesons are also being carried on by groups from MIT, Princeton, and Michigan. These experiments have not as yet progressed far enough to yield specific results. In all, some 25 experiments are under way.

Operational Features of Interest

Use of the external proton beam is now an established part of the experimental procedure. When properly diaphragmed down, this beam becomes the "pencil beam" (Figure 3), and these two versions have now been used successfully in counter, emulsion, cloud-chamber, and bubble-chamber experiments. These beams make possible many new kinds of experiments, as well as improvements in many others, because they make high energy protons accessible. The use of these external beams usually involves a large amount of supplemental apparatus and heavy shielding, and has caused a serious shortage of floor space in their vicinity. Also, these elaborate experiments require a great deal of time to set up and take down. To prevent loss of Cosmotron running time, an additional experimental area adjacent to the present one is being planned, which will allow operation of the Cosmotron for one experiment while another is being set up.

One of the major achievements of the year was the development of an external proton beam which has proved very useful for experiments. After emerging from the Cosmotron, the beam is passed through a large magnet which acts like a lens and focuses the protons at distances of 20 ft or more. Thirty to forty percent of the 10^{11} internal circulating protons can be brought out in the external beam. At a distance of 50 ft from the Cosmotron they can be focused into a spot 1.5 in. in diameter. Moreover, this beam can be used with great flexibility. All energies from 1 to 3 Bev can be made available, the focus can be moved over a wide area, and the beam itself, by magnetic de-

Figure 3. Hydrogen diffusion photograph showing pencil beam of 3-Bev protons. The pencil beam, which contains approximately 500 protons, enters the chamber from the top and passes first through a thin target of steel. In this exposure a V -particle is apparently produced in this target.

flection, can be directed into many experimental positions.

The invention of the bubble chamber was a very significant development for high energy accelerators. Because of their high density, short sensitive time, and lack of distortion, these devices are being used by a great many experimenters around the Cosmotron. Two versions now in use include one filled with liquid propane and one filled with liquid hydrogen. The propane bubble chambers have proved to be very reliable and to a considerable extent have replaced both emulsions and conventional cloud chambers. The hydrogen bubble chambers are technically quite difficult to operate, but for studying interactions between elementary particles and protons they have no equal. A small $3 \times 3 \times 8$ -in. hydrogen bubble chamber is now being used to study associated production by π^- -mesons.

A larger liquid hydrogen bubble chamber is being constructed. Its dimensions will be $20 \times 9 \times 10$ in. and it will be provided with a magnetic field

of 15,000 to 20,000 gauss. The many problems connected with sealing of cold joints, expansion mechanisms, and safe operation have required much attention. Many tests on instrumentation have been carried out. Every effort is being made to obtain a device which not only will reveal many interactions in the liquid hydrogen but also will permit accurate interpretation. The large magnetic field, the great depth of the chamber (10 in.), fast expansions and recompressions through a wide throat, and careful temperature control should all contribute toward these objectives.

Hydrogen, since it is the only substance possessing protons unmixed with neutrons, is of particular value as a target for the study of the interaction of high energy particles with protons. Since liquid hydrogen is the most convenient form of this element for most experiments, there is a great demand for it for use in targets and bubble chambers, which has in the past far exceeded the supply. Fortunately a hydrogen liquifier will soon be in operation which is capable of delivering up to 50 l/hr or enough to satisfy any foreseeable demand.

A measure of the level of activity in the high energy program is the number of scientists connected in one way or another with activity going on around the Cosmotron. An estimate of the number of physicists, exclusive of engineers and operating crew, includes 33 Brookhaven physicists, 62 visiting physicists, 6 graduate students, and 7 outside collaborators, of whom 4 are from foreign countries.

The summer is a particularly active period as many physicists from universities and colleges take advantage of the summer recess to gather here to exchange views or to join some experimental group. This year, in high energy physics, at least part of the summer was spent here by some 48 visitors, both theorists and experimentalists, including 7 from foreign countries.

NUCLEAR STRUCTURE

The researches in this field are conducted to obtain information on the energy level structure of nuclei. When a charged particle, such as a proton for example, or a neutron, or gamma radiation interacts with a nucleus, a new nuclear energy state is produced which in general is unstable. This unstable state may decay into a stable state in a very short time by the emission of a particle or gamma radiation or it may take a measurable time for the stable state to be formed. In the latter case, the intermediate unstable state is designated radioactive and a time characteristic of the decay to a stable state is referred to as the

mean life of the unstable configuration. Studies of the modes of the decay of the radioactive nucleus, as to the number and energy of the particles and gamma-rays emitted and the mean life of the decay, lead to information on the energy level structure of the nucleus. When the intermediate nucleus resulting from an interaction reverts to a stable configuration in a time too short to be measured with existing techniques, it is necessary to study the interaction products simultaneously with the interaction process. Many different techniques are used in the study of nuclear energy level spectra. As these are improved and new techniques are developed, more details are being observed which lead to a better understanding of the very complex nature of nuclear structure. Some of the principal results of these researches during the past year are described below.

A new type of isomerism, called *K*-isomerism, has been found in Hf^{180m} . Here an *E1* transition from a state of spin $I=9$ ($K=9$) to a rotational state $I=8^+$ ($K=0$) is slowed down by a factor of $\sim 10^{16}$, i.e., though this is an allowed transition as far as total spin change is concerned, the transition is *K*-forbidden. The quantum number *K* introduced by Bohr and Mottelson, which measures the projection of *I* along the symmetry axis of the nucleus, changes here by 9 units.

The complex decay of Eu^{152} has been analyzed with the aid of the coincidence sorter described in last year's report. This sorter provides information on time-correlated events in the decay of a radioactive nucleus and has been a valuable tool in the

Figure 4. Coincidence sorter photograph of gamma-gamma coincidences from the decay of Eu^{152} . The strongest transitions are indicated on the figure.

Figure 5. Decay scheme of Eu^{152} obtained from coincidence sorter pictures. Energy of transitions in kev.

studies of complex nuclear spectra. Figure 4 shows a coincidence sorter picture of gamma-gamma coincidences resulting from the decay of Eu^{152} . Distances along the X and Y axes correspond to energy losses in the two NaI(Tl) crystals of the coincidence spectrometer. The main coincidences are indicated by white arrows on the figure. Figure 5 is the decay scheme deduced from another picture of longer exposure which brings out weaker transitions.

The study of the gamma-ray spectra associated with radioactive decay and with nuclear reactions has shown the need for high precision and good resolution in the determination of the gamma energies. An intermediate-image pair spectrometer having high energy resolution and high transmission has been completed. For a point source of conversion electrons, the momentum resolution of the spectrometer can be varied by adjustable baffles from 0.5 to 4% with corresponding transmissions of 1 and 8% of 4π , respectively. A gamma-electron coincidence facility has been adapted to the spectrometer and an electron-electron coincidence detector is under construction. Sources of Ga^{70} , Eu^{152} , Hf^{180} , Hf^{181} , W^{187} , Au^{194} , and Au^{196} have been investigated.

In performance tests of the spectrometer, by using protons accelerated in the research Van de Graaff to produce the reaction $\text{F}^{19}(p, \alpha)\text{O}^{16}$, the 6.06-Mev nuclear pair transition in O^{16} was observed. The pair line half-width can be varied from 0.56 to 2.5% with corresponding absolute transmissions of 0.07 to 6.3 counts per 10^5 source transitions, respectively. Weak resolved pair lines due to the 6.91- and 7.11-Mev levels of O^{16} have been observed. The spectrometer has proved to be particularly useful for studies of weak transitions.

As an example, the de-excitation of the 2^+ second excited state of Pt^{196} , which goes to the 2^+ first excited state by a 332-kev $E2$ transition, has been shown to branch less than 0.05% to the 0^+ ground state. The branching, if any, is therefore more than 1000 times weaker than in the neighboring even- A isotopes of Pt which have a similar level order.

In order to fill in the details of the character of the unstable states of nuclei resulting from nuclear interactions, it is important to be able to observe mean lifetimes of very short duration. With new electronic techniques it is now possible to measure mean lives as short as 3×10^{-11} sec. This has been accomplished with a modification of the usual limiter-diode type of fast coincidence system. In this new coincidence analyzer, the overlap time of shaped, limited signals generated by the detection of time-correlated events is converted into a voltage pulse proportional to the overlap time. In a coincidence experiment, the complete coincidence-output pulse-amplitude spectrum is measured and compared to that of a standard "prompt" source under identical operating conditions. The spectrum is recorded under conditions such that, with progressively-biased integral-discriminators, the response of the coincidence system is measured simultaneously at different resolving times for a fixed delay inserted between the two detectors.

Figure 6. Measurement of the lifetime of positrons annihilating in Pb .

A measurement of the mean lifetime of positrons in lead with this analyzer is illustrated in Figure 6, in which are plotted the relative response curves of the discriminators in the "prompt" (γ -rays from Co^{60}) situation and in the "delayed" (positrons from Na^{22}) coincidence situation. The mean life of positrons in lead is found to be $(1.68 \pm 0.25) \times 10^{-10}$ sec.

Other mean lifetimes measured by this technique include the following cases.

NUCLEUS	ENERGY, KEV	MEAN LIFE, SEC
Hg^{198}	411	$(3.5 \pm 1.5) \times 10^{-11}$
Pb^{207}	570	$(1.2 \pm 0.3) \times 10^{-10}$
V^{51*}	320	$(2.8 \pm 0.4) \times 10^{-10}$

In a program jointly sponsored by Columbia University and Brookhaven, certain short-life beta activities are being studied to gather data for the determination of beta-decay coupling constants. Studies have been made of the beta decay of He^6 , O^{15} , A^{35} , A^{41} , Ca^{39} , and A^{34} . The magnitude of the five possible coupling constants may be derived from four sources: the shape of beta spectra, the ft values ("comparative lifetimes") of super-allowed transitions, K -capture to positron ratios, and recoil experiments which measure the electron-neutrino angular correlation functions. The beta spectra were measured with the Columbia 180° iron-core spectrometer and the BNL thin-lens spectrometer, gamma spectra and half-lives with conventional stilbene or NaI(Tl) scintillation spectrometers equipped for continuous recording of data. Since several of the beta emitters studied were gases with half-lives of the order of one second, a pumping system was constructed which purified the radioactive gas and transported it continuously from the target chamber to the spectrometer during the measurement. The radioactive gases studied were produced by charged-particle and neutron reactions at the BNL 60-in. cyclotron, and by neutron reactions at the BNL reactor.

A precise measurement of the He^6 beta spectrum was made to determine a limit for the possible mixing between the G-T invariants (tensor or axial vector) in the beta-decay interaction. In a previous investigation of the electron-neutrino angular correlation of He^6 , the tensor invariant was shown to be dominant for this transition. The limit obtained from the shape of the spectrum is $G_A/G_T = +0.05$. The decay was observed to be

simple with an end-point energy of 3.50 ± 0.02 Mev.

The beta spectrum of O^{15} , which has a "doubly closed shell minus one" configuration, was re-measured because the maximum beta energy determined by spectrometer and that by Q value measurements were in disagreement. An end-point energy of 1737 ± 20 kev was found; the ft value calculated from this measurement is 4230 sec, which is 20% higher than the previously reported value.

The decay scheme of 1.83-sec A^{35} was investigated. This isotope predominantly undergoes a mirror transition to the ground state of Cl^{35} , and has been considered suitable for an electron-neutrino angular correlation experiment for the purpose of identifying the Fermi invariant in the beta-decay interaction. A maximum beta energy of 4.96 ± 0.04 Mev was measured which is 0.5 Mev higher than the previous values and is in good agreement with coulomb energy predictions. Two weak gamma-rays were found with energies of 1.19 ± 0.04 and 1.73 ± 0.04 Mev, which agree with reported levels in Cl^{35} . Seven % of the A^{35} decays to excited states in Cl^{35} . The new ft value of the ground state transition is 6200 ± 400 sec, which is nearly twice the previous value. The square of the G-T Matrix element calculated from this ft value is less than 0.13, which indicates that A^{35} would be very suitable for the suggested angular correlation experiment.

The decay scheme of A^{41} was investigated. Two beta groups were observed with end points of 2.48 ± 0.04 Mev and 1.199 ± 0.008 Mev with relative intensities of 0.88 and 99.1%, respectively. The beta spectrum of the lower group has an allowed shape. The spectrum of the upper energy group exhibits an α -shape in agreement with shell model predictions for the spins of the involved levels.

Preparations for the study of Ca^{39} and Sc^{41} are under way. These two nuclei are the last pair of the important "closed shell ± 1 nucleon" mirror nuclei available, and precise data for determining their decay scheme and ft values are lacking. The possibility of using the reaction, $\text{K}^{39}(p,n)\text{Ca}^{39}$, which has not been previously reported, was investigated. The yield of the reaction was found to be sufficient for a beta-spectrum measurement of Ca^{39} . A half-life of 0.9 sec was measured which is 10% lower than the mean of the previously reported values.

A new $0 \rightarrow 0$ beta-active nucleus, A^{34} , has been found. The isotope was made by the reaction, $\text{S}^{32}(\alpha, 2n)\text{A}^{34}$. Because of the presence of large

*Measured in cooperation with Massachusetts Institute of Technology.

amounts of A^{35} resulting from the competing (α, n) reaction, detection was possible only by measuring the activity of its radioactive daughter, Cl^{34} . Negatively charged recoil ions, which were collected electrostatically, exhibited the characteristic 1.5-sec half-life of Cl^{34} .

Associated with the study of beta spectra is the study of the neutrino and antineutrino. The equilibrium beta spectrum from thermal fission of U^{235} was determined in order to infer the antineutrino flux distribution from a thermal reactor. A suitable plastic scintillation counter was used as a beta-ray spectrometer. It was found that the fission beta spectrum could be derived from a Gaussian which describes the beta end-point distribution:

$$e^{-E_{\text{Max}}^2/2(\Delta E_{\text{Max}})^2},$$

where $\Delta E_{\text{Max}} = 3.85$ Mev.

The antineutrino spectrum was applied to the reactions $\bar{\nu}(p, n)\beta^-$ and $\bar{\nu}(d, 2n)\beta^-$ in order to determine the average pile cross sections, $\bar{\sigma}_p$ and $\bar{\sigma}_d$, respectively. The results were:

$$\bar{\sigma}_p = 6 \times 10^{-44} \text{ cm}^2 \quad \text{and} \quad \bar{\sigma}_d = 2 \times 10^{-45} \text{ cm}^2.$$

The first value is in good agreement with the observations of the inverse beta reaction by Cowan, Reines, Harrison, Kruse, and McGuire at Savannah River. The second reaction is being searched for by the same group. The spectrum was also applied to $Cl^{37}(\bar{\nu}, \beta^-)A^{37}$ by Davis assuming $\bar{\nu} \equiv \nu$.

Another method used to obtain information about the energy level structure of nuclei is to study the spectrum of the gamma-rays emitted by the nucleus formed when a neutron is captured by a stable nucleus. Studies of this type have been carried out with cadmium, titanium, chlorine, and tellurium by using neutrons from the Brookhaven reactor and observing the gamma-ray spectra with the aid of a thin-lens magnetic spectrometer. K x-ray - K photoelectron coincidence spectra with a resolution of about 2% have been taken in the manner described in last year's report. Previous internal conversion data for $Cd^{113}(n, \gamma)Cd^{114}$ in addition to the external conversion data have allowed the assignment of eleven transitions in Cd^{114} . These assignments fit into the decay scheme illustrated in Figure 7. The four lines observed from titanium are of such high intensity that they must belong to the reaction $Ti^{48}(n, \gamma)Ti^{49}$. The strong line of 1382 ± 4 kev corresponds to the transition from the first excited state to the

Figure 7. Proposed decay scheme of Cd^{114} from the gamma-ray spectrum of $Cd^{113}(n, \gamma)Cd^{114}$. The five transitions from the capturing state indicated on the left of the figure are from the data of Kinsey and Bartholomew. The twelve low energy transitions have been observed with the thin-lens spectrometer at Brookhaven. Five new states in Cd^{114} are proposed to explain the observed spectrum. The figures next to the lines representing the transitions are the gamma-ray intensities per 100 neutrons captured.

ground state and the lack of a crossover from the third excited state at 1728 kev to the $f_{7/2}$ ground state suggests that the 1728-kev state corresponds to the $p_{1/2}$ state and the 1382-kev state corresponds to the $p_{3/2}$ state of the odd neutron. The $Cl^{35}(n, \gamma)Cl^{36}$ spectrum has disclosed only five gamma-rays between 400 kev and 2.5 Mev, four of which are quite strong. All five of these transitions fit well with the known level scheme of Cl^{36} . Four transitions were seen in the case of tellurium, three of which are of such high intensity that they are assigned to $Te^{123}(n, \gamma)Te^{124}$. These three lines agree well with the energy of known transitions from the radioactive decay of Sb^{124} to Te^{124} .

Figure 8. Left Side: The solid curve at the left, representing the ratio E_2/E_1 plotted against Z (scale at bottom), shows an abrupt rise between $Z=86$ and $Z=88$, while the dashed curve at the right, showing the same ratio against N (rare earth region, scale on top) rises steeply between $N=88$ and $N=90$. Right Side: E_2/E_1 plotted against E_1 . Solid curve, heavy elements; dashed curve, rare earth region.

The research Van de Graaff accelerator has been used together with scintillation detectors for studies of various nuclear reactions in light elements. A level in O^{16} at 8.87 Mev, whose position had already been established, was further investigated by measuring the angular correlation of gamma-rays in N^{16} beta decay. Both N^{16} in the ground state and the 8.87-Mev level in O^{16} were shown to be 2^- . The position and properties of the 8.87-Mev level do not agree with the predictions of the alpha-particle model of O^{16} .

A guest scientist from Columbia University has started a program to study the (d,n) and (d,p) reactions with H^3 and He^3 using deuterons accelerated in the BNL 60-in. cyclotron. Cross sections and angular distributions are measured with particular attention to the lower energy particle groups corresponding to excited states of the product nuclei.

The apparatus and detectors have been checked by scattering experiments and certain well-known reactions. A preliminary study of the energy distribution of charged particles from the $d-He^3$ reaction has been made. At 15° (lab) a rough measurement of the cross section gave a value of 3×10^{-28} cm²/sterad for the $He^3(d,p)He^4$ reaction. An estimate of the total cross section made from this and the Butler stripping theory is one millibarn, which is lower than the anticipated value by a factor of 10.

Some new regularities in nuclear spectra of theoretical interest have been established. In the

previous report it was pointed out that there exists a well-defined region of nuclei with even number of protons and even number of neutrons where the pattern of excited states is "near-harmonic," i.e., where the ratio of the energy of the second excited state (E_2) to that of the first (E_1) is approximately 2.2. There is an abrupt transition from this region to the rotational region ($E_2/E_1 \approx 3.3$) when the neutron number changes from 88 to 90. A similar near-harmonic region has been found in the trans-lead nuclei, but here the transition is governed by the proton number rather than by the neutron number (see Figure 8), and takes place as the proton number changes from 86 to 88.

The theory of the nuclear many-body problem is being improved in the numerical accuracy of the results and also in the general understanding of the range and limitations of the theory. Work has been completed on further studies of the nuclear equilibrium properties, with emphasis on the effects of the exclusion principle on the interaction operators which determine the nuclear binding energy and equilibrium density.

A theory has been developed which accounts for the difference between the nuclear density distribution and the potential seen by an interacting nucleon. The considerably greater range of the potential is due to a combination of the finite range of nuclear forces and of the effects of the nonlinear relation between density and potential, this being a consequence of the nuclear forces.

Theoretical consideration of the possibility of the occurrence of electric monopole transitions (these proceed solely by internal conversion) has been emphasized and calculations of the transition probability for this process have been carried out for a "point-charge" nucleus.

As stated in previous reports, experiments have been conducted on the tritium and helium-3 content of meteorites to obtain data related to the cosmic-ray age of meteorites and the cosmic-ray intensity in extraterrestrial space. The H^3 concentration in two recently fallen iron meteorites, Norfolk and Para de Minas, was measured as being 2.7×10^6 tritons/g and 5.9×10^5 tritons/g, respectively, at their time of fall. Two old iron meteorites, Charcas and Canyon Diablo, have less than 10^4 tritons/g. Since meteorites come from extraterrestrial space, the H^3 activity gives a direct measure of the cosmic-ray intensity in extraterrestrial space. The H^3 content of Norfolk compared to the H^3 produced in iron by high energy protons gives a flux of 9 particles/cm²/sec if there is a low energy cutoff at 1 Bev. This is three times the flux striking the earth's poles in 1949. On the

other hand, the flux determined from the Norfolk data equals that striking the earth in 1954 when there was no low energy cutoff. The Para de Minas meteorite gives a flux five times smaller.

The He^3 and Li^6 contents of six iron and five stone meteorites were measured by neutron activation. The fact that there is no direct relation between the Li^6 and He^3 contents indicates that the extraterrestrial slow neutron flux is less than 1 neutron/cm²/sec. The H^3 and He^3 contents of Norfolk and Para de Minas combine to give them cosmic-ray ages of 0.9×10^9 years and 1.7×10^9 years, respectively.

The A^{40} contents of seven iron meteorites were measured by neutron activation. The A^{40} content is approximately proportional to the He^3 content with a proportionality factor of 0.05. This means that the A^{40} results from the spallation of iron by high energy protons. Since the threshold energy for A^{40} production from iron is high compared to that for H^3 production, the slight variation of the $\text{He}^3/\text{A}^{40}$ ratio indicates a slight variation in the low energy flux bombarding the meteorites. The K contents of seven iron meteorites have also been measured by neutron activation. These are too small to contribute to the A^{40} contents of all but two of the iron meteorites.

NEUTRON PHYSICS

The study of the interactions between neutrons and nuclei continues to provide valuable information relative to nuclear structure. As techniques are improved and new techniques are developed, the data obtained in such research provide greater insight into the character and properties of nuclei. A continuing program of research uses neutrons from the Brookhaven reactor and the fast chopper together with time-of-flight technique to observe the interaction with nuclei of monoenergetic neutrons in the energy range from several kilovolts down to thermal energies. This chopper has been provided with a new rotor which has a steel core to reduce the γ -ray background, thus permitting the use of scintillation detectors which have inherently higher resolution. A 64-tube bank of scintillation counters using a B_2O_3 -ZnS mixture is being constructed. With a new type of analyzer containing 1024 channels, designed by the electronics group, it will be possible to count all the neutrons from each burst with the highest resolution attainable with the present flight path.

The program with the fast chopper has been extended by constructing a xenon gas scintillation counter for use in connection with fission parameter measurements. The detector is very fast and

Figure 9. Xenon gas scintillation counter.

is stable at room temperatures. It is particularly useful for experiments with the transuranic fissionable isotopes, all of which are highly (alpha) radioactive. The detector is shown in Figure 9. A Pu^{239} sample was mounted in a position such that it could be placed in the neutron beam from the fast chopper. The counter was filled with xenon gas at atmospheric pressure, and the filling tube sealed off and immersed in dry ice and acetone to trap out impurities which otherwise would quench the xenon scintillations. The detector was used in an experimental confirmation of the constancy of ν , the numbers of neutrons per fission, for Pu^{239} over the energy range from thermal to 0.3 ev.

The program of measurements in the kilovolt region to obtain an average value of $\bar{\Gamma}_n^0/D$, as outlined in the preceding annual report, has been carried out to obtain values for Ag, In, Eu, Eu^{151} , Eu^{153} , Sm, Dy, Er, Yb, Hf, Ta, W^{183} , Th, U^{233} , U^{235} , and U^{238} . In Figure 10 the solid circles are values of $\bar{\Gamma}_n^0/D$ obtained by averaging over resonances in the kilovolt region, and the open circles are values obtained from the analysis of individual resonances. The solid curve is the result of the most recent "cloudy crystal ball" calculations making use of a potential well of rounded edge having the parameters shown.

A continuation of the measurements of potential scattering cross sections is being carried out for a large number of heavy nuclei by averaging over the resonances in the kev region. These studies should give useful information concerning the detailed variation of the nuclear radius as a func-

Figure 10. Average values of Γ_n^0/D as a function of atomic weight.

tion of atomic weight. Measurements have been made on Ag, Ta, Th, and U.

An extensive study of the neutron resonance structure of U^{235} has been completed within the past year and submitted for publication. Fission widths for 12 resonances were determined by methods outlined in the previous report and their size distribution is shown in Figure 11.

The resonance structures of U^{234} and U^{236} have been investigated up to 200 ev. The isotopes are quite similar to U^{238} and Th in the size and spacing of levels. By combining the data on the level spacings (energy difference between adjacent levels) in these four nuclei, information can be obtained about the distribution of spacings. The type of distribution shown in Figure 12 is known as a differential distribution, and indicates that the distribution of spacings is not uniform. Further analysis of data on other nuclei will be necessary to find a general law of distribution for level spacings.

An improved theory has been developed for the magnitude and energy dependence of the parameters which determine the cross section for neutron-nucleus scattering. Further work on the consequences of width fluctuations is being pursued. In particular, an attempt is being made to understand the meaning of the fluctuation of fission widths from level to level in terms of its relation to current nuclear models. A study of effective range theory in the presence of absorption is under way. This study is one phase of a program which has as its aim the understanding of the effects of different well shapes for complex potentials on cross sections, penetrabilities, etc. Another phase of this program involves machine calculations of cross sections for various assumed complex potentials.

Research has continued on the scattering of long wavelength neutrons by crystalline material. As described in last year's report the neutron beam

from the Brookhaven reactor is filtered with a piece of Be at liquid nitrogen temperature. The cold neutrons produced in this manner are then allowed to strike a crystal and the energy distribution of the resulting scattered neutrons is obtained with the aid of the slow chopper and time-of-flight measurements.

The energy distribution of long wavelength neutrons scattered by a crystal of aluminum has been studied for many orientations of the crystal relative to the direction of the incident beam. The discrete peaks predicted by theory are observed, and their measured positions are used to

Figure 11. Distribution of fission widths in U^{235} .

Figure 12. Distribution of level spacings based on data from four even-even nuclei.

Figure 13. Frequency distribution of lattice vibrations for vanadium.

determine the energies and wave vectors of the phonons of the lattice vibrations of the crystal. The relationship between the phonon energies and wave vectors thus determined can be used to test possible models of interatomic forces.

In contrast with the coherent scattering observed with the single crystal of aluminum, that which is found for polycrystalline vanadium is incoherent. Thus the energy distribution of scattered neutrons for vanadium is continuous and is closely related to the frequency distribution of the lattice vibrations. The frequency distribution obtained from the experimental data is shown by the solid curve in Figure 13. The broken line curve is computed from the simple Debye model with a Debye temperature of 338°K, and the dotted curve represents a modified calculation which includes the different modes of polarization and the geometrical effects of the Brillouin zones. The fact that neither of the calculated curves agrees with the experimental results indicates the need for a more detailed model than that of Debye.

The results thus far obtained are encouraging enough to justify a new experimental arrangement designed specifically for these experiments. By drilling a hole 16 in. in diameter and 28 in. deep in the graphite reflector at the top of the reactor, the intensity is increased by a factor of 25 over that found at the east face. Special shielding blocks were constructed to permit the sample to "see" a greater portion of the reactor surface. The cold

Figure 14. Phase spectrum of 1.66-Mev neutrons scattered at 90° from iron over a 121-cm flight path.

Figure 15. True time spectrum of 1.66-Mev neutrons scattered from iron at 90° over a 121-cm flight path.

neutrons at 90° from the incident beam will be measured by time-of-flight technique with the scattered beam traveling parallel to the top of the reactor.

Studies of neutron interactions at energies higher than those readily available from the reactor are being carried out at the 18-in. cyclotron and at the 60-in. cyclotron. The protons accelerated in the 18-in. cyclotron, incident on a T-Zr target, produce pulses of neutrons of about 2 mμsec duration with a repetition period of 54 mμsec. These short pulses, combined with millimicrosecond time-of-flight techniques, have been used to study the elastic and inelastic neutron scattering from iron and carbon. Figure 14 is a plot of the phase spectrum as observed, and Figure 15 shows the true time spectrum of 1.66-Mev neutrons scattered from iron. The angular distributions of elastically scat-

Figure 16. Time-of-flight spectrum of the radiation from 22-Mev deuterons on a thick Be target viewed from 12.5 meters by a plastic scintillator. The channel width of the time-to-height converter is 8 μ sec, and the width of the gamma spike is less than one channel. Running time is about 6 min per block of channels.

tered neutrons from iron, at incident neutron energies of 1.48, 1.56 and 1.66 Mev, exhibit an optical diffraction type of pattern. The angular distribution for inelastic scattering from iron shows a slight asymmetry about 90° . The elastic scattering from carbon was studied as a check on the technique and proved to agree well with previous work.

During the course of the work on neutron scattering, improvements were made in the focusing of the proton beam on the target with the aid of a pair of quadrupole magnets. Improvements have also been incorporated in the target design and in the collimation and detection of the scattered neutrons. Preparations have been started to shift over from single-channel time-of-flight equipment to multichannel equipment in order to speed up the process of obtaining data.

A new technique has been under investigation by which the 60-in. cyclotron can be utilized to provide a high intensity pulsed neutron source for high resolution neutron time-of-flight spectroscopy in the Mev and especially the kev range. The feasibility of the method has been demonstrated, and it is now possible to produce on an external target bursts of 22-Mev deuterons of duration $< 5 \mu$ sec and of amplitude ~ 10 ma at a repetition rate of 400 cps. The method utilizes the inherent phase bunching of a cyclotron beam, but the pulse repetition rate is reduced from the frequency of the dee voltage (11 Mc/sec) in order to permit long

flight paths and to achieve high resolution. The arc is pulsed at the desired repetition rate and with a pulse duration sufficient to provide 5 to 10 beam bunches for acceleration. As these bunches reach deflection radius, the cyclotron deflector is pulsed to extract only one of the beam bunches.

Figure 16 shows the count rate versus the time-of-flight of the neutrons from a thick Be target with the detecting plastic scintillator 12.5 meters from the target. The gamma-ray spike and the neutron distribution from 25 Mev through 1 Mev are clearly evident.

ATOMIC AND MOLECULAR PHYSICS

A continuing program of research is being carried out with the high precision mass spectrometer described in previous reports. The high precision available with this instrument has revealed small discrepancies, outside the precision of measurement, in certain atomic mass values obtained from different cycles of mass doublets. Considerable rechecking and study of these discrepancies revealed that they were very probably caused by small differences in orbit distributions in the spectrometer of the two ion species of certain doublets. Ions formed by simple ionization of gas molecules have, before acceleration, only the thermal energy of these molecules while those formed by dissociation generally have a larger initial kinetic energy and hence, in general, a wider angular distribution from the source slit. Because of slight inhomogeneities in the magnetic field, these differences in orbit distribution cause relative distortions of observed peaks and consequent errors in the measured values of their fractional separation. Although attempts to eliminate this source of error have not been completely successful, the indications are that it can be eliminated by some slight modifications of the beam collimation and detector adjustments.

Collateral work was done on development of a novel detector for positive ions incorporating a scintillating material and a photo-multiplier tube. This detector appears to be capable of providing a signal-to-noise ratio materially better than the simple Faraday collector and wide band amplifier in use at present.

Another continuing program of research uses the techniques of atomic beams and paramagnetic (electron) resonance. This program has as its objective the measurement of spin, magnetic dipole, and higher electric and magnetic moments of nuclei, with special emphasis on radioactive nuclei. A microwave gas absorption spectrometer and a nuclear resonance spectrometer have been used

in the past and are available for special problems.

The paramagnetic resonance spectrometer has been improved appreciably in sensitivity and stability. A study is being made of the V^{51} nucleus. The separation of V^{51} from the target material, Ti, which has been irradiated at the 60-in. cyclotron, has proved to be extremely difficult.

The atomic beam apparatus is being modified to permit measurements to be made of nuclear magnetic moments to a precision of one part in a thousand, and hence to observe hyperfine structure anomalies. These measurements involve a determination of resonance lines to a precision of one part in 10^7 . Electronic equipment is being developed capable of this precision. The beam system itself is being modified to reduce the line widths from 60 to 3 kc/sec.

SOLID STATE PHYSICS

Structure of Solids

The neutron diffraction program of the Physics Department has centered around the studies on magnetic, ferroelectric, and antiferroelectric crystals. Considerable progress has been achieved in this field. New techniques and equipment have also been developed.

An important advance in experimental technique is the development of suitably polarized neutron beams for refined structural studies of magnetic materials. A polarized beam of monochromatic neutrons may be obtained by Bragg scattering from a magnetized ferromagnetic crystal possessing suitable scattering amplitudes. One of the existing spectrometers has been modified to permit the examination of the scattering properties of crystals of high polarizability. Measurements were made of the polarization efficiency and the depolarization in transmission as a function both of crystal thickness and of applied magnetic field for magnetite and iron single crystals. The magnitude of the extinction effects in the same iron and magnetite crystals was also investigated. From such data, the necessary conditions can be established for the operation of a useful polarizing crystal.

The ordering of magnetic spins has been studied in antiferromagnetic CoO. Above the transition temperature, T_c , the magnetic Bragg peaks, which occur as superlattice lines, are absent. The diffuse magnetic peaks are located around the corresponding Bragg peaks and can therefore be studied without the presence of the much stronger nuclear peaks which would be present in ferromagnetic substances. The diffuse peaks behave qualitatively in the same way as previously re-

ported for ferromagnetics. At T_c they reach maximum intensity and minimum width in agreement with the theory of Van Hove. The Van Hove pair correlation function for magnetic spins has been derived by Fourier inversion of the data on CoO. The short-range part of the correlation has been found to have a very weak temperature variation. The pronounced increase in the diffuse intensity at T_c is caused by an increase in the long-range part of the pair correlation.

In a number of alloy systems discontinuities have been found in the magnetic moment versus composition curve at the onset of a superlattice. Preliminary neutron diffraction studies on ordered Fe_3Al indicate that the values of the moments of the iron atoms depend on the nearest neighbor population. For those iron atoms surrounded completely by iron nearest neighbors, a value of approximately $2.2 \mu_B$ is observed, whereas the other iron atoms in the lattice, with 50% aluminum and 50% iron as nearest neighbors, possess roughly half this moment.

Further work has been done on ferrites. Neutron diffraction studies have been completed on the mixed manganese-magnesium ferrite system. For all the samples dealt with, the distribution of the manganese is unaltered; that is, approximately 90% of the manganese present remains fixed in the tetrahedral sites. Calculation of the average tetrahedral bond length from the observed oxygen positions for the various compositions showed a general decrease relative to the sum of the ionic radii of the bonding ions as the manganese concentration was increased. Substitution of manganese apparently results in a more covalent tetrahedral bond.

A neutron diffraction study of the magnetic structure of Fe_4N has been completed. This crystal consists of a nitrogen atom at the body-center position in a face-centered cubic cell of iron atoms. With the Fe magnetic moments at the corner and face positions denoted by μ_1 and μ_2 , respectively, the only reasonable magnetic structures are:

- (1) $\mu_1 = \mu_2 = 2.22$,
- (2) $\mu_1 = 3, \mu_2 = -4$ (antiferromagnetic alignment),
- (3) $\mu_1 = 3, \mu_2 = 2$.

Neutron data showed immediately that (2) was incorrect, but it was not possible to distinguish between (1) and (3) in a comparison of calculated and observed data. A field-on-field-off measurement on the (100) peak showed a small intensity change, in agreement with model (3), but forbidden by (1).

The study of ferroelectric $BaTiO_3$ has been continued. Additional single-crystal neutron data

have been collected in the tetragonal phase and several refinement calculations have been carried out. When measured relative to Ba, the shifts (from cubic positions) along the ferroelectric *c*-direction are about 0.06 Å for Ti, -0.09 Å for the O above Ti, and -0.06 Å for the O's on the side faces of the perovskite cell. The atomic positions of ferroelectric BaTiO₃ in its orthorhombic phase were also determined by a single-crystal neutron diffraction analysis. Pillar-shaped crystals with their major axes along the cubic (110) direction were maintained as single domains by the application of an electric field. The structure obtained can be viewed as a framework of slightly distorted oxygen octahedra in which the central Ti ions are displaced toward one of the octahedron edges (polar axis) by 0.13 Å. The Ba ions are also shifted in the same direction but by the smaller amount of 0.07 Å. The similarity between this structure and that of the tetragonal phase indicates that Ti plays an essential role in the ferroelectricity of this crystal, as already suggested by Slater.

The structure of NH₄H₂PO₄ has been determined in a single-crystal neutron study. There are definite N-H...O bonds in the structure, but the (N-H)'s are about 10° off the N,O line of centers. The oxygens are exerting sufficient influence to distort the NH₄ groups, but not enough to result in linear N-H...O bonds. As expected, the O-H...O system is very similar to that found in neutron studies of KH₂PO₄.

Radiation Effects

The other major research activity in solid state physics is the study of defects in crystals. While the major effort is concerned with radiation effects in solids, other departures from perfect periodicity, e.g., order-disorder phenomena, are under active investigation. The problems are being attacked by many diverse techniques both experimentally and theoretically.

Long wavelength neutron transmission experiments on irradiated graphite, described last year, led to an absolute determination of the concentration of lattice defects in this crystal. The technique is being applied to other types of solids of low neutron absorption: α -Al₂O₃, a high melting ionic oxide, and beryllium, a metal. A single crystal of α -Al₂O₃, which had been irradiated for four months at room temperature, showed a measurable but very small effect on the transmission. The value predicted by theory is some 6 times greater. Either the rate of production of defects in Al₂O₃ is smaller than expected, or it has already reached saturation because of thermal

annealing. In order to minimize annealing effects, samples will have to be irradiated and examined at low temperature. This is known to be essential for metallic substances. Consequently, during the past year, a large amount of effort was put into rebuilding the crystal spectrometer used in these experiments to provide a larger detectable intensity and to provide facilities for examining specimens at low temperatures. Having lost its former identity almost completely, it is now designated as the CNV Spectrometer (Cold Neutron Vacuum Spectrometer) and consists essentially of three liquid nitrogen temperature dewars having a common vacuum system for thermal insulation. The specimen dewar will maintain and interchange samples at liquid nitrogen temperatures and has special provisions for loading with samples which are already at these temperatures (needed for the examination of irradiated metal specimens). Other items which have been incorporated to increase the precision of the instrument are: 1) an automatic rocking device for rotating the monochromator to obtain background, 2) a versatile and accurate timer, and 3) a new programmer offering a program of 14 different operations in any combination of 10 to operate all units automatically.

Displaced atoms, and particularly the associated strains or structural changes, can be studied by x-ray techniques. Diamond is under extensive investigation because radiation effects in this crystal are pronounced and of considerable theoretical interest. Upon heavy irradiation (4×10^{20} fast nvt) diamond exhibits an x-ray diffraction pattern characteristic of an amorphous material in which many features of the diamond structure are retained. There is also pronounced small-angle scattering. The density of the irradiated diamond is lower by 14% as determined by hydrostatic methods. The integral Fourier inversion of the pattern yielded a radial distribution curve (number of carbon atoms between the distances r and $r+dr$) strongly characteristic of the diamond structure. Detailed analysis of these data is under way. The amorphous structure may be due to strains in the diamond caused by the presence of interstitial atoms, or to structural changes more akin to partial transformation to graphite. It is hoped that a definite model will evolve from a detailed analysis of the data combined with annealing investigations.

Another material in which radiation effects are being studied with x-ray is sodium azide (in cooperation with Picatinny Arsenal). The compound is known to decompose under gamma-ray and

reactor irradiation. Sodium azide is a layer structure with the cubic close-packed stacking sequence. X-ray studies have shown that both gamma-rays and reactor irradiation definitely produce mistakes, i.e., "stacking fault" in this packing sequence. This is an unusual manifestation of radiation damage since a stacking fault involves the cooperation of many atoms to shear layers with respect to each other. The number of stacking faults is found to increase with increased irradiation or mechanical deformation. Annealing studies on the irradiated and mechanically deformed states are in progress.

A series of experiments, partly described last year, have shown that diffusion rates may be increased by irradiation to such an extent that the short-range order of alloys is increased at a temperature at which normal reaction rates are negligible. These conclusions were based primarily on resistivity studies. As a by-product of this study, the resistivity of α -brass was found to decrease with increasing short-range order. The relation between resistivity and short-range order has been further investigated by measurements on very carefully quenched samples of AuCu_3 . In this alloy the electrical resistivity was found to increase with increasing short-range order. This result is supported by theoretical studies. Changes in short-range order are being used as a sensitive tool to measure certain radiation effects in alloys, namely, the migration of defects in which a change in short-range order results from the accelerated atomic diffusion.

The effect of radiation on the optical absorption of solids is of inherent interest and, in addition, can become a useful tool for the determination of the number of displaced atoms produced by fast particles. Several different approaches can be used. First, one may search for absorption bands produced by fast particles and not by ionizing radiation and thus demonstrate that one or more of these bands arise from vacancies or interstitials. Second, one can attempt experiments with materials such as the alkali halides, in which the absorption bands associated with vacancies are well known, and produce changes in the vacancy concentration by radiation. Third, one may look for damage in materials like the azides, in which the crystal may be decomposed, and correlate the decomposition with the radiation damage. The first of the above approaches has been used with Al_2O_3 and with fused and crystalline silica. These high-melting oxides are very resistant to coloration by ionizing radiation but color easily upon neutron irradiation. The growth of the absorption bands

in Al_2O_3 was studied as a function of irradiation. It was found that the growth may be resolved into a linear part and an initial part which saturates exponentially. The linear part is interpreted as due to the steady state production of defects by fast neutrons and this steady rate may be compared to theoretical expectations. If a reasonable value such as 0.1 is taken for the oscillator strength, the number of color centers turns out to be less than that theoretically expected by about a factor of ten. Low-temperature irradiations and measurements are needed, as well as an independent determination of the oscillator strength, before this discrepancy can be resolved.

Coloring of the alkali halides by gamma-rays has been beset in the past by difficulties in obtaining reproducible results. Recently, it has been shown that when these materials are colored at room temperature (with the crystals always kept in total darkness) by gamma-rays, the F -centers which are produced decay, and this decay can be resolved into a fast and a slow component. The fraction of fast decay is large when the total coloring is small and the fast component becomes small as the total F -center density approaches saturation. Proper cognizance being taken of this observation, a very considerable improvement in reproducibility is obtained for F -center coloring as a function of gamma-ray dose. It might now be worth while again to attempt quantitative experiments on radiation damage in the alkali halides, which previously failed because of lack of reproducibility.

The cooperative program with Picatinny Arsenal on the effects of radiation on azides has benefited greatly from the successful operation of the new spectrophotometer. The radiation-induced absorption spectra of KN_3 (potassium azide) have been worked out and the stability and growth kinetics of some of the observed bands determined. The results are similar to those obtained previously for NaN_3 by reflection techniques.

A cooperative program with Brown University (under Dr. R. Truell) to determine changes in ultrasonic attenuation and in the elastic constants of irradiated crystals has led to the following results. Reactor irradiation markedly increased the attenuation of ultrasonic waves in Si, Ge, and quartz. Changes in the wave velocity which reflect changes in the elastic constants are much smaller. In contrast, gamma-ray irradiation of quartz results in very little attenuation change, if any. A cube of silicon was irradiated at the edge of the reactor lattice 2 in. from the end of a slug of natural

Figure 17. Radiation-induced strain in a piece of glass. Left: Glass before irradiation, viewed with polarized light. Right: Same piece of glass photographed again with polarized light after a reactor irradiation of one hour. A similar piece was to be irradiated for five hours, but shattered before removal from the reactor.

uranium. In this position it should receive a "directional" fast flux from the slug two to eight times greater than the random fast flux. This cube shows ultrasonic double refraction perpendicular to the "directional" beam but not parallel to it.

This is the first observation of a directional effect in the production of lattice imperfections and will be studied intensively. Strains introduced by radiation can often be studied by examination with polarized light. A typical example is shown in Figure 17.

Irradiation can also affect the chemical reactivity of solids either via ionization effects or by means of displaced atoms. Several examples of ionization-induced reactions have been under study in cooperation with the Nuclear Engineering Department and the Polytechnic Institute of Brooklyn with emphasis on gamma-ray-induced solid state polymerizations. It has been clearly established by now that these reactions proceed via a free radical mechanism in the solid state without any local fusion. Some structural x-ray work is essential for further understanding of the mechanism. A clear-cut example of the second phenomenon, i.e., changes in chemical reactivity due to displaced atoms, has been discovered and studied during the past two years. The reaction is that between graphite and oxygen, whose rate is influenced in the following ways by displaced atoms

and ionizing radiation. 1) Prior reactor irradiation increases greatly the oxidation rate of graphite in the 250° to 400°C range. The increase in the reaction rate is a catalytic effect in the sense that the 1% displaced atoms at these reaction temperatures are not themselves being oxidized preferentially but facilitate the over-all oxidation. 2) Ionizing radiation (gamma-rays) present during oxidation also increases the rate of oxidation of unirradiated graphite but by a much smaller factor. This effect is enhanced by the presence of displaced atoms in irradiated graphite where a further increase of the rate is observed. The gamma-ray effect is probably due to the ionization of oxygen molecules since gamma-rays have not been observed to have any effect on the properties of graphite at these exposures. 3) The activation energy for the oxidation of unirradiated graphite with oxygen as the oxidant was found to be 48.8 kcal/mole and with air was 50.0 kcal/mole. These values are quite similar and it is reasonable to assume that the activation energies are independent of the oxidant. Neutron irradiation, however, resulted in a considerably lower activation energy for the reaction, i.e., 36.1 kcal/mole.

The low-temperature irradiation facility has functioned smoothly and has been used extensively during the past year. In addition to staff

work, irradiations have been done for Knolls Atomic Power Laboratory, North American Aviation, Bell Telephone Laboratory, Argonne National Laboratory, Massachusetts Institute of Technology, Rutgers University, and Brown University.

Theoretical work on the physics of solids continued with emphasis on order-disorder problems. A simple "chemical" theory of the kinetics of order-disorder transformations was described last year. This idea was expanded into a more elaborate theory based on basic statistical mechanical principles and the simple theory was shown to be a special case of the more general one. An infinite array of distribution functions was introduced to express the occupation of all possible sets of lattice sites. These distribution functions determine all the kinds of order in the lattice, including the usual long- and short-range order. They are shown to obey general equations of motion which are linear and in which the kinetic parameters of atom movements occur as coefficients. Solutions of the equations of motion must be found by approximations which depend on expressing higher-order distribution functions by combinations of those of lower order. The simplest of these procedures was explored in detail for two mechanisms of atom movement, direct interchange and vacancy interchange, and for two common lattice types: AB, b.c.c., and AB₃, f.c.c. The result is a calculation of the time dependence of long-range order in homogeneous systems, and is expected to be reliable whenever the long-range order is reasonably high. Present evidence suggests predominance of the vacancy mechanism, at least in close-packed systems. The simple vacancy model was applied to experiments of Burns and Quimby on electrical resistivity in Cu₃Au. The observed relaxation times, over a range of temperatures below the critical temperature, are in reasonably good accord with theory when parameters derived from diffusion measurements in Cu and Au are employed.

Theoretical work was also done on the effect of short-range order on the electrical resistivity of binary alloys with calculations made for Cu₃Au and α -brass. Both the type of short-range order and the angular dependence of an electron scattered by an impurity enter into the calculation. The final results were found to depend sensitively on these factors. Good agreement with experiment was obtained for the case of Cu₃Au, poorer for α -brass.

An accurate computation has been made of the incoherent scattering of x-rays by carbon. This was

necessary for the analysis of the diffraction pattern of irradiated diamond. These data were calculated from the latest wave functions for carbon based on the Hartree-Fock method including exchange. The data are also of intrinsic interest to the diffractionists because of the frequent use of organic materials in calculating absolute scattering intensities.

INSTRUMENTATION

In a nuclear laboratory much of the instrumentation is used for the detection and analysis of radiation. Some work has been done on radiation detectors, and a considerable amount of effort was devoted to data-processing equipment. A modest analogue computer setup has been established in the Instrumentation Division, and construction has started on a high performance digital computer. Fast, high intensity photoflash units were developed for chemical and biological applications. A recording densitometer was designed for the Medical Department, and a large number of other electronic circuits have been built. The Division maintains a facility for service and calibration of health physics instruments. Hundreds of electronic circuits, test instruments, and meters have been repaired. A wide variety of laboratory glassware has been fabricated by the three glass blowers. Some of the more interesting developments are described briefly below.

The sodium iodide scintillation counter is one of the most useful radiation detectors available today. Under the proper conditions the pulse height is proportional to the energy of incident gamma-rays over a wide range of energies. Careful analysis has shown that the relationship departs from linearity by a small amount at low energies. Experiments are in progress to determine why the pulse height is not exactly proportional to energy, and also to see whether the energy resolution of scintillation counters can be improved.

Also in the field of detection, experiments have been continued to measure the energy lost by electrons (and radiation in general) in passing through air and other gases. As a result of these experiments and similar work at other laboratories it seems likely that a better value for the energy required to produce one ion pair in air will be adopted. The formerly accepted value of 32.5 ev will probably be replaced by one close to 34.0 ev. This constant is of considerable importance in radiation dosimetry.

New designs were made in two other types of radiation detectors. One is an ionization chamber for use in locating and measuring the intensity of the external proton beam from the Cosmotron. The chamber is connected through a rigid extension to a battery-operated, portable-survey-instrument amplifier. The amplifier is modified to integrate the intensity of each burst of radiation and to retain the reading so that it can be read in the interval between bursts. It may also be used to sum the amount of ionization produced by successive bursts. The second detector is a set of three thin-window flow counters surrounded by a dozen large Geiger counters and a heavy shield. The Geiger counters are used to detect and reject background counts which penetrate the heavy shield. The low-background counters are used to measure samples of fallout from atomic weapons tests.

Physicists are interested in measuring shorter and shorter time intervals. In order to develop suitable detectors and circuits it is necessary to study the high-frequency characteristics of all the components. High speed oscilloscopes exist but have several disadvantages: the display is too faint to see and must be photographed; high speed amplifiers, which are likely to produce distortion, are required; and such oscilloscopes are expensive. A technique has been developed which gives a visual display of the wave form of repetitive transients on a cathode-ray tube or curve plotter. Each wave form is sampled at one point; successive samples scan through the wave form in time. Sampling is done at a low level, so that fast amplifiers are unnecessary. The output is a point by point plot of the input. The system is useful in the range of 10^{-9} sec.

In many cases the amplitude distribution of the pulses from a radiation detector is of interest and single or multichannel pulse height analyzers are employed to sort the pulses according to size. This year two 100-channel analyzers were built, based on a British-Los Alamos design. Circuits transform the pulse height measurement into a time measurement. The data are stored in digital form in a computer type of serial memory. There is a continuous display of the data on a cathode-ray tube and means for automatically typing the stored numbers at the end of an experiment.

A multichannel time sorting instrument for neutron time-of-flight measurements, described last year, which also employs a type of digital computer memory (16 cathode-ray tubes) to store up to 10,000 counts in each of 1024 channels, was delivered in June 1955. Other data-handling projects

were a 10-channel electronic counter with electric typewriter printout for automatically recording the data from up to ten counting systems in a counting room of the Chemistry Department, and circuits to record on punched cards the (digitized) settings of the positioning controls on a microscope.

In the past year the Laboratory decided to build a high-capacity digital electronic computer. It is to be a copy of a computer now under construction at Los Alamos, known as Maniac II. Such a computer consists of a memory for storing numbers and instructions; an arithmetic unit to perform operations of addition, subtraction, multiplication, etc.; and a control section which controls operations as directed by the instructions. The memory of this computer stores information as dots on cathode-ray tubes, 6000 dots on each of 96 tubes. Some 5000 radio tubes are used in the arithmetic and control chassis. The memory capacity is several times larger than that of most present computers, and the operating speed is high by current standards.

A small analogue computer system has been established in this Division. It consists of a cheap commercial analogue computer and several auxiliary computing elements built here. The setup is being used to solve problems in biology, solid state physics, and accelerator design.

A high speed photoflash device was built for the Chemistry Department. Power supplies, control circuits, and an optical system were constructed for use with special flash tubes to provide high intensity, short duration illumination of a liquid sample. The apparatus makes possible the study of short time light-induced effects, which may contribute to our understanding of photosynthesis.

Another high speed light source was built for use with a phase contrast microscope, which is used to photograph small biological subjects such as bacteria. The flash is short enough so that the rapid motions and pulsations are stopped and clear photographs become possible.

Several other unusual instruments were designed in the year past. Among them are: a circuit which measures the amount of current which flows from a sharp point directed toward the sky and turns off meteorological equipment before lightning occurs; a preset timer for use at the Cosmotron to control research apparatus relative to the timing of the radiation bursts produced by the accelerator; a power oscillator installed near the ion source of the proton Van de Graaff, which deflects the ion beam so as to chop it into a train of short bursts for measuring nuclear properties of

short time duration; and a heater, thermometer, and control circuit for controlled drying of thin samples of biological material.

ACCELERATOR DEVELOPMENT

As in previous years, the Accelerator Development Department concentrated most of its efforts on the design and development of the Brookhaven Alternating Gradient Synchrotron. At this time, the design of the synchrotron is in its final stage and it is expected that orders for most major components will be placed during the next fiscal year.

The basic experimental investigations of the behavior of strong-focusing synchrotrons were

completed at the Electron Analogue. One highlight of this study took place in December 1955 when it was demonstrated that passage through phase transition is possible. Indeed, the initial phase transition passage took place under rather unfavorable experimental conditions. Subsequent detailed studies showed that, in the analogue, the phase transition could be passed with little loss in beam intensity.

The design of the linear accelerator was consolidated by the decision, after a detailed study of accelerating systems, to use a system based on the principles of the conventional University of California machines. Several important modifications will be incorporated in the Brookhaven linear accelerator. A computed drift-tube shape makes possible inclusion of the whole 50-Mev accelerat-

✓ Figure 1. Electron Analogue with vacuum tank covers removed showing arrangement of guide, focusing, and correction lenses.

ing system in a sectionalized tank 110 ft long. The tank will be copper-clad steel so that the conventional rf liner is unnecessary. Focusing will be accomplished by quadrupole magnets in the drift tubes. Injection into the linear accelerator will be at 750 kev from a Cockcroft-Walton set which is now on order.

The magnet study was continued with the help of numerous magnet models. On the basis of these data the diameter of the AGS was frozen at 843 ft. The fixing of this important parameter made it possible to design the complete structure complex.

Figure 2. Pile driver at work driving supporting piles for the AGS magnet foundation.

Work was started in the fall of 1955 on the construction of the service building, which will contain offices, laboratories, electronic and machine shops, the control room of the AGS, a large experimental assembly area, and the power room for the machine. It is expected that this building will be occupied by the Department in October 1956. The excavation for the magnet tunnel has been completed and all the piles of the magnet foundation have been driven.

During the year members of the Department presented papers at meetings of the American Physical Society, AAAS, IRE, The Nuclear Science and Engineering Congress, and the CERN International Accelerator Conference at Geneva. A total of 67 visiting scientists came to Brookhaven from the U.S., Australia, Canada, England, France, Germany, Holland, Italy, Sweden, Switzerland, and the U.S.S.R. to discuss accelerator design concepts with members of the Department.

Progress in major component design has been steady and is outlined below.

ELECTRON ANALOGUE

The Electron Analogue is a device constructed in 1954 to test experimentally the dynamic behavior of strong-focusing synchrotrons. It was hoped that this specialized accelerator would shed more light on three aspects of AGS operation: the locations, widths, and strengths of resonances; the feasibility of phase transition passage; and the effects of nonlinear fields. As the phase transition energy is a function of the mass of the accelerated particle, it was necessary to use electrons in the analogue in order to bring the phase transition energy down to a value which is relatively easy to achieve, i.e., 2.75 Mev. The diameter of the analogue was made fairly large, 45 ft, in order to facilitate observation of electron pulses orbit by orbit. However, with this large radius of curvature and the low injection energy of 1 Mev, it would have been extremely difficult to construct precise magnetic guide lenses. Consequently, the strong-focusing lenses of the analogue are electrostatic.

As reported previously, the analogue was constructed in 1954 and operated satisfactorily under dc conditions. Resonances and their characteristics were explored experimentally and were found to agree well with theoretical predictions.

Early analogue operations had shown that the locus of the equilibrium orbit was quite wobbly, a fact which contributed to the width of the resonance bands. Consequently, after the basic resonance location studies were finished, attempts

Figure 3. Oscilloscope showing beam of Electron Analogue going through phase transition. Main trace indicates beam intensity as a function of time. Upper trace shows radial position of electron beam.

were made to straighten out the equilibrium orbit by means of dipole "kicker" electrodes. Kickers were energized in groups with 6th- and 7th-order harmonic corrections because the largest disturbances occur in the neighborhood of the betatron oscillations at order $6\frac{1}{2}$. The corrections reduced the widths of the 6th and 7th integral resonances as much as 50%.

Once the resonance pattern had been established, experiments were started to study the excitation of the various resonances. Sloped voltage pulses were applied to quadrupole lenses when the machine was operating in the vicinity of a resonance. The resultant change in n would then carry the operating point through the resonance. As expected, it was impossible to carry the beam through integral resonances. Furthermore, total beam losses occurred nearly every time a sum resonance crossing was attempted. Other resonances and sub-resonances could be traversed rapidly with only small beam-intensity losses. At slower crossing rates losses were observed consistently at one-third integral resonances. Analysis showed that these losses were due to nonlinear field components introduced by the kicker electrodes which were actually quadrupoles connected to act as dipoles; their fields contained significant nonlinear components. The theoretical explanation was verified when augmented nonlinear field components considerably increased the one-third integral resonance losses.

After the resonance studies were completed, rf was applied to the accelerating cavity and the beam was accelerated up to phase transition energy. In December 1955 phase transition was attempted under relatively unfavorable circum-

stances, without the utilization of the radial control circuit. The attempt was successful in that a large fraction of the electron beam was observed to go smoothly through phase transition. Subsequent refinement of control circuits made it possible to accelerate about half the injected beam through phase transition to an arbitrary cutoff energy of 6 Mev, which corresponds to several phase oscillations beyond the transition point.

In the spring of 1956 operation of the analogue became increasingly erratic. Orbit distortions indicated that the machine had become misaligned as a result of nearby earth-moving operations in connection with the construction of the Cosmotron beam-catcher dike, which started in early February. Consequently, the decision was made to open the vacuum tanks and resurvey the locations of the focusing lenses, and level and radial misalignments of as much as 0.050 in. and 0.020 in. respectively, were found in the machine. After realignment in level to ± 0.004 in. and in radius to ± 0.0025 in., which took a month, operational tests showed marked improvement in the performance of the analogue, and the experimental program was continued.

Attempts were made to determine experimentally the inherent nonlinearity of the analogue. This was accomplished by observing the changes in betatron oscillation frequencies with respect to changes in electron momentum. The betatron oscillation frequency was then made independent of momentum by introducing the necessary quadratic nonlinearities with sextupole correcting lenses.

In the analogue the electrons undergo only a few phase oscillations during their acceleration cycle. This is not the case in the AGS. It is, therefore, of interest to check whether repeated crossings of the higher-order resonances, caused by phase oscillations, will affect the beam stability. AGS phase oscillation conditions were simulated in the analogue by applying an ac field to one quadrupole lens. Observations made with unaccelerated beams showed that the small intensity losses were essentially independent both of sweeping frequency from 0.5 to 30 kc/sec and of the position of the operating point unless an integral stop band was encountered. An integral resonance or sum resonance invariably caused total beam loss.

At the end of June the analogue was put on standby. The accumulated data is being analyzed and future requirements will determine whether the machine will be reactivated for a brief interval.

MAGNET

The design of the magnet has been continuing with the study of the magnetic and mechanical characteristics of several models. Model No. 3 is an approximately full-scale model made of 1-in.-thick laminations of low-carbon steel, with a machined contour. As expected, the relatively large lamination thickness produced serious eddy-current effects in the dynamic field behavior. However, the remanent field had characteristics that compensated some of these eddy-current effects to such an extent that the use of thick plate in the magnet is still being considered. Further measurements are needed, particularly under various rates of pulsing, before its use can be considered truly satisfactory. Eddy-current effects contributed to producing a small difference in field values between the open and closed types of contour, but these differences have no very serious effect on the behavior of the particles.

Magnet Model No. 4 is also approximately full scale and has been fabricated from thin sheets, 0.035-in.-thick, low-carbon steel laminations stamped by a precision die. The laminations were assembled by a thermal bonding technique into 5-in.-thick blocks. Before further assembly, each of the 5-in. blocks was measured magnetically and mechanically to determine the extent of the variations that might be expected in the final magnets. Some of these variations could be correlated fairly well with the different heats of steel and some with mechanical differences. Then the blocks were assembled to form two 3-ft-long magnets, one with the open type of contour and one with the closed; magnetic measurements and analysis are still in progress. From the data, the magnetic field values at the center of each 5-in. block were substantially the same in the assembly as before and the interaction between blocks seems to be slight. Particular attention was paid to the behavior of the fields off the ends of the magnet since these contribute serious nonlinearities in the focusing properties and are important considerations from the point of view of orbit dynamics.

Several modifications of the magnet contour have been studied through computations by relaxation methods and by consequent testing with Magnet Model No. 2, a half-scale, dc magnet with separate poles. In order to offset effects of saturation in the pole, studies were made of contours which would produce regions of constant gradient somewhat off center toward the low-field side. In other words, the position of the equilibrium orbit of the particles would not be

Figure 4. Testing of the individual blocks of Magnet Model No. 4.

at the geometric center line of the pole but would be on the low-field side of the center. This proved quite advantageous since there is, in this case, more iron to carry the greater flux in the regions where the fields are high and less iron where less is needed for the smaller amount of flux where the fields are low. There are slight differences between the open and closed types of contour for this off-center position for the equilibrium orbit but these differences are not serious.

From the results of the measurements and further calculations, it was possible during the spring to determine an optimum cross section for the final magnet. The pole width was chosen to be 12.5 in. with the equilibrium orbit position located about 1 in. from the geometric center toward the low-field side and with a gap height at the orbit position of 3.5 in. The usable magnetic aperture is approximately 7 by 2½ in. Outside dimensions of the magnet cross section are 39 by 33 in.

One of the major problems confronting the magnet group is the choice of magnetic steel. This steel should have relatively high permeability at both low and high induction and its coercive force should be low in order to insure low remanent fields. With these requirements in mind, a thorough investigation of various steels has been proceeding. An extensive program of permeameter measurements has been carried out and a survey of available steels has been made with the cooperation of the research laboratories of several steel firms.

Fabrication of the 240 AGS magnets is complicated since fabrication techniques such as heat treatment and welding can seriously affect the

Figure 5. Drawing of the AGS magnet cross section.

magnetic properties of the units. Manufacturers have suggested several different fabrication techniques, two of which are being considered, fabrication by chemical bonding, and by welding. To evaluate these methods, full-scale models have been ordered, and 45 tons of steel have been purchased for this purpose.

The selection of the over-all magnet dimensions made it possible for the power group to design the magnet power supply. Preliminary specifications were made and discussed with various fabricators of heavy power equipment. On the basis of their comments, the final specifications are now being drawn up, and the order for the power supply is expected to be placed in the fall of 1956. The approximate characteristics of the power system are:

Voltage, dc, no load	6000 v
Voltage, dc, full load	4600 v
Maximum current (13,000 gauss)	6525 amp
Peak power demand	30,000 kw
Average power demand	2700 kw
Repetition rate at full load	20 per min
Total energy in rectified pulse	18.5 megajoules
Stored energy in magnet	13.8 megajoules
Energy dissipated in magnet and bus	8.2 megajoules

SYNCHROTRON FOUNDATION

From the inception of strong-focusing designs it has been evident that extremely accurate

magnet alignment is essential for the successful operation of an AGS. The permanency of this alignment will depend on the stability of the magnet foundation. During the past two years this problem has been evaluated by the Accelerator Development Department, the Stone and Webster Company, and Professors A. Casagrande of Harvard and N.A. Christensen and P.P. Bijlaard of Cornell, who were retained as consultants. Soil condition studies indicated that the 1600-ft-deep sand and gravel deposits at Brookhaven had never undergone glacial consolidation. Test areas were subjected to graduated loads increasing to 3000 lb/ft² and the stress-strain characteristics of the soil were experimentally obtained. These tests confirmed the previous conclusions.

During fiscal year 1956, the data from various test borings, load tests, continuous subterranean temperature observations, and foundation analyses were consolidated and a foundation design was adopted. The magnet units will be supported by a 36×30-in. steel box girder divided into 120 sections each about 21 ft long. The girder ends will be supported on concrete pile caps, each terminating four 50-ft-long 10BP42 steel H piles. While it is believed that this foundation structure will suffice in the magnet tunnel, special problems are posed in the target building by the proximity to the magnet support piles of 11,000 tons of shielding. This problem was alleviated by surrounding each pile group in the target building with a 12×12-ft sheet pile box in order to keep surface soil stresses away from the piles. The shield will be placed on a 3-ft-thick concrete mat resting directly on the soil. However, 5 ft of this slab adjacent to the magnet supports will be supported cantilever style. At this time all the bearing and sheet piles have been driven into the soil.

Figure 6. Cross-sectional sketch of the AGS magnet foundation.

LINEAR ACCELERATOR

During the early design period for the Alternating Gradient Synchrotron, the linear accelerator group undertook an investigation of possible new designs for the accelerating system of the 50-Mev linear accelerator which is to be the injector. This study was concluded early this year and a decision was made on the specific design to be used. During the investigation three novel structures were developed. One of these, however, proved to be advantageous only up to about 20 Mev; a second was unusable in the low energy range. The choice was thus narrowed down to include only a system of coupled resonant cavities which seemed to present some mechanical advantages, and the conventional University of California design which is more economical of power. Since these two systems were quite similar in over-all desirability and since the cavity system seemed to demand a further period of some months of development, the final decision was made in favor of a modified Berkeley design. In this design three major modifications have been incorporated. The first change is in mechanical design. The conventional linear accelerator uses a radio-frequency cavity of light construction enclosed in a heavy vacuum tank. The Brookhaven linear accelerator combines these two functions in a single copper-clad steel tank. This design presents advantages of mechanical rigidity and reproducibility.

The second modification is in the drift-tube design. A method has been evolved for computation of drift-tube shapes. The computed drift tubes are roughly elliptical in axial section in contrast to the empirically designed cylindrical drift tubes of the Berkeley machines. The new drift tubes are

somewhat more economical in power consumption and provide more adequate space for focusing mechanisms. Detailed computation of drift-tube shapes is in process at the AEC UNIVAC computer installation at New York University.

The third change in design relates to the focusing technique. Grid focusing in the conventional machine results in serious beam loss by interception and aberration. Since high intensity is particularly desirable for the synchrotron injection, grid focusing will be replaced in the Brookhaven machine by alternating gradient focusing using pulsed quadrupole magnets located inside the drift tubes. As mentioned in previous reports, rather efficient permanent magnet quadrupoles with gradients as high as 1000 gauss/cm have been developed for this purpose. If, as appears desirable, a constant rate of acceleration is to be maintained along the machine, this gradient is not sufficiently high; at the injection end of the linear accelerator, gradients of the order of 6000 gauss/cm will be required. Consequently a program of study of pulsed quadrupole electromagnets has been undertaken. In such quadrupoles it has been shown that gradients over 10,000 gauss/cm are easily achieved in an aperture 0.75 in. in diameter.

Detailed design of the tanks and drift tubes of the machine has been in progress since the type decision was made, and design of several of the tanks has been finished. Furthermore, several "power" and "mechanical" model sections have been designed and built. They will be used to test the mechanical stability of the proposed drift-tube support scheme and to evaluate rf characteristics under high power conditions.

The rf program has concentrated on low-level circuits and on development of circuits for the 3W10,000A power triode. The 3W10,000A program is being carried out as an "insurance" feature since it is expected that a klystron will be developed to serve as an rf power supply for the linac. For this purpose a development contract has been negotiated with the Eitel-McCullough Company which is expected to produce a 200-Mc/sec, 5-Mw klystron by early 1957.

A considerable amount of work has been done on the problems connected with injecting protons into the linac, and from the linac into the synchrotron. A careful study of preaccelerators showed that a Cockcroft-Walton accelerator would be best suited for a preinjector, and an 800-kv machine has been ordered from the Philips Company with delivery expected in the second quarter of 1957.

For injection into the synchrotron, an analysis of various inflection schemes indicated that the ad-

Figure 7. Drawing of an ovoid drift tube of the AGS linac.

vantages of a special momentum distribution of the linac beam to match that of the synchrotron would not justify the additional technical difficulties which would be encountered with the required 30° injection. Consequently, it was decided to inject protons approximately tangentially into the synchrotron.

RADIO-FREQUENCY

Early in the year delivery of the ferrite for the first model rf cavity was completed. The design of this cavity has undergone one major change. The principal new feature involves the cooling of the ferrite. Previously it had been planned to air-cool this material. However, in the new design, water-cooled copper disks are placed between adjacent ferrite rings. Construction of a model power amplifier and saturating, or tuning, power supply was also completed.

The model power amplifier is a six-stage, push-pull, shunt-peaked system utilizing EIMAC M6424 tetrodes in its final amplification stage. As ferrite deliveries for the second section of the model cavity had not been completed, the amplifier was tested on a dummy load. No trouble was encountered in amplifying the input of 1.5 v to the required output value of 8 kv. During the construction of the amplifier new tubes with higher power ratings became commercially available. Consequently, a new design was evolved which took advantage of these new tubes. This unit will use fewer tubes and, therefore, will also be much smaller in size. This is important since space in the magnet tunnel is at a premium.

VACUUM

Early in the year one of the first commercially available models of the new titanium evaporation pumps was received by the Department. This "Evapor-ion" pump has undergone thorough performance tests, which demonstrated that the ultimate vacuum obtainable with it is generally better than that produced by oil diffusion pumps. The Evapor-ion pump has been adopted for use with the AGS because it has adequate pumping speed, and is expected to produce major simplifications in the vacuum and control systems. It is now planned to locate 48 of these pumps around the circumference to maintain a vacuum of 1 to 2×10^{-6} mm Hg.

Work is progressing on the design of the vacuum chamber. Magnetic measurements of elliptical Inconel sections in Magnet Model No. 4 have left some doubt as to whether it will be feasible to use 0.09- to 0.11-in.-thick vacuum chamber

walls. Consequently, studies are now in progress to investigate rib-supported thin-wall vacuum chambers.

CHEMISTRY

The research program of the Chemistry Department has continued to emphasize the broad fields of nuclear chemistry, chemistry and applications of isotopes, chemical effects of radiation, chemical effects of nuclear transformations, and molecular structure and solid state. There has been considerable and effective participation in the research program by visitors. It may also be mentioned that, for reasons pertaining to certain individual experiments, some of the work described below has been done by BNL staff members at other AEC laboratories.

NUCLEAR CHEMISTRY

Nuclear Reactions

The investigation of nuclear reactions induced by protons of billion-electron-volt energies has continued throughout the year. Most of this work is still carried on in the circulating proton beam of the Cosmotron. However, the radiochemical group has also participated actively in the program for producing external proton beams, applying activation techniques to the measurement of beam intensities and intensity distributions. This external beam program has been very successful, and focused proton beams of various energies containing up to 50% of the circulating beam intensity are now available at the Cosmotron.

One important experiment that has become possible through the availability of external proton beams is the absolute measurement of a reaction cross section which can then serve for beam monitoring in the circulating beam. The reaction $C^{12}(p, pn)C^{11}$ has been chosen for the purpose. This work is being done in the so-called pencil beam, a well-collimated, focused proton beam of variable energy and of diameter less than one-half inch. This beam, at an intensity level of a few hundred to a few thousand protons per pulse, is passed through a plastic (hydrocarbon) scintillator one inch thick and one inch in diameter. Simultaneously the flux of protons in the beam is determined by a counter telescope immediately downstream from the scintillator. After an irradiation, the C^{11} activity (of 20.5-min half-life) induced in the plastic is measured by internal scintillation counting with anticoincidence counters to reduce

the background. The contribution of secondary particles produced in the thick target to the production of C^{11} is determined in a separate experiment, in which C^{11} production by the pencil beam is measured as a function of target thickness at a much higher beam intensity. Preliminary runs with the technique described have shown that the cross section of the $C^{12}(p,pn)$ reaction is 28 ± 2 mb for proton energies between 2 and 3 Bev. The values are about 25% higher than those determined earlier by a less direct and less reliable method. The experiment is being continued to improve the accuracy and to extend the measurements to lower energies.

The $C^{12}(p,pn)$ reaction is one example of a whole class of reactions whose cross sections do not show large variations with bombarding energy in the range accessible with the Cosmotron (0.4 to 3.0 Bev). All hitherto studied simple reactions (i.e., reactions involving small changes of A) among light nuclei fall into this category. On the other hand, cross sections of some simple reactions of heavy nuclei have been found to decrease markedly with increasing proton energy. To investigate just how the energy dependence of the cross section for a particular reaction type changes with the target mass number, the excitation functions of a series of p,pn reactions have been measured. The target nuclides were C^{12} , N^{14} , F^{19} , Cu^{65} , Mo^{100} , Ce^{142} , and Ta^{181} . For each of these p,pn reactions (except for that on Ce^{142}) the cross section was found to be nearly constant for proton energies between 0.4 and 3.0 Bev. The exceptional behavior of the $Ce^{142}(p,pn)$ reaction, whose cross section decreases by about a factor of two when the proton energy is increased from 0.4 to 1.0 Bev, is not understood. If, as is indicated by other data, p,pn reactions take place by a knock-on mechanism, that is, by the direct ejection of a neutron from

the nucleus, the near-constancy of the p,pn cross sections with energy might be interpreted in terms of an almost energy-independent elastic proton-neutron scattering cross section. With a pure knock-on mechanism one would also expect a rather regular variation of p,pn cross section with target mass number at a given proton energy, and the data with the target nuclides listed did not appear to bear out this prediction. Among the light nuclides, it has been possible to correlate the magnitude of the p,pn cross section with the number and distribution of energy states of the product nuclide which are stable with respect to nucleon or alpha-particle emission. For example, N^{14} has a very low p,pn cross section (6 mb at 0.4 Bev, compared to about 31 mb for C^{12} at the same energy) because all states of N^{13} except the ground state disintegrate into $C^{12} + p$. To check further whether p,pn cross sections of heavier nuclides also exhibit irregular variations, a number of p,pn cross sections in a small region of A were carefully measured at 0.4 and 3.0 Bev, with the use of enriched isotopes. The results presented in Table 1 show that the p,pn cross sections indeed do not vary smoothly with mass number or neutron number. Since primarily those proton-neutron collisions taking place near the periphery of a nucleus are likely to lead to p,pn reactions, the cross section variations are perhaps indicative of differences in neutron densities near the nuclear surface and may thus be connected with nuclear shell structure.

Some processes which are very much more complex than p,pn reactions have also been studied further. In a previously reported survey of reaction products resulting from the interaction of lead with protons between 0.4 and 3.0 Bev, one of the striking results was the appearance, in rather high yields, of light fragments such as F^{18} , Na^{24} , Mg^{28} , and P^{32} . It seemed of interest to study the formation of such products from other target elements. The cross sections for the production of F^{18} and Na^{24} from Al, Cu, Ag, Ta, Au, Pb, and U have now been measured at 1, 2, and 3 Bev, and similar studies on the cross sections for C^{11} production are under way. In Figure 1 the Na^{24} formation cross sections are plotted against target mass number for these three proton energies. The F^{18} values are lower by factors of 2 to 5, but show the same general dependence on energy and target mass number as the Na^{24} data. The two branches of the σ versus A curves indicate two different mechanisms for the formation of F^{18} and Na^{24} , one predominating in light element targets, the other in heavy elements. From Al, Cu, and Ag, the F^{18}

Table 1
Cross Sections for p,pn Reactions on Nuclei
with Mass Numbers Between 54 and 65

Target nucleus	Neutron number	$\sigma_{p,pn}$ at 0.4 Bev (mb)	$\sigma_{p,pn}$ at 3 Bev (mb)
$^{26}Fe^{54}$	28	46	43
$^{28}Ni^{58}$	30	49	44
$^{29}Cu^{63}$	34	68	72
$^{29}Cu^{65}$	36	70	68
$^{30}Zn^{64}$	34	68	65

Figure 1. Cross section for formation of Na^{24} at 1, 2 and 3 Bev as a function of target mass number.

and Na^{24} are presumably produced mostly by a conventional spallation mechanism, i.e., a knock-on cascade leading (in about 10^{-21} sec) to an excited nucleus from which nucleons, deuterons, alpha-particles, etc., are evaporated (in perhaps 10^{-14} sec) to form the final product. The observed cross sections for the production of F^{18} and Na^{24} from heavy elements (Ta to U) can presumably not be explained in terms of such a process. Among other mechanisms which have been suggested to account for the data are a very asymmetric type of fission and a so-called fragmentation process. By the latter term is meant the breakup of a nucleus into two or more large fragments in a time comparable to the duration of the knock-on cascade and therefore short compared with the time required for the distribution of energy throughout the nucleus. It is thought that such a fragmentation process may be the result of a local hot spot in a nucleus created when successive scattering collisions of a pion produced inside a nucleus lead to the breaking of several nucleon-nucleon bonds in a small region.

Properties of Radioactive Nuclides

Experimental investigations of the relative probabilities of K -electron capture and positron emission for first forbidden transitions have been under way at this laboratory for some time. During the past year the K -capture/ β^+ ratio of the unique first forbidden ground state transition of Sb^{122} has been measured. The maximum energy and inten-

sity of the very rare positron branch was determined by a triple-coincidence pulse analyzer, and the intensity measurement combined with the previously known K -capture probability gave a K/β^+ ratio of 270 ± 50 . The end-point energy was found to be 565 ± 25 kev.

The experimentally measured K/β^+ ratios for three unique first forbidden transitions, in Rb^{84} , Sb^{122} , and I^{126} decays, can now be compared with values calculated from beta-decay theory. The choice of beta-decay interaction affects the theoretical result. Pure tensor interaction and unscreened electron wave functions have been used in the present calculations. For Sb^{122} and I^{126} the agreement between theory and experiment is satisfactory, whereas the measured K/β^+ ratio for the unique first forbidden Rb^{84} transition exceeds the calculated value by a factor of about 2.5. The reason for this apparent discrepancy is not understood at present. However, since there were certain experimental difficulties with the Rb^{84} measurement, which were connected with the presence of Rb^{83} in the source, it is planned to repeat the Rb^{84} determination with radiochemically cleaner material.

Among the decay scheme investigations carried out during the past year was one concerning some neutron-deficient isotopes of palladium and rhodium. The original objective was to compare the gamma-rays emitted by Rh^{98} with those found in the decay of the previously investigated Tc^{98} . However, the study was extended to include Pd^{98} , Pd^{99} , Pd^{101} , and their rhodium daughters, all

Figure 2. Probable disintegration schemes of Rh^{98} and Tc^{98} .

prepared by alpha-particle bombardment of ruthenium. The radiations were investigated with a scintillation coincidence spectrometer.

Rh^{98} decays with a half-life of 8.7 ± 0.1 min by emission of 2.5 ± 0.2 -Mev positrons in coincidence with 650 ± 10 -keV gamma-rays (Figure 2). Its Pd^{98} parent was shown by successive daughter extractions to decay with a half-life of 17.5 ± 0.5 min. Rh^{99} (4.7 ± 0.1 hr) showed 0.74-Mev positrons (10%) in coincidence with 335 ± 10 -keV gamma-rays (70%). Other gamma-rays were observed at 615 ± 15 keV (20%), 890 ± 20 keV (weak line coincident with 335-keV gamma), 1.26 ± 0.03 MeV, and 1.41 ± 0.04 MeV (weak). Pd^{99} (21.6 ± 0.6 min) was identified by successive Rh daughter extractions. Its maximum positron energy is 2.0 ± 0.1 MeV and the following gamma-rays were observed: 140, 275, 420, and 670 keV. The 140-keV gamma-ray is the most intense and the 420-keV peak represents two gamma-rays of about the same energy in cascade. Rh^{101} (4.7 ± 0.2 days) decays by electron capture followed by emission of 312 ± 10 -keV gamma-rays. Pd^{101} (8.5 ± 0.3 hr) emits 0.58 ± 0.04 -Mev positrons (4%) by decay to the ground state of Rh^{101} . The gamma-rays observed were at 288 keV (15%), 590 keV (15%), 720, 1190, and 1280 keV (last three less intense). The photopeak at 288 keV represents two coincident gamma-rays of about the same energy. Mass assignments were confirmed by a study of the relative yields of the various radioactive isotopes as the bombarding alpha-particle energy and isotopic composition of the Ru target were varied.

The potential usefulness of a radioactive oxygen isotope with a half-life longer than that of O^{15} (2 min) stimulated a search for O^{20} . Rough estimates indicated that its half-life might be as long as an hour if the β^- transition to the first excited state of F^{20} at 0.65 MeV is allowed (the ground state transition is almost certainly forbidden); if the main transitions are to higher F^{20} levels, an even longer half-life may be expected. Magnesium oxide, containing oxygen enriched to 1.5% O^{18} , was bombarded with 40-Mev alpha-particles to produce O^{20} by $\alpha, 2p$ reaction. Any O^{20} formed would decay to the known 11-sec F^{20} which emits 1.63-Mev gamma-rays; these gamma-rays thus served as an indicator for the presence of O^{20} . Failure to produce any measurable O^{20} activity in a long MgO^{18} bombardment showed that the half-life of O^{20} must be greater than 150 yr or less than 10 min if the $\alpha, 2p$ cross section on O^{18} is ≥ 0.1 of the $\alpha, 2p$ cross section on Mg^{26} which was simultaneously determined to be ~ 1 mb. Other experiments with H_2O^{18} targets, gas sweeping, and gas purification

Figure 3. Excitation function for the production of Mg^{28} by the reaction $\text{Al}^{27}(\alpha, 3p)\text{Mg}^{28}$.

also gave negative results and served to show that if O^{20} has a half-life between 1 sec and 10 min, the $\alpha, 2p$ cross section on O^{18} must be less than a few millibarns.

A nuclide in many ways analogous to O^{20} is 22-hr Mg^{28} . It is usually made by $\alpha, 2p$ or H^3, p reaction on Mg^{26} . However, the specific activities attainable by these methods are limited, and for some tracer applications carrier-free material may be very desirable. The possibility of producing Mg^{28} by an $\alpha, 3p$ reaction of Al^{27} was therefore investigated and the method was indeed found to be practical with the 41-Mev alpha beam of the BNL cyclotron (Figure 3). At 41 MeV, the $\alpha, 3p$ cross section was found to be 0.2 mb. In 1-mil aluminum foil (such as might be used for a cyclotron exit window) 0.1 microcurie of Mg^{28} per microampere hour is produced by 41-Mev alpha-particles, and to obtain carrier-free Mg^{28} one merely dissolves the aluminum target in concentrated NaOH and filters the solution through fritted glass which retains the Mg^{28} as a radiocolloid.

Neutrino Detection

An experiment has been in progress to study the nuclear interactions of neutrinos with the particular aim of determining whether neutrinos and

antineutrinos differ in their nuclear interactions. The principle of the experiment was to attempt to invert an electron capture radioactive decay process requiring neutrinos (ν) with the antineutrinos ($\bar{\nu}$) from a nuclear reactor. The reaction studied is the inverse of the electron capture decay of A^{37} , namely,

The cross section for this reaction if neutrinos and antineutrinos are identical is calculated to be $2.6 \times 10^{-45} \text{ cm}^2$, but if the neutrino differs from the antineutrino in its nuclear interaction the cross section for the above process may be nearly zero. In the experiment Cl^{37} is irradiated with antineutrinos from a nuclear reactor and the radioactive A^{37} (34-day half-life) is observed by chemically separating it from the chlorine and counting the A^{37} decays. Since the magnitude of the cross section is small it was necessary to irradiate large amounts of chlorine (25% Cl^{37}) with a high flux of antineutrinos to produce a measurable amount of A^{37} activity.

Experiments have been performed with 1000-gallon quantities of carbon tetrachloride and the Brookhaven reactor as a source of antineutrinos. However, because of the low power level of the Brookhaven reactor and background effects from cosmic radiation it was not possible to observe cross sections below 10^{-43} cm^2 . In October 1955 the experiment was set up near a production reactor at the Savannah River plant. At this location a high antineutrino flux was anticipated along with good shielding from cosmic radiation. The apparatus consists of two gas-tight 500-gallon tanks of carbon tetrachloride equipped with agitators and a gas processing system for removing argon from the tanks. The A^{37} was removed from the carbon tetrachloride by sweeping the liquid with a helium gas stream. Argon was removed from the helium gas stream by adsorption on charcoal at low temperature. The argon gas sample adsorbed on charcoal was then removed, purified, and placed inside a small, low-level G-M counter for counting measurements. The background of the counter was 30 cts/day, and an increase in counting rate of 4 cts/day above background is observable.

Several experiments have been performed, and no statistically significant increase in counting rate which could be ascribed to A^{37} has been found. It has been tentatively concluded that the cross section for the reaction $\text{Cl}^{37}(\bar{\nu}, e^-)A^{37}$ is less than $0.9 \times 10^{-45} \text{ cm}^2$. The experiment is being continued in an attempt to increase the over-all sensitivity.

CHEMISTRY AND APPLICATIONS OF ISOTOPES

Statistical Mechanics of Isotopic

Molecular Liquids and Solids

Several different lines of experimental evidence (e.g., the vapor pressures of isotopic isobaric molecules, the vapor pressures of isotopic isomers, and the empirical rule of the geometric mean) indicate that the difference in vapor pressure of isotopic polyatomic molecules is not a function of the molecular weight alone, as would be predicted by a hard sphere model. In the case of a special model possessing a harmonic potential and exhibiting small quantum effects in all degrees of freedom (i.e., high temperature behavior), it has been shown that the logarithm of the vapor pressure ratio depends on the reciprocal masses of the atoms. This provides a direct theoretical proof of the rule of the geometric mean for high temperature systems and leads to a formal explanation of the difference in vapor pressures of isotopic, isobaric, and isomeric molecules.

Vapor Pressure of the Isotopic Liquid Hydrogens

Hydrogen molecules undergo free rotation in the liquid. The rotation, therefore, makes no contribution to the vapor pressure. The usual treatment of the hydrogen molecule as a hard sphere predicts identical vapor pressures for HT and D_2 , whereas the rule of the geometric mean, $P_{HT}^2 = P_{H_2}P_{T_2}$, predicts a 35% larger vapor pressure for HT than for D_2 at 20° K. In order to decide between these predictions the vapor pressure ratio P_{H_2}/P_{HT} has been determined over the temperature range 14° to 30° K. This work was performed at the Los Alamos Scientific Laboratory in collaboration with the cryogenics group. Since pure HT is thermodynamically unstable at these temperatures with respect to the disproportionation into H_2 and T_2 and since this equilibrium may be established by the beta activity of the tritium, the work was performed with a dilute solution of HT in H_2 (mole ratio $\sim 2 \times 10^{-8}$). The determination of the specific activity of the liquid and of the gas in thermal equilibrium with it serves to determine the desired vapor pressure ratio, after correction for the deviation from Raoult's law. The deviations are expected to be small and an adequate correction can be made by theoretical computations.

The liquid was condensed from gas which had been prepared by dilution of T_2 in H_2 and then purified and equilibrated through a palladium valve at 550° C. The liquid was catalytically converted to equilibrium hydrogen (99.8% $p\text{-H}_2$). Care was taken to insure isotopic equilibrium be-

tween the vapor and the liquid and to avoid reflux of the vapor above the liquid. The experiments show that the vapor pressure of HT is greater than that of D₂, and furthermore the results are in quantitative agreement with predictions of the rule of the geometric mean after correction for deviations from Raoult's law.

Force Constants for Nitrogen Dioxide

One of the problems in the study of vibrational spectra is the determination of a suitable function for the potential energy of a molecule. In general, there are more force constants to be determined than there are vibrational frequencies available, and the usual procedure is to assume that some of these constants are negligibly small. While it is sometimes possible to determine all the force constants in the case of small, highly symmetrical molecules, more generally they are obtained by the use of different isotopic species. The latter procedure leaves the force constants intact but changes the frequencies.

This method has been applied here to nitrogen dioxide. If the potential energy for this molecule is described in terms of internal coordinates, the following force constants are required: f_d , the N-O bond stretching constant; f_a/d^2 , the constant for deformation of the interbond angle; f_{da} , the constant for simultaneous stretching of both bonds, and f_{da}/d , the constant for simultaneous bond stretching and angle deformation. The vibrational frequencies of N¹⁴O₂ and N¹⁵O₂ were obtained from the infrared absorption spectra measured with a Perkin-Elmer Model 21 spectrometer. The results, with those for N¹⁴O₂ obtained by other workers, are given in Table 2. From the three frequencies of N¹⁴O₂ and ν_2 of N¹⁵O₂, the complete set of force constants shown in Table 3 was calculated.

The rather large positive value of the interaction constant, f_{da} , is explicable on the basis of the following resonance structures (originally suggested by Pauling):

Thus, if the left-hand bond is stretched, structure (a) will be favored over structure (b). This implies that the right-hand bond will be stiffened, so that there is a positive interaction constant. A similar resonance effect exists in the case of the carbon

Table 2
Vibrational Frequencies of N¹⁴O₂ and N¹⁵O₂

Vibration	N ¹⁴ O ₂		N ¹⁵ O ₂
	Grating	Prism*	Prism*
$\nu_1(a_1)$	1322.5 ± 0.2** cm ⁻¹	1324 ± 3	1312 ± 3
$\nu_2(a_1)$	749.7 ± 0.1†	749.9 ± 0.5	739.7 ± 0.5
$\nu_3(a_1)$	1616.0 ± 0.2**	1615 ± 2	1578 ± 2
$\nu_1 + \nu_3(b_1)$	2905.2 ± 0.3**	2906 ± 2	2858 ± 2

*This work.

G.E. Moore, *J. Opt. Soc. Amer.* **43, 1045 (1953).

†F.L. Keller and A.H. Nielsen, *J. Chem. Phys.* **24**, 636 (1956).

Table 3
Force Constants for NO₂ in Millidynes/Å.

	I*	II**
f_d	10.42 ± 0.50	10.38 ± 0.60
f_a/d^2	1.099 ± 0.018	1.294 ± 0.040
f_{da}	2.038 ± 0.250	1.446 ± 0.30
f_{da}/d	0.4533 ± 0.1740	0.0984 ± 0.156

*From observed fundamental frequencies.

**From zero-order frequencies.

dioxide molecule. The other interaction constant, f_{da}/d , has such a large relative error associated with it that little significance can be attached to its magnitude.

The frequency data also make it possible to calculate the partition function ratio of N¹⁵O₂ and N¹⁴O₂. The result (near 25°C) is $f = 0.9564 e^{43.9/T}$; at 25°C, $f = 1.108$.

Electron Exchange Reactions

Studies of the dependence of the ferrous-ferri electron exchange reaction on perchloric acid concentration have indicated the existence of two reaction paths, one involving hydrated ferric ion and another involving hydrolyzed ferric ion. The specific rate constant for the latter path is of the order of one thousand times that of the former. In order to explain this striking difference in rate, previous workers have postulated that the net electron transfer may be accomplished by a mechanism involving the transfer of a hydrogen atom through the hydration spheres of the activated complex. A

similar mechanism has been suggested to account for the fact that the rates of exchange between ferrous ion and FeCl^{++} , FeCl_2^+ , FeF^{++} , FeF_2^+ , and FeF_3 are all equal within an order of magnitude to that of the ferrous-ferric exchange.

The idea of a hydrogen atom transfer mechanism for electron exchange has been tested by measuring the rate of the ferrous-ferric exchange in heavy water solvent as a function of perchloric acid concentration. The results show that the specific rate constants for both the hydrolyzed and nonhydrolyzed paths are decreased by a factor of two in going from light to heavy water, suggesting that the activated complex contains hydrogen and that the rate-determining step involves the motion of a hydrogen ion or atom. The large difference in rate between the two reaction paths cannot, however, be explained in terms of the participation of hydrogen in the hydrolyzed path alone, since the fractional decrease in rate is the same for both reaction paths. The changes in dielectric constant and viscosity introduced by the change of solvents are considered to be too slight to account for the observed reduction in the rate constants.

Mass Spectrometer Studies

Computations of the mass spectra of methanol, ethanol, and the propanols based on the statistical theory of mass spectra of polyatomic molecules have been completed. This model, developed by Eyring, assumes that the electron impact process produces excited molecule ions having lifetimes sufficient for the random distribution of excess energy. The relative abundances of the various ion fragments are then determined by the relative rates of various modes of unimolecular decomposition of the parent ion and subsequent decomposition of ion fragments. The calculation of a mass spectrum requires a knowledge of the frequency factors and activation energies in the rate equations and initial distribution of excess energy in the parent molecule ion. Activation energies were determined from appearance potentials and supplementary thermochemical data. Frequency factors were taken empirically with the limiting assumption that they are the same for similar processes in different molecules. Satisfactory agreement with experiment was obtained with the assumption that larger molecules received somewhat greater amounts of internal excitation.

• The assumption of complete equilibration of the excitation energy of the parent molecule ion among all degrees of freedom prior to dissociation leads the theory to predict that production of a given fragment is very small near the threshold en-

ergy for the given process. Thus, on account of the limited sensitivity of the mass spectrometer, it would be expected that mass spectrometrically observed appearance potentials would be higher than thermochemical ones. The expected magnitude of this appearance potential difference is computed to be quite large for processes in large molecules (with many degrees of freedom). Since this discrepancy does not seem to be experimentally observed, there is reason to believe that at least some decomposition takes place without complete equilibration of energy in the parent ion.

Appearance potentials have been determined for $\text{C}_2\text{H}_5\text{Cl}$, $\text{C}_2\text{H}_5\text{Br}$, and $\text{C}_2\text{H}_5\text{I}$ by conventional mass spectrometer techniques. These data have been used to calculate carbon-halogen bond dissociation energies in the ethyl halides of 3.6 ± 0.3 , 2.8 ± 0.2 , and 2.4 ± 0.2 ev for the respective C-Cl, C-Br, and C-I bonds.

Organic Reaction Mechanisms and Biosynthesis

A continuing study of the biosynthesis of nicotine in tobacco plants, in collaboration with the Botany Department of Columbia University, has been under way for some time. In a search for precursors of various parts of the nicotine molecule, both ϵ - N^{15} -labeled lysine and uniformly C^{14} -labeled lysine were supplied to sterile cultures of tobacco roots, and the roots were allowed to grow for several weeks before the nicotine was harvested. No incorporation of isotope was found in either case; this indicates that a suggestion by previous workers that lysine might be a precursor of parts of the nicotine molecule was incorrect. A similar feeding of 4a, 7a, 7- C^{14} -tryptophan also failed to yield isotopically labeled nicotine, which indicated that the common biological pathway leading from anthranilic acid to nicotinic acid was not involved in the biosynthesis of nicotine.

To test the possibility that nicotinic acid might still be a precursor of nicotine in tobacco plants, the acid with ring tritium labeling was prepared by neutron irradiation of a mixture of the acid with lithium carbonate. C^{14} -labeled nicotinic acid, prepared by neutron irradiation of nicotinamide, was also available, and both of these compounds were fed to the root cultures. A quite significant amount of radioactivity was found in the resulting nicotine in both cases. A sample of the tritium-labeled nicotine was oxidized to nicotinic acid by aqueous potassium permanganate, and the acid was found to contain 98% of the activity present in the nicotine. These results indicate that nicotinic acid is indeed a precursor of the pyridine ring of nicotine in tobacco plants, but that it is prob-

ably formed by a pathway other than the usual one leading to nicotinic acid from anthranilic acid in many biological systems.

In a study of the isotope effect in the decarboxylation of various organic compounds, sodium trichloroacetate was found to decarboxylate 23% more slowly in deuterium oxide than in water. This supports the postulation of stabilization by electromeric anionoid hyperconjugation (no-bond resonance with a negatively charged atom) during the reaction. Similar results had been obtained previously in the decarboxylation of the trinitrobenzoate anion. A study of the reaction in water and ethanol gave results which are energetically consistent with this postulate.

Another instance of the probable importance of anionoid hyperconjugation is provided by an investigation of the acidity of the various haloforms. An infrared study has been made of the change in carbon-hydrogen stretching frequencies in the association of these compounds with triethylamine. Bromoform and iodoform were found to be about equal in this respect, and both showed greater acidity than chloroform. This result is to be expected if anionoid hyperconjugation, rather than inductive effects, is important in this association.

Activation Studies of Mediterranean Potsherds

A series of Roman, Greek, and Near Eastern pottery fragments of the chronologic period second century B.C. to second century A.D. has been subjected to neutron activation analysis. The fragments, which were supplied by archeologists associated with the Institute for Advanced Study, had been thoroughly examined archeologically and identified as to their origins. The object of the analysis was to determine whether trace impurity constituents of the fragments would be characteristic of the clay of which they were made and hence would provide an indication of the region in which the piece was fabricated. Such information is of archeological interest in tracing ancient commerce and interactions of culture.

It has been found that following a short irradiation in the reactor the induced activity is dominated by that arising from sodium-24 and manganese-56. The ratio of these activities is constant within approximately 20% for fragments originating in the same region and differs by as much as a factor of four for fragments from different regions. This initially encouraging result is being further studied and extended.

Tracer Studies in Coprecipitation

The technique of precipitation from homogeneous solution has been utilized in a tracer study

of coprecipitation in binary systems of rare earth oxalates. The systems neodymium-cerium, ytterbium-cerium, neodymium-ytterbium, and yttrium-cerium have been studied in an attempt to correlate the extent of coprecipitation with the solubility products of the two rare earths oxalates involved. These rare earths were chosen because the solubility products of their oxalates have been measured. In the Nd-Ce and Nd-Yb systems, gamma-emitting tracers of both components were prepared by neutron irradiation, and the analysis of precipitates and solutions was carried out by counting gamma-rays of characteristic energy with a single-channel pulse height analyzer. A spectrophotometric method for Ce was employed for the Yb-Ce and Y-Ce systems and for part of the analysis in the Nd-Ce case.

It has been found that the Deorner-Hoskins distribution law is followed in all these systems. In three of the four systems studied the less soluble rare earth oxalate was concentrated in the solid phase; however, there is no quantitative correlation between the distribution coefficient, λ , and the solubility products of the two rare earths. On the basis of these studies it has been concluded that the distribution coefficient, λ , is determined by the kinetics of the precipitation and that the rate-determining step is first-order with respect to the concentration of the rare earth in solution.

CHEMICAL EFFECTS OF RADIATION

Aqueous Solutions

Reactions induced by radiations in aqueous solution are brought about by formation in the water of the molecular decomposition products, H_2 and H_2O_2 , and the free radicals, H and OH , which react with whatever solutes are found in the water. The aim of studies in this field is to obtain a consistent description of all observed reactions in terms of their initiation by these common sources of activation, the yields of which (in terms of number of molecules or radicals produced per unit energy input) should be the same in all dilute aqueous solutions for a given radiation. Great progress has been made in recent years in unraveling the reaction mechanisms for a number of different solutions in dilute sulfuric acid (0.4 *M* and lower) so that yields of the radicals and molecules in these solutions can be found. It has been observed that in solutions of oxidizing agents the yield of molecular hydrogen falls with increasing concentration of the oxidizing solute; this is taken to mean that the hydrogen molecules arise from H atoms which are formed close together and may react with one another to form

hydrogen before they diffuse into the solution and react with solutes. Similar effects are found in the yield of H_2O_2 , which results from primary combination of OH radicals; the yield can be lowered by addition of reducing agents to the water.

In accordance with this picture the yield of the molecules produced generally increases and the yield of radical reactions decreases as the quality of radiation is varied in the direction of greater track density or "linear energy transfer" (i.e., greater release of energy per unit distance along the track of the fast particle which is actually transferring energy to the irradiated medium for the case of the radiation in question, with correspondingly higher initial concentration of radicals along the track). During the past year studies have continued with radiations covering the whole range of available track densities in order to establish the molecular and radical yields in sulfuric acid solution. Solutions were chosen for study on the basis of our understanding of the reaction mechanisms, so that the observed amounts of reaction could be interpreted in terms of the yields of formation of the radical and molecular products from the water. Reactions studied include the oxidation of ferrous sulfate in aerated solution, the yield of which is given by $2G_{\text{H}_2\text{O}_2} + G_{\text{OH}} + 3G_{\text{H}}$ (where G with a subscript means the number of the given radical or molecule produced from water per 100 ev of energy deposited by the radiations); the oxidation of ferrous sulfate in oxygen-free solution, with yield equal to $2G_{\text{H}_2\text{O}_2} + G_{\text{OH}} + G_{\text{H}}$; and the reduction of ceric sulfate, the yield given by $2G_{\text{H}_2\text{O}_2} + G_{\text{H}} - G_{\text{OH}}$. The yields of the four products, H, OH, H_2 , and H_2O_2 , are connected by an equation of material balance so that three observations are sufficient to deter-

mine the whole system. In addition, a small decrease in G_{H_2} with a corresponding increase in G_{H} caused by the presence of oxygen in the solution was determined by comparison of the ceric product yields in the absence and presence of air. Thus from the three determinations for a particular kind of radiation, values of the primary yields G_{OH} , G_{H} , and $G_{\text{H}_2\text{O}_2}$ were found, with G_{H_2} then being determined by material balance; and in many cases this was compared with an actual determination of the hydrogen gas evolved from the solution. The determinations were made with gamma-rays and with 2-Mev electrons from the electrostatic generator; with beams of deuterons and of helium ions from the 60-in. cyclotron, having energies ranging from 20 or 40 Mev, respectively, downwards to about a third of these maximum values (the determinations at lower energies become very inaccurate); and with recoil particles from the n, α reactions produced by neutrons in the thermal column of the reactor with lithium or boron atoms which were dissolved in the form of lithium sulfate or boric acid in the solutions being studied.

A selection of the data obtained is shown in Table 4. It is seen that agreement of calculated and observed hydrogen yields is satisfactory (considering that the calculated value is obtained by the difference of larger numbers), which indicates that the assumed reaction mechanisms are correct, or at least consistent. The variation of the various yields with the track density of the radiation accords qualitatively with expectations.

Studies continue with gamma-rays or x-rays to refine the details of the reaction mechanisms for ferrous ion oxidation and to determine how the mechanisms and the gamma-ray water de-

Table 4
Primary Yields in the Action of Various Radiations on Aqueous
0.4 M Sulfuric Acid Solutions

Radiation	$-dE/dX$ (ev/Å)	G_{H}	$(G_{\text{H}})_{\text{O}_2}$	G_{OH}	$G_{\text{H}_2\text{O}_2}$	$G_{-\text{H}_2\text{O}}$	G_{H_2}	$(G_{\text{H}_2})_{\text{O}_2}$ calc.	$(G_{\text{H}_2})_{\text{O}_2}$ exp.
Co^{60} γ or 2-Mev e^-	0.02	3.65	3.65	2.95	0.80	4.55	0.45	0.45	0.35*
D^+ , 18 Mev	0.52	2.39	2.53	1.75	1.03	3.81	0.71	0.64	0.81, 0.88
D^+ , 8 Mev	1.0	1.71	1.91	1.45	1.17	3.80	1.05	0.95	—
He^{++} , 32 Mev	2.25	1.28	1.48	1.06	1.25	3.56	1.14	1.05	1.09, 1.07
$\text{B}(n, \alpha)$ $E_\alpha = 1.5$ Mev $E_{\text{Li}} = 0.85$ Mev	~25.	0.23	0.23	0.41	1.57	3.54	1.66	1.66	—

*Determined at Oak Ridge.

Table 5
Initial Yields and Rate-constant Ratios from Ferrous Sulfate Oxidation by Gamma-rays

<i>pH</i>	2.72	2.15	2.02	1.57	0.4(0.4 M H ₂ SO ₄)
$\frac{k_{H,Fe^{+3}}}{k_{H,O_2}}$	0.10	—	0.007	—	—
$\frac{k_{HO_2,Fe^{+3}}}{k_{HO_2,Fe^{+2}}}$	0.30	—	0.10	—	<0.005
$\frac{k_{H,Fe^{+3}}}{k_{H,H^+,Fe^{+2}}}$	—	7.2	~4*	1.35	<0.1
$\frac{k_{OH,Fe^{+2}}}{k_{OH,H_2}}$	—	5.7	—	6.7	—
$\frac{k_{H_2O_2}}{k_{H,H^+,Fe^{+2}}}$	—	—	~600**	—	1200
<i>G</i> _{air}	13.2	—	14.2	—	15.5
<i>G</i> _{air-free}	—	7.5	—	7.8	8.2
<i>G</i> _{H†}	3.08	3.30	3.34	3.45	3.64

* Interpolated.

** Calculated from the values above.

† Calculated yield of H atoms from water.

composition yields vary with acid concentration. The kinetics of such reactions are determined by the competition of different solutes present for reaction with any given kind of radical formed, and studies of variations of the rate of reaction with concentration lead to a determination of the ratio between the specific rate constants for various reactions. Thus in the oxidation of ferrous sulfate, H atoms can react with O₂ to form HO₂ radicals, which can oxidize three molecules of ferrous iron; or the H atom may itself oxidize one mole of ferrous iron directly, in conjunction with a hydrogen ion, to yield a ferric ion and a molecule of H₂. The ratio of the specific rate constants for these two reactions has been studied by determining the yields for oxidation of ferrous sulfate in solutions of various concentrations, in which the O₂ was maintained at low levels by bubbling nitrogen containing small proportions of oxygen through the solution. It was found that $k_{H,O_2}/k_{H,H^+,Fe^{+2}} = 1200$ in 0.8 M H₂SO₄. At lower acidities in the

ferrous sulfate system other competitions become important, including reactions of H and HO₂ with ferric ions to regenerate ferrous ions and thereby reduce the yield, so that the reaction rate decreases as reaction proceeds. It was, in particular, recently found that at a *pH* of 2 or over a direct reduction of ferric ions by H atoms can occur in competition with the reaction of H atoms with oxygen, a fact that had not been previously recognized since the back reaction had been attributed entirely to the reduction of ferric ions by the radical HO₂. The results of a long study of the ferrous sulfate system at different acidities, carried out in both aerated and air-free solutions, are shown in Table 5. A marked variation with acidity shown by some of the rate constant ratios is probably to be explained on the basis of the change with *pH* of the ionic form of the ferric iron. Thus in 0.4 M acid the ferric iron is present mostly as the sulfate complex, while at *pH* 2 a considerable fraction of it is present as a hydroxide complex, which seems to be more

active towards reduction with either H or HO_2 . Particularly interesting is the fact that the ratio of rates of reaction of H with O_2 and with Fe^{++} varies by only about a factor of 2 as the pH is changed from 2.0 to 0.4, a factor of about 40 in the hydrogen ion concentration, although the hydrogen ion certainly must participate in the oxidation of Fe^{++} by H and not in the reduction of O_2 by H. This result appears to favor the idea that the H atom, even at acid concentrations as low as 0.01 M, is almost completely complexed by H^+ to form the oxidizing ion H_2^+ , as originally proposed by Joseph Weiss.

Table 5 also shows that the yield of decomposition of water increases in a regular way with increasing acidity, which leads to an increase in the initial yield of oxidation of ferrous sulfate both in aerated and deaerated solution. Studies of ferrous chloride oxidation in hydrochloric acid solutions have shown that almost the same yield is obtained in 0.4 M HCl solutions as in 0.4 M H_2SO_4 , which shows that the increase in net water decomposition is not a specific effect of sulfuric acid but seems to be due to the presence of hydrogen ions themselves. The rate of oxidation of iron in the hydrochloric acid solutions was found to be strongly inhibited by the ferric iron formed in the reaction, unlike the rate in sulfuric acid solution at high acidity. The effect of ferric iron was ascribed to its reduction by H atoms in competition with their reaction with O_2 . It was found that chloride ions favored the reaction of H with ferric salt in a manner which could be quantitatively explained by ascribing to the complexes FeCl^{++} and FeCl_2^+ specific rate constants for reaction with H atoms relative to the uncomplexed ferric ion and to reaction of H atoms with O_2 . The results may be summarized by the rate constant ratios $k_{\text{Fe}^{++}}/k_{\text{O}_2}=0.004$, $k_{\text{FeCl}^{++}}/k_{\text{O}_2}=0.23$, and $k_{\text{FeCl}_2^+}/k_{\text{O}_2}=0.48$.

Organic Compounds

Study of reaction mechanisms in organic radiation chemistry has continued by the use of solutions of iodine in hydrocarbon solvents. Gamma radiation of iodine in cyclohexane and in *iso*-octane showed that the rate of iodine uptake was independent of concentration in the range 10^{-5} M to 10^{-2} M, which indicates that the reaction was due to free radicals of long life. An increase at higher concentrations of I_2 indicates the participation of another mechanism. That the free radicals do not include any free H atoms, at least in the case of cyclohexane, is shown by the fact that the amount of iodine disappearing is equal to the amount

taken up into firm organic combination. The yield of iodine disappearance decreases when oxygen is present in a way which indicates simple competition between O_2 and I_2 for reaction with the radicals.

Solutions of iodine in benzene give much more complex results, with some of the iodine going into unstable compounds which are readily hydrolyzed, and another portion of it forming an extremely deeply colored compound of unknown character. The rate of iodine uptake into benzene on irradiation varies exponentially with increasing dose rather than remaining constant as in the case of aliphatic hydrocarbons. In spite of all these complications the amounts of H_2 and of acetylene formed in the irradiation of benzene are changed very little by the presence of iodine.

The products formed when solutions of iodine in butane are irradiated have been the subject of detailed study. Radioactive iodine was used; after irradiation the solution was added to a mixture of carrier alkyl iodides which was then separated by distillation. Although the kinetics of iodine uptake appears simple, the products certainly are not, since methyl, ethyl, propyl, isopropyl, *n*-butyl, and *sec*-butyl iodide are all found. It is particularly striking that the quantity of propyl iodide is many times smaller than the quantity of methyl iodide, which shows that the butane molecule does not undergo a simple split to propyl and methyl radicals. Work on this reaction is continuing.

Gas Phase Reactions

Until recently, direct chemical reactions of ions have been assigned a rather subordinate role in radiation chemistry. However, it has now been demonstrated that in the radiation-induced exchange of H_2 and D_2 , ions play an important if not the dominant role in both the initiation and the chain mechanism.

If mixtures of H_2 , D_2 , and a rare gas are exposed to 2-Mev Van de Graaff electrons or alpha-rays, HD is formed in a reproducible way. Addition of moderate amounts of helium, neon, or argon, all with ionization potentials larger than H_2 , has little effect on the amount of HD formed. On the other hand, addition of krypton or xenon, which have ionization potentials less than hydrogen, greatly reduces the amount of HD formed; in fact, as little as 0.1% xenon reduces the HD formation by more than an order of magnitude. None of the rare gases affect either the mercury-photosensitized exchange or the spontaneous exchange at high temperature, both reactions involving chains carried by free H atoms:

These facts can be best understood on the basis that the radiation-induced reaction proceeds by an ion mechanism, the chain-carrying step probably being a reaction such as:

The inhibiting effect of the xenon and the krypton is then explained by charge transfer reactions such as:

The ion reaction (i) must be much more rapid than the atom reaction (a). Such a conclusion agrees with theoretical expectations, and with recent mass spectrographic experiments reported in the literature.

CHEMICAL EFFECTS OF NUCLEAR TRANSFORMATIONS

Atoms which have large recoil energies by virtue of having undergone nuclear transformations are capable of many interesting and often useful chemical reactions. Several organic and inorganic systems have been studied, and the use of recoil carbon-14 and tritium in producing labeled organic compounds has been extended.

Carbon-14 Recoil Synthesis

It has become increasingly evident that the inordinate difficulty in bringing labeled com-

pounds to radiochemical purity might possibly have been due to synthesis products which were difficult to remove because of their trace presence in the irradiated compound. By "synthesis product" is meant any product formed which has one carbon more than the parent compound, exclusive of the carbon analog of the parent compound. In most cases it would be reasonable to expect their chemical behavior to be similar to that of the parent compound. Trace degradation products may also have been important.

In order to study the specific nature of the synthesis reactions, irradiations of benzene in 2-methylpyrazine, and of acetamide have been carried out in the Brookhaven reactor. The presence of two possible synthesis products, toluene and propionamide, was then investigated by carrier methods. In the irradiation of acetamide, both propionamide and propionic acid were added as carriers on the assumption that the synthesized, excited three-carbon fragment might in some cases collapse to give the latter product. The hydrolysis was carried out in both acid and base to investigate possible differences in the state of the irradiated material. Degradations were also carried out, and the results are given in Tables 6 and 7.

While it is clear from these results that synthesis does take place, it is also evident that the reactions to give toluene or propionamide involve processes other than a simple displacement of a "hot" methyl radical. The activity in the methylene, carboxyl, and ring carbons of the carrier materials studied

Table 6

Acetamide

Compound	Basic Hydrolysis						Acidic Hydrolysis			
	$\text{CH}_3\text{---COOH}$		$\text{CH}_3\text{---CH}_2\text{---COOH}$			$\text{CH}_3\text{---COOH}$		$\text{CH}_3\text{---CH}_2\text{---COOH}$		
1. Specific activity m μ C/mg C	0.539	0.840	3.30	1.44	1.49	0.886	1.520	1.496	0.759	0.573
2. Percent of summed activity by position	39.1	60.9	52.9	23.1	23.9	36.9	63.1	52.9	26.8	21.0
3. Specific activity neat material	0.715		2.18		1.24		1.01			
4. Activity accounted for by degradation	95.8%		95.4%		96.8%		93.5%			
5. Activity relative to total activity in irradiated sample	6.44%		6.69%		8.12%		5.00%			

Table 7
Benzene + 2-Methylpyrazine

Compound
1. Specific activity mμC/mg C	0.024	1.01	0.068*
2. Percent of activity summed by position	13.9	86.1	
3. Specific activity neat material	0.173		
4. Activity relative to total activity in irradiated sample	1.05%		
	1.92%		

*This is an upper limit.

cannot be credited to an inversion reaction, although most of the activity in the methyl group may arise by this path. A possible mechanism for formation of synthesis products would involve the inelastic collision of fragments such as $\text{CH}_3\cdot$ or $\text{CH}_2\cdot$, having energies in excess of 0.5 ev but not above 10 ev, with the molecules in question. In this way, propionamide with the methylene carbon active might be formed by the insinuation of $\text{CH}_2\cdot$ between the methyl and carbonyl carbons. Unstable three-carbon intermediates leading to partial equilibration of the three positions may also be possible precursors. Malonic and succinic acids produced by hot atom and radiation chemical processes could ultimately lead to acetic acid and propionic acid. Note the higher activity yield in acetic acid for the acid hydrolysis.

Since the material is produced in a strong radiation field, the possibility cannot be ignored of radical recombinations in and around any radiation damage or recoil track leading to these products. It is hoped that experiments under way at present may distinguish between these pathways.

Heterogeneous Tritium Labeling

The "hot atom" reactions of recoil tritons with organic compounds have been found equally interesting. The tritons produced by the $\text{Li}^6(n,\alpha)\text{T}$ reaction are extremely energetic and have an appreciable range in matter. This has led to the technique of making mechanical mixtures of lithium salts with the desired organic compounds and irradiating the mixture. Such an irradiation with thermal neutrons produces tritons which move

Table 8
Tritium Distribution among C-H Positions in Hexoses

Hydrogen attached to carbon No.	Glucose		Galactose*	
	Specific activity, dis/min micromole	% Total activity in C-H positions	Specific activity, dis/min micromole	% Total activity in C-H positions
1	36 ± 4	3	180 ± 30	8
2	74 ± 10	6	120 ± 40	5
3	350 ± 15	29	500 ± 30	22
4	170 ± 20	14	750 ± 50	32
5	2 ± 15	0	250 ± 10	11
6	290 ± 10	24	260 ± 10	11
6	290 ± 10	24	260 ± 10	11

*This sample diluted 20-fold with inactive galactose to facilitate chemistry and counting.

from their point of origin in the lithium salt to some final destination in the organic compound, frequently replacing a proton in the latter substance. This heterogeneous recoil labeling has been studied in two types of organic compounds: the sugars, glucose and galactose, and the simple hydrocarbons, methane and ethane.

In the sugars it was found that approximately 12% of the recoil tritons which stopped in the organic phase ended in nonlabile C-H positions in the otherwise unchanged hexose molecules. The specific activity of tritium located in each of the seven nonlabile C-H positions of the sugar molecules could be determined by preparation of suitable degradation products and the assay of these products for tritium activity. It was found in both sugars that the labeling was surprisingly non-uniform: the distributions of activity are shown in Table 8. The very nonuniform nature of the labeling can perhaps be explained by a consideration of steric effects in the reaction of hexose radicals with tritium atoms. The crystal structures of the sugars are probably also of importance in determining the distribution.

In the studies of methane and ethane, the irradiated material was fractionally distilled after the addition of carrier alkanes. Tritium activity was observed in the hydrogen, methane, ethane, ethylene, C_3 , C_4 , and even higher hydrocarbons. The preponderant activities were found in the parent substance in either case, and in hydrogen.

A practical consequence of these experiments is the demonstration that tritium-labeled sugars and hydrocarbons can easily be obtained in radiochemically pure form and high specific activity: such compounds will almost certainly be useful in biological and chemical tracer studies.

Alkyl Halides

The "hot atom" reactions of recoiling halogen atoms have also been extensively studied in the systems ethyl, *n*-propyl, isopropyl, *n*-butyl, and *sec*-butyl iodides, and in normal and isopropyl bromides. Both the liquid and solid phases were investigated, and in the case of the alkyl iodides the irradiated material was subjected to fractional distillation after the addition of iodide carrier. The radioactive iodine was produced by fast neutrons from the Brookhaven cyclotron through the reaction $I^{127}(n,2n)I^{126}$ and the relatively long life of the isotope I^{126} (13 days) permitted fractionation experiments which were impossible in the case of the I^{128} formed by thermal capture ($t_{1/2} = 25$ min). Despite the fact that the recoil energies of the I^{126}

and I^{128} atoms are 100,000 ev and 100 ev respectively, no essential difference was observed in the chemical fate of the activated species. In the case of the bromides, the effect of recoil energy was studied with the isotopes Br^{78} (from $Br^{79}(n,2n)$ reactions), Br^{80} , and Br^{82} (from thermal and fast neutron capture). Here, again, the effect of change of phase and of recoil energy on the over-all probability of organic combination ("retention") was studied. It was found that the solid phases gave, in general, higher retentions than the liquids for all bromine isotopes, that Br^{80} and Br^{82} gave similar results, but that Br^{78} gave significantly higher retentions.

Metal Atom Recoil Studies

In addition to the above investigations, two more crystalline systems were examined: these were ferrocene (*bis*-cyclopentadienyl iron (II)), and potassium cobalticyanide. In each of these the central metal atom of the complex recoils away upon capture of a thermal neutron and emission of gamma-rays, and the subsequent chemical fate of these atoms was traced through their radioactivity. In the case of ferrocene the retention (probability of finding the radioactive iron in a ferrocene molecule) was 12% while in potassium cobalticyanide the retention was 19%. Both of these crystalline compounds exhibited characteristic annealing behavior; that is, their retentions increased on being heated subsequent to irradiation. In ferrocene the extent of annealing appeared to depend on the fast neutron dose the samples had received.

The investigation of the hot atom chemistry of recoil atoms in potassium cobalticyanide included attempts to identify the cobalt-containing fragments present in the crystal through application of the technique of paper electrophoresis. Dissolution of the irradiated cobalticyanide in water produced at least four separable species, two of which could be immediately identified as cobalticyanide and cobaltous ion. The others were thought to be complex anions of cobalt containing cyanide and water in the sixfold coordination sphere.

MOLECULAR STRUCTURE AND SOLID STATE

Spectroscopy of Rare Earth Compounds

An analysis of the absorption and fluorescence spectra of a strong electrolyte ($EuCl_3$) in solutions had indicated that the point group symmetry of the electrical fields about the positive ion was D_{2h} in water and C_{2v} in methanol and in ethanol.

Further study, including an investigation of the temperature dependence of the fluorescence spectra, confirmed these particular symmetries. Consistent with them and with known configurational characteristics of the solvents, several models of the solvated ions were constructed but no unique ones could be established.

There has been a disagreement in the literature on the assignment of J values to an important optical transition of europium ion which has been characterized as $0 \rightarrow 2$ by some workers and as $0 \rightarrow 3$ by others. It was found possible to resolve the difficulty by confirming the $0 \rightarrow 2$ assignment by means of studies of spectra of several salts of europium. Moreover, recently revised x-ray crystal structure determination has shown that the $0 \rightarrow 3$ assignment was erroneous.

Photochemical and Solvation Effects in Chlorophyll

Recent advances in the field of plant photosynthesis have been mainly concerned with elucidating various dark reactions which follow the initial absorption of light by the leaf pigments. The nature of the primary light-induced reactions is still obscure, however, and work has been carried out to help clarify this aspect of the problem.

Complex and rapid photochemical effects in chlorophyll solutions are being studied with the aid of flash-photolysis apparatus having very high time resolution ($\sim 3 \mu\text{sec}$). This equipment, developed and built here during the past year, allows one to follow the time course of changes in the absorption spectrum of test solutions after excitation by a very short, intense light flash. By this means the absorption spectrum of a metastable form of chlorophyll has been quantitatively established and the kinetics of its conversion back to unexcited chlorophyll has been analyzed. This metastable state, which is believed to store energy

in vivo, has been shown to decay by a unimolecular thermal conversion to the ground state, and by bimolecular quenching reactions either with unexcited chlorophyll or with other metastable molecules. Although the half-life of the metastable state at room temperature is only about 10^{-4} sec, the kinetic rate constants for all three decay processes have been evaluated. The question of the nature of the metastable state is of the greatest interest. Experiments are now under way testing various possibilities (such as triplet, tautomeric form of chlorophyll, redox product, etc.). The time resolution of the apparatus is good enough to permit direct kinetic measurements on the reactions between excited chlorophyll and added substrates, and such work is planned.

Low-temperature absorption spectroscopy is also being used to study unstable products formed in photochemical reactions of chlorophyll, the high energy intermediates being stabilized by trapping in glassy solvents. Reversible reactions between chlorophyll and such substrates as quinone, phenylhydrazine, and oxygen have been studied by this means. The quinone reaction, which is energy-storing, has been shown to involve the cyclopentanone side ring of chlorophyll, and to require the presence of magnesium, while the presumed photoreduction by phenylhydrazine probably occurs in the main porphyrin ring and is independent of any complexed metal. In solvents containing pyridine, and at low temperatures, chlorophyll reacts photochemically with oxygen to give an intermediate with a new type of absorption spectrum corresponding neither to chlorin, porphyrin, nor any of the semiquinone spectra hitherto identified.

The absorption spectra of chlorophyll have also been studied in solutions, fluid at low temperatures, and in the absence of photochemical processes. It has been surmised that the chief differences in the well-known spectra of a given chlorophyll in different solvents at room temperature had their origin in the presence of solvates whose relative proportions varied with the solvent. This surmise has proved to be correct. It was possible to match the different spectra at will by altering the proportion of the solvates present in two ways: by changing the concentration of the polar solvent with hydrocarbons and by changing the temperature.

Neutron Diffraction and Magnetism

Several neutron diffraction investigations have been completed during the past year. These include a study of manganese ferrite, lead nitrate,

Figure 4. Neutron diffraction spectrometer for single crystal studies.

and the three polymorphic forms of manganous sulfide. In addition, a new spectrometer designed specifically for single crystal investigations has been put into operation (Figure 4).

The novel design features of the new spectrometer are the adaptation of a commercial x-ray spectrogoniometer and provision for a continuous wavelength change. The use of a commercial unit was made possible by the design of a small high-pressure BF_3 counter which requires a relatively small shield and can thus be substituted for the usual x-ray detector.

As part of a program of investigation of the magnetic structure of the simple ferrites, a study of three different preparations of MnFe_2O_4 was undertaken. The observed magnetic scattering was found to be consistent with the Néel model of ferrimagnetism and with the measured saturation moment. It was not possible, from the data, to explain the small, but real, deviation of the measured saturation magnetization from the ideal value. It was also found that MnFe_2O_4 has more nearly a normal spinel structure than an inverted one, which is somewhat surprising. In the preparations examined, 80% of the tetrahedral crystallographic sites were occupied by manganese ions.

There is evidence that, in high temperature forms of certain metallic nitrates, the nitrate group undergoes almost free rotation about an axis perpendicular to the plane of the group. The transition to free rotation, which occurs in the range 150° to 275°C , is often accompanied by a phase change. No such phase change has been reported for $\text{Pb}(\text{NO}_3)_2$ and the nitrates isomorphous with it. However, a gradual transition to free rotation without phase change has been postulated by Vegard and Roer, who examined the structure at room temperature as well as the lattice constants at higher temperatures.

The temperature dependence of the neutron diffraction pattern of powdered $\text{Pb}(\text{NO}_3)_2$ has been examined in the range 18° to 325°C . There is apparently no transition to free or almost free rotation of the nitrate group in this temperature range. The parameters of Vegard and Roer have been revised, and it is concluded that the potential barrier for hindered rotation is greater than $V_0/kT=10$ if a cosine potential is assumed. Some changes do take place in the intensities of the strongest reflections even on slight heating above room temperature. These changes are either irreversible or slow in recovery on cooling again to room temperature; they cannot be explained comfortably in terms of uniform parameter

changes or rotation. It is possible to explain these effects, at least in part, by postulating long-range disorder in the crystal.

The study on manganese sulfide was directed toward an experimental verification of some of the implications of indirect exchange mechanisms for antiferromagnetic structures. Manganous sulfide exists in three polymorphic forms. There are two cubic modifications, α - MnS having the rock salt structure and β - MnS with the zinc blende structure. The third form is hexagonal β - MnS with the wurtzite structure. The magnetic susceptibilities of all three forms, in well characterized preparations, have been measured and the antiferromagnetic structures determined by neutron diffraction. α - MnS is found to exhibit ordering of the second kind, in agreement with earlier work. The spin direction, however, lies in the ferromagnetic (111) sheets rather than along cube edges. In the cubic β - MnS case, the magnetic structure is the hitherto unobserved "improved ordering of the first kind" proposed by Anderson. The spin direction is normal to the unique cubic axis. The hexagonal β - MnS antiferromagnetic structure can be derived from the cubic β - MnS by stacking the close-packed (111) sheets of the zinc blende form according to the scheme ABA--- appropriate to hexagonal close-packing. The magnetic unit cell is orthohexagonal with $a'_0 = a_0\sqrt{3}$, $b'_0 = 2a_0$, $c'_0 = c_0$, where the unprimed symbols refer to the original hexagonal cell. The spin direction is normal to the (011) plane.

These antiferromagnetic structures are well correlated with an indirect exchange mechanism. α - MnS has a next-nearest neighbor interaction which can be accounted for by such a coupling mechanism since the next-nearest neighbors and the intermediate anion lie along a straight line, which is the most favorable orientation. In cubic β - MnS the magnetic ions occupy exactly the same positions as in α - MnS , but the S^{2-} ions have been shifted to the tetrahedral sites. In this structure the intermediate anion now connects nearest neighbors through the tetrahedral angle. Hence, if the indirect exchange mechanism is operative, a nearest neighbor correlation would be expected. Ordering of the third kind, the structure of β - MnS , does indeed correspond to a nearest neighbor interaction. The hexagonal β - MnS involves a change in the magnetic ion lattice, but retains the same local spatial relations between the Mn^{2+} and S^{2-} ions, so that an indirect exchange mechanism would predict the same correlation as is found for cubic β - MnS ; which is indeed the case.

SPECIAL TOPICS IN THEORETICAL CHEMISTRY

Bond Moments

It has been found convenient in the interpretation and prediction of dipole moments of polyatomic molecules to subdivide the total dipole moment into bond moments, isolated moments associated with each pair of bonded atoms in the molecule, the vector sum of these bond moments being the observed dipole moment. This treatment has had a certain amount of empirical success; i.e., sets of bond moments have been found which fit the observed dipole moments of large groups of molecules in which the bonds may be assumed to be similar. Recently interest has grown in the determination of bond moments from infrared intensity data, the quantity derived directly from experiment being the derivative of dipole moment with respect to one of the normal coordinates of the molecule. From this information bond moments may in many cases be derived, albeit not unambiguously.

It is of interest to examine the possibility of obtaining theoretical bond moments from molecular orbital wave functions for complex (containing at least three atoms) molecules. It is obvious that there is no unique procedure for doing this. However, it is possible to transform the molecular orbitals for a molecule into equivalent orbitals which are more or less localized in the bonds of the molecule, i.e., the coefficients of the atomic orbitals making up the equivalent orbitals will be large only for a pair of neighboring atoms. It would seem that the moments associated with these orbitals should provide the closest theoretical approximation to the isolated bond moments discussed above. In applications of the method to CO_2 and H_2O , two additional criteria have been imposed for the determination of the equivalent orbitals and, hence, the bond moments. These conditions are that the direction of the total bond moment shall coincide with the bond axis and that the electronic contribution to the bond moment shall be a maximum.

The results of the calculation indicate that theoretical bond moments defined in this way do agree well with bond moments assigned from dipole moment measurements, provided that atomic hybridization moments are omitted from the total bond moment. A moment of 2.60 D is calculated for the $\text{C}=\text{O}$ moment in CO_2 . The treatment of water indicates that it is impossible to define separate bond and line pair moments which exhibit

any degree of constancy over a range of angles. These are therefore combined into a total bond moment which has the values 1.06, 1.24, 1.32, and 1.37 at bond angles of 90° , 105° , 120° , and 180° .

The same calculation applied to the C-H bond in methane leads to a moment of 0.6 D ($\text{C}^+ \text{H}^-$). Similarly, the H-B-H bridge moment in diborane is 2.03 D ($\text{B}_2^+ \text{H}^-$) in a line perpendicular to the B-B bond.

Strong Electrolytes

The Debye-Hückel theory of strong electrolytes successfully describes the dependence of activity coefficients on concentration only at very low concentrations. Failure of the theory at higher concentrations can, from one point of view, be ascribed to the hydration of ions. Stokes and Robinson have effected considerable improvement in fitting experimental data by applying the Debye-Hückel theory to the hydrated ion rather than to the bare ion. Their approach to the problem regards the solvent which is incorporated in the sphere of hydration as unavailable to serve as "free" solvent. This is equivalent to expressing the free energy of the entire solution as

$$F = (n_1 - n_2 h) \bar{F}_1 + n_2 \bar{F}_2'$$

where h is the hydration number, n_1 and n_2 are the number of moles of solvent and solute, respectively, and $\bar{F}_1$ and $\bar{F}_2'$ refer to the molar free energies of solvent and hydrated solute.

The method of handling the hydration problem which has been adopted in the present study retains the simple form for the total free energy of the system, i.e.,

$$F = n_1 \bar{F}_1 + n_2 \bar{F}_2,$$

but employs an "effective" concentration in computing the molar free energy, $\bar{F}_2$, of the solute. This procedure results in an equation relating the activity coefficient to the concentration which from a computational point of view is far more convenient to use than that of Stokes and Robinson. With the hydration number and ion size as adjustable parameters it is possible to fit experimental data to as high a concentration as 6 molal for some 1-1 electrolytes.

Thermodynamics of Irreversible Processes

In the recently developed thermodynamic theory of irreversible processes, irreversible phenomena are described in terms of the rate of entropy production during the process and in terms of certain linear laws relating the flux of heat or matter

to temperature or potential gradients. It has been shown that steady states can be characterized in this theory as having a minimum of entropy production associated with them. However, the proof has been restricted to systems for which the linear coefficients are constants. Since these coefficients are related to the heat conductivity, diffusion constants, and conductances, all of which are known to be functions of temperature, pressure, and concentration, it seemed desirable to extend the proof to cover such cases. A more general proof has been carried out for systems whose coefficients are functions of temperature, pressure, and concentration, but not functions of gradients of these variables.

ENGINEERING

This section describes the research and development studies of the Nuclear Engineering and Reactor Departments. The service activities of these two departments, including reactor operations, the production and distribution of radioisotopes, neutron and gamma irradiations, waste concentration and disposal, and meteorological services, are described in a later section headed "Technical Operations and Services."

The research of the Nuclear Engineering Department has continued to be centered on the development of new reactor systems, or components of reactor systems, that will further the economic development of nuclear energy. In particular, interest in the Liquid Metal Fuel Reactor (LMFR) has grown, and it has been added to the official list of reactors now being developed by the Atomic Energy Commission.

LIQUID METAL FUEL REACTOR

Last November an Information Meeting on the LMFR was held at Brookhaven. Over 175 people attended representing 115 industrial organizations holding reactor information access permits. At this meeting, the Head of the AEC Reactor Development Division invited interested groups to submit proposals for, or statements of interest in, the design and construction of an LMFR experiment (LMFRE) in cooperation with Brookhaven. Thirteen such proposals were submitted. On the basis of the one submitted by the Babcock and Wilcox Company, negotiations are now under way for a prime AEC contract with that company, first for a study of the scope, preliminary design, and required research and development; then for the detailed engineering design and construction, and possibly the operation, of an LMFRE. Meanwhile,

the Brookhaven staff members continue their research and development and act as technical advisors to the AEC on the design and construction.

As a result of the impetus of the AEC's intention to construct an LMFRE as soon as possible, efforts of the Department on this project have expanded considerably. Both staff and operating budget have been increased. During the past year over 25 scientists and engineers from industrial organizations, including a few from other countries, have been sent to the Laboratory to gain experience in reactor design and technology by participating as guest staff members in the work on the LMFRE. Furthermore, an 11,000-square-foot works area building has been authorized, construction of which will start in the fall, to house a number of the large loops for circulating uranium-bismuth solutions. A new Engineering Building, to replace the temporary building T-197, has also been authorized, detailed design of which will start in the next fiscal year, and construction in fiscal year 1958.

Important research studies on the LMFR were described in some detail in the last Annual Report. These studies have been continued during the past year; the progress made is summarized below.

Reactor Physics

The reactor physics experimental group has been engaged in the design and planning of exponential experiments on assemblies of bismuth rods, graphite stringers, and uranium-235 foil, and the design of a low-power reactor to be used as a neutron source for these exponential experiments. The purpose of this series of experiments is to obtain the data required for establishing the optimum parameters for the core of the LMFRE. Additional critical assembly facilities in building T-525 are being provided for this work.

The theoretical group in reactor physics has refined earlier calculations for LMFR breeders by carrying out multigroup computations, using the Univac at New York University. The results obtained are consistent with the earlier ones based on two-group theory.

Theoretical studies have been made of reactors with a core of uranium dissolved in bismuth and of uranium suspended in other low-melting metals. External moderation has been assumed in these reactors, i.e. moderation takes place in the reflector. Atomic concentrations of uranium from 0.05 to 10% have been investigated; graphite has been assumed for the reflector. Results indicate that small high-flux reactors are feasible and

should be especially useful as research reactors that will provide neutrons at intermediate energies.

The kinetics of liquid metal fuel reactors have been studied by means of Univac calculations on the open-loop kinetics of a circulating fuel reactor. These computations are now being extended to the Brookhaven preliminary design of the LMFR. The systems studied consist of a primary U-Bi loop and a secondary closed-circuit air loop. The reactor is assumed to have a negative prompt (fuel) temperature coefficient and a negative delayed (moderator) temperature coefficient. The main purpose of this study is to determine the stability limitations of the system, although an attempt is being made to obtain its actual kinetic behavior by approximate methods.

Estimates of the control rod effectiveness in the Brookhaven preliminary design of the LMFR have also been made as a function of the number, size, and location of the rods. Calculations have been made for both black and grey rods. The results will be useful in establishing the design of the LMFR.

Fuel Processing

One of the unique aspects of the LMFR is the possibility of continuous removal of fission products to maintain low concentration levels in the fuel. As a thermal breeder, the LMFR must operate with low fission-product concentrations in order to achieve high neutron economy. The work of the past year has reinforced the belief that the volatile fission products can be removed from LMFR fuel by a physical degassing process and that a large and important fraction of the non-volatile fission products can be extracted into a fused salt. Measurable progress has also been made in scaling up some of the processes from the laboratory toward the plant stage. This has resulted from experimental and theoretical work on the following topics: equilibria existing in metal-gas and metal-salt systems in gram-scale and pound-scale static experiments; the same in continuously flowing systems, or loops; the thermodynamics of alloy systems and salt mixtures; and methods of determining and controlling the composition of liquid salt and metal process streams.

In the small-scale work, the goal has been the determination of reproducible values of distribution coefficients and separation factors for individual fission products in salt-metal systems. These are defined as follows:

Distribution coefficient $K_i = \text{conc. of } i \text{ in salt} / \text{conc. of } i \text{ in metal}$
 Separation factor $SF_i = K_i / K_U$

where i and U represent a particular fission product and uranium, respectively. A high separation factor being desired, the several K_i values should be high and that for K_U low. In order to optimize the separation, the relation between the K 's and the system variables had to be investigated. One of the most important variables is the concentration in the metal phase of magnesium (a certain amount of which must be added to the fuel as a corrosion inhibitor) because the reactions responsible for the extraction of fission products are of the form

cerium being a representative fission product. Since the MgCl_2 is present in great excess, the mass action law predicts that the following relation should hold:

$$K_{\text{Ce}} = (\text{a constant})(\text{Mg conc.})^{-3/2}.$$

This relation has been verified in a series of experiments in which bismuth containing cerium and variable amounts of magnesium was contacted with the fused ternary eutectic NaCl-KCl-MgCl_2 . The constant was found to have a value of about 10,000 when the magnesium concentration is expressed in parts per million; thus if Mg concentration is 100 ppm, $K_{\text{Ce}} = 10$. This is a satisfactorily large value, and figures of the same order of magnitude have been found for several other rare earth fission products including samarium, the worst of the nonvolatile poisons. Results on uranium distribution have been less precise because of a greater tendency for this element to enter into side reactions. It appears fairly certain, however, that under conditions where K_{Ce} , for example, is 10, the value of K_U will be 0.1 or less, giving a separation factor of at least 100.

In order to confirm these results on a larger scale, under conditions closer to those that will prevail in a plant, the "bench contactor" program was started. The bench contactors are stainless steel pots with a capacity of about two liters. Each is equipped with connections through which materials can be added and removed without exposure to air, a sight port, gas and vacuum connections, heaters, and thermocouples. Liquid salt and metal phases are equilibrated in these, in quantities large enough to allow repetitive analyses, so that the effect of a change in conditions can be directly determined by before-and-after analyses on a single system. In general, the distribution coefficients obtained with this equipment have confirmed those found in the small-scale work; the results have been, if anything, even more favor-

able. The experiments have also shown that salt-metal systems having compositions of interest for the LMFR can be kept for long periods in stainless steel at 500°C without loss of uranium, as long as the magnesium concentration in the metal is at least 25 ppm.

The closest approach yet made to plant practice was the operation of Loop B, a device described last year for continuously circulating a U-Bi solution through the Brookhaven reactor, a degassing unit, and a fused-salt contacting unit. This loop was operated not only to test the salt extraction process under operating conditions but also to provide the first experimental data on xenon removal. The results on both processes were encouraging. Exposure of the metal stream to a vacuum, or even to an atmosphere of inert gas, reduced the xenon content to a value too low to measure; and at least part of the fission-product iodine proved capable of volatilizing out of the bismuth. Since I^{135} has a half-life of 6.7 hr, the latter finding suggests the possibility of removing it rather than its daughter

Xe^{135} ; from a kinetics standpoint, I^{135} removal appears more desirable. In the salt process, the rare earth and uranium distributions checked those obtained in static experiments sufficiently well; in addition, distribution coefficients were obtained for the first time on several other elements. The K 's for alkali and alkaline earth metals were very high, as would be predicted from the stability of their chlorides. Those for elements other than those of columns 1A, 2A, or 3A of the periodic table were either erratic or low, also as would be expected. One very interesting Loop B result was the fact that steel coupons immersed in the flowing bismuth picked up a disproportionate amount of fission-product activity, as if the elements were being adsorbed. Further research is planned on the equilibria existing at the interfaces between liquid and solid phases at high temperatures.

Research into the fundamental thermochemistry of LMFR fuel mixtures has continued along the lines described in last year's report. Use of the

Figure 1. Flow diagram of Loop B.

Figure 2. Loop B. In-pile processing valve board and instrument panel.

high-temperature galvanic cell technique has proved most fruitful in ascertaining the free energy of mixing of a number of solutes with liquid bismuth. Given this quantity for a fission-product element, together with the free energy of formation of its chloride, one can calculate approximately what its distribution coefficient should be under a given set of conditions. In the case of cerium, the element which has been most completely investigated both as to its distribution and thermochemistry, a good agreement was found. Information on free energies of mixing is also of great value from a theoretical point of view, since it can be compared with the predictions of the various alternative theories which have been proposed for the nature of liquid metallic mixtures. For this reason the magnesium-bismuth system was investigated over a wide range of composition. The observed free energy-versus-composition relation fitted closely to a curve of the form called for by a Dolezalek type of description of the system in terms of molecules of intermetallic compound persisting in the liquid phase.

The extremely strong interaction between bismuth and most of the elements studied, especially cerium, is of interest. This can best be illustrated by a few values of activity coefficients, shown in Table 1.

The salt mixtures used in the LMFR process are doubtless more nearly ideal than the metallic solutions, but it is still important to have some knowledge of their thermodynamic properties. Accordingly, a program has been started to determine the activity coefficients of one or more fission-product chlorides in the ternary eutectic. The use of a cell such as

seems to be indicated, and the behavior of such cells is now under investigation.

Returning to the practical use of the salt-extraction process, it will be necessary in the efficient operation of a large-scale system to know the composition of each phase at all times. If the process involves several stages, or a column, simultaneous readings will be needed at several points. Any

delay between an accidental change of composition and its detection could result in excessive transfer of uranium from the fuel to the salt, or a failure of the salt to extract fission products. It will, therefore, be necessary to develop continuously-reading instruments sensitive to small changes in the compositions of the phases.

A property of the salt-metal system, considered as a whole, which is closely related to its selective extraction behavior is its electrode potential. The relative amounts of oxidized and reduced material present will be reflected in this half-cell potential, which can be measured against a reference half-cell. The problem here is to develop a reliable reference electrode for fused-chloride systems; work on this is now under way.

Table 1

Activity Coefficients of Solute Elements in Bismuth

Element	$T, ^\circ\text{C}$	Mole Fraction	Activity Coefficients
Li	450	0.0717	1.1×10^{-5}
Na	450	0.010	4.5×10^{-5}
Mg	850	0.10	3.3×10^{-3}
Ce	500	0.028	4.9×10^{-14}
U	500	0.0047	1×10^{-5}

Continuous polarography is another technique which may be expected to give information about the salt phase. It has been well developed for aqueous solutions, and its extension to fused salts should be possible. Research on this problem has been undertaken on a small scale at Brookhaven, and it has been found possible to operate a dropping bismuth electrode in fused chlorides for several hours without plugging. The bulk of the polarography work, however, has been subcontracted to outside laboratories—the Cater Laboratories of Pasadena, California, and the University of New Hampshire (Professors H. Haendler and C. Wheeler).

Finally, absorption spectroscopy appears promising as a monitor of the salt phase. On this, too, programs have been started both at Brookhaven and at the University of New Hampshire. Professor Haendler has completed his experimental setup and obtained good curves on several salts dissolved in the KCl-LiCl eutectic.

Those fission-product elements which are removed by neither the degassing nor the salt-extraction processes cannot be entirely neglected, although their importance to the neutron economy

is relatively small. Because of their very low poisoning effect, they can be allowed to accumulate in a reactor over fairly long intervals, and a batch process would be adequate for their removal. Such a batch process might be the slagging of liquid fuel with an excess of strong oxidant such as BiCl_3 . This would put the uranium and almost all the fission products into the salt phase, which would then be dissolved in water, and any desired separations could be carried out by the conventional methods of aqueous chemistry. The use of high-temperature electrolysis is also under study, both as an alternative to chemical oxidation of the fuel and as a method for separating the slag into its components.

Experiments in which bismuth chloride was contacted with bismuth alloys of several of the more noble fission products showed that a few of these, such as ruthenium and molybdenum, cannot be oxidized at all in the presence of excess bismuth. This is, of course, to be expected, in view of the relative stabilities of the chlorides of bismuth and ruthenium. A possible path to their removal lies in the use of extraction of the fuel with a liquid metal immiscible with bismuth, such as zinc or aluminum. The results of preliminary experiments on zinc extraction of ruthenium look encouraging.

Blanket Development

The study of the methods of preparation of equiaxed thorium bismuthide (Th_3Bi_5) dispersions in liquid bismuth has continued. The most promising method at present consists of electrodepositing thorium from molten thorium chloride onto an iron cathode, scraping off this deposit, and introducing it into the bismuth with stirring. Large melts containing 7% thorium have been made in this way. Methods of reconstituting an equiaxed slurry have also been investigated. When thorium is completely dissolved in bismuth at high temperatures and the solution is subsequently cooled, large platelets of thorium bismuthide are formed. The resulting alloy is viscous and does not flow. However, by quenching a 5% solution of thorium in bismuth from 1000°C , small platelets are obtained which can be converted to equiaxed particles by heating for an hour at 500°C . If this method of reconstituting slurries proves completely successful, it will be possible to process such slurries by heating to dissolve all the thorium bismuthide and subsequently reprecipitating the slurry. The effect of additives on the particle shape of the reconstituted thorium bismuthide is being investigated. The formation of equiaxed dispersions by shooting techniques is also being studied.

Blanket Processing

A selective oxidation step might well prove as useful in processing an LMFR blanket as it is for the fuel. However, knowledge was not precise enough to permit specification of any particular reaction sequence with certainty. Accordingly, a series of distribution experiments has been carried out on salt-metal systems involving uranium and thorium. The results show that the halides of these elements have almost identical free energies of formation per equivalent. In the case of fluorides, however, the thorium compound is slightly more stable than uranium fluoride, while in the chloride system the uranium compound appears to be more stable. It will not be possible to achieve separation factors like those of the fuel process, but some pyrochemical treatment of the blanket may be practicable.

Corrosion and Mass Transfer of Steels

Since most of the steels considered for use as container materials for the LMFR have chromium as an alloying element, the solubility of chromium in bismuth has been studied. The chromium concentration in the bismuth affects the solubility of iron: it has been noted that as the chromium dissolves into bismuth saturated with iron, the

iron concentration decreases. The product of the iron and chromium concentrations in solution appears to be reasonably constant as the chromium concentration increases above 10% of its saturation value. The solubility of titanium in bismuth has also been determined, and titanium in bismuth has been shown to reduce the solubility of iron, at least down to 500°C. Experiments at 750°C in which pure iron was dipped into bismuth saturated with titanium showed no corrosion; however, a metallic deposit was found on the dipped rod, which on analysis did not correspond with any known intermetallic compound of iron and titanium. Similar experiments with bismuth saturated with zirconium also showed no corrosion, but these dipped rods did not have metallic deposits.

The thermal convection loop program has been expanded and is yielding very valuable information on the behavior of a variety of steels in contact with the uranium-bismuth fuel. The effect of temperature gradient and upper temperature is being studied. These experiments indicate that the process of inhibition involves the formation of a zirconium nitride film as indicated in the previous report. It appears that the higher the activity of nitrogen in the steel, the more corrosion

Figure 3. Bismuth impregnation of graphite at a temperature of 450°C and a pressure of 120 psi He.

resistant the steel is. Two more runs were completed on the pumped high-velocity loop with 125° gradients (525° to 400°C). An attempt was made to study the effect of direct impingement (right-angle bend) of the fuel solution (U-Bi), on the corrosion resistance of the construction material ($2\frac{1}{4}$ chrome-1 molybdenum steel). Corrosion products, iron and chromium, have been found in the portion of the loop having the lowest film temperature, i.e., the finned cooler.

Graphite-Bismuth-Uranium Studies

Graphite is being considered for the moderator of the LMFR, therefore its impregnation by bismuth or bismuth-uranium fuel is being studied. Graphites which show very little penetration have been obtained from commercial sources. Figure 3 shows the impregnation of a few types of graphite as a function of time. These curves can be explained if the graphite is releasing gas during the course of the experiment. Since graphite impregnated with bismuth may undergo thermal cycling during the course of reactor operation, the effect of such cycling on its crushing strength was tested. Graphite samples cycled 133 times from 175° to 450°C showed no apparent decrease in the crush-

ing strength. Since radiation-induced changes in the thermal conductivity of graphite may be important in reactor operation, an apparatus for measuring thermal conductivity of irradiated specimens at elevated temperatures has been constructed and is being tested. The effect of irradiation on the reaction of uranium, zirconium, magnesium, and fission products with graphite is also being investigated by means of a series of capsule tests. In these, a graphite crucible is encased in an evacuated aluminum container which in turn is encased in another evacuated aluminum container. This double vessel is then inserted in the reactor for neutron irradiation. The U-Bi fuel in the inner container provides heat and fission particles. In this way it should be possible to obtain within the capsule the high temperatures and fission fragment flux required for this study. This technique permits the irradiation of many samples without the complication of introducing a heat source into the reactor.

Experimental Loops

During the year, a number of loops were in different stages of design, construction, and operation. The in-pile operation of Loop B was probably

Figure 4. Loop G.

the most important loop activity of the year. It ran continuously for a period of about 6500 hr and provided very valuable information on the removal of both the volatile and nonvolatile fission products from a U-Bi fuel as mentioned above. Mechanically, the loop performed most satisfactorily until its shutdown, which was necessitated by certain heater failures and leaks in the electromagnetic pump cells.

A large figure-of-eight loop, Loop G, was built of low-chrome steel to investigate corrosion and erosion resistance of this and other alloys at bismuth velocities up to 25 ft/sec at temperatures up to 1100°F and at temperature differences between the hottest and coldest points up to 300°F. By the end of the year, the construction of Loop M, an all-stainless steel (347) loop, was about three-quarters completed. This loop, the first at BNL in which a fused salt will be circulated by a pump, is being built to test various items of equipment and instrumentation for use with the KCl-NaCl-MgCl₂ eutectic. The design of another major loop, Loop N, is nearly completed; it will be used to test various extraction column designs for removing rare earths from U-Bi with fused salts. In addition, several other smaller loops have been operated to obtain information on corrosion, mechanical components, and chemical behavior of graphite, as described above.

REACTOR PHYSICS

In addition to the work on the LMFR described above, the reactor physics group has continued experimental studies on slightly enriched uranium lattices in ordinary water. Such core parameters as neutron multiplication, neutron migration, and buckling have been determined for various lattice spacings, rod sizes, and enrichments. A new technique has been established for the measurement of some of these parameters. Smaller than normal sized lattices inserted in a strong neutron flux have given some precise data and, indeed, some data not otherwise obtainable.

A series of critical assemblies has been tested to obtain the data required to establish the design for the Brookhaven Medical Reactor. Similar experiments have been carried out jointly with members of the staff of the Naval Research Laboratory to secure results pertinent to the design of their new reactor.

HEAT TRANSFER STUDIES

As part of a continuing liquid metal heat transfer program at Brookhaven, a research project was recently completed on the determi-

nation of both local and tube-average coefficients for flow of mercury normal to a staggered tube bank. The bank consisted of sixty 0.5-in. tubes, six wide and ten deep, arranged in an equilateral triangular array. Results have been obtained which show the effects of flow rate, Prandtl number, wetting, gas entrainment, and tube location on tube-average coefficients. In addition, the angular variation of the local coefficient has been determined for various conditions of operation.

The heat transfer runs covered the 20,000 to 200,000 Reynolds number range. The coefficients for tubes in the interior of the bank were well correlated by the equation

$$Nu = 4.03 + 0.228 (Pe)^{0.67}$$

where Nu and Pe represent Nusselt and Peclet Moduli, respectively. As a result of this work, the question of cross-flow heat transfer in tube banks is now believed to be on a much firmer scientific basis. In addition to heat transfer data, important pressure drop information was also obtained.

FLUORIDE VOLATILITY PROJECT

The fluoride volatility process is a method of processing irradiated natural uranium fuel elements by fluorination in an interhalogen solution to fluoride compounds and subsequent decontamination of the uranium as UF₆ by distillation. A project has been active at Brookhaven for several years, the purpose of which is to investigate certain engineering aspects of a process in which BrF₃ and BrF₅ are the fluorinating agents. In the past year, all the work on this project was on the construction of, and development of components for, a continuous dissolver pilot plant capable of dissolving 5 lb of fuel per hr.

The purpose of the pilot plant, which is of all-Monel construction, is to make possible the study of a) effects of temperature (up to 150°C) and of Br₂·BrF₅ and UF₆ concentrations on dissolution rate, b) behavior of plutonium and fission products in the system, c) conversion of BrF₅ to BrF₃, and d) startup and shutdown procedures. The plant will be operated with the following feed materials, in the order listed: a) natural uranium, b) natural uranium-plutonium alloy, and c) irradiated uranium of varying plutonium contents. The plant should be ready for shakedown operation in the fall of 1956.

ULTIMATE WASTE DISPOSAL

During the past year the work on ultimate waste disposal was mainly concerned with 1) the devel-

opment of a ball kiln unit for calcining bulk metals in the wastes, such as aluminum and zirconium, to their stable oxides; 2) the leaching of soluble fission products from these oxides; and 3) the development of electrodeionization cells for removal of bulk anion nitrates, fluorides, etc. from waste solutions. All these objectives center on fixation of the fission products in stable solids and are, therefore, in direct continuity with previous work on adsorption and fixation in montmorillonite clay.

A bench-scale ball kiln unit was constructed and operated successfully with simulated aluminum nitrate feed and finally with a spike of radioactive cesium-137. The unit was made of stainless steel throughout and no corrosion problems were encountered. Off-gases were passed directly to an absorption tower containing NaOH, but no attempt was made to measure the volume of non-condensable gases. No difficulties were observed from the very small carry-over of oxide dusts in the vapor stream as measured by the gamma radiation from cesium-137. It appears that the dust was removed to the limits of measurement in the entrance zone of the absorption tower. It is not to be presumed, however, that a full-scale plant would not produce a serious dust removal problem.

A similar experiment was run on the decomposition of zirconium fluoride by hydrolysis with steam at high temperatures in a ball kiln unit constructed of Monel. In these tests there were indications that complete hydrolysis could be achieved at temperatures lower than those necessary in the batch hydrolysis equipment. No significant corrosion was observed in the apparatus during the relatively short period of operation.

Since the greatest difficulty will be encountered in processing wastes containing aluminum and zirconium fluorides as well as aluminum nitrate, a bench-scale plant capable of handling this type of feed was designed and is now being built. It will provide process data such as reaction rates, off-gas composition, decontamination factors, and corrosion rates under realistic conditions. The plant is complete in all major details with the exception of leaching facilities. It consists of two ball kilns, a product collection tank, and two off-gas adsorption towers. Leaching characteristics of the product will be studied in the laboratory.

During the past year a program of leaching studies has been carried out on stable metal oxides containing fission products. Results are incomplete, but data obtained so far point toward a simple method for extracting cesium-137 of suffi-

cient purity for use in high intensity sources. In addition, leaching plateaus are being approached on both aluminum and zirconium oxide samples.

Electrodeionization studies have been concentrated mainly on aluminum nitrate-ammonium nitrate and zirconium fluoride-aluminum nitrate systems. In these cases the product is a hydrated oxide, and cells had to be developed which would operate satisfactorily in the presence of solids without clogging. An immersion assembly has been developed which consists of a sandwich of two membranes with an anode held in a plastic frame. In operation several of these assemblies would be suspended in a tank of solution to be processed, and precipitation of solid oxides would take place in the tank but outside the membrane assemblies. This mode of operation also simplifies maintenance and replacement of membranes. Processes using this type of unit have been developed and tested for two types of waste: aluminum nitrate-ammonium nitrate wastes, calcining of which is hazardous because of the second component; and zirconium fluoride-aluminum nitrate wastes, the corrosive nature of which makes processing in a metallic system difficult.

WASTE PROCESSING

Personnel of the Waste Processing Development Project have been investigating the feasibility of treating aqueous wastes from fuel processing plants to produce a molten salt product. Seven runs were successfully made with the auger-driven calciner described in the last Annual Report.

Volume reduction factors of from 2.54 to 3.86 were achieved. In all cases a decontamination factor between the feed and the overhead of about 1000 or better was obtained. One run was made to demonstrate the ability of the equipment to run continuously for extended periods of time. In a 70-hr run in which simulated neutralized waste from the MTR fuel element recovery process was processed, downtime was at a minimum.

Several exploratory runs have been made with a so-called "hot tube" calciner. This is simply a long pipe, insulated and wrapped with copper wire, in which induction heating is used to supply the necessary energy for dehydration and production of an anhydrous melt. Flow of the melt is by gravity. So far only pure nitrate solutions have been processed, at very low rates.

Laboratory data have been obtained on the corrosion resistance of various metals to feed waste streams under calciner conditions, and to product melt streams.

Equipment has been constructed to measure the radiation stability of the fused salt products.

FISSION PRODUCTS UTILIZATION

Radiation Application Research

Graft copolymerizations have been successfully accomplished by several techniques. In principle, the process depends on irradiation of a polymer to produce free radical sites capable of initiating polymerization of a monomer, the monomer used being different from the monomer forming the polymer used. The reaction can be achieved by 1) irradiation of polymer swelled with monomer, 2) irradiation of polymer in contact with excess monomer, 3) irradiation of polymer dissolved in monomer, and 4) irradiation of polymer alone and subsequent immersion in monomer.

The systems studied to date have been quite varied, but emphasis has been concentrated on polyethylene films and styrene monomer. An attempt is being made to clarify the kinetic picture and to determine the effects of the variables—temperature, radiation intensity, monomer concentration, and oxygen. The rate of grafting appears to be diffusion controlled in a number of instances, and this diffusion factor varies with the progress of the grafting.

Oxygen has been found to influence greatly the rate of grafting by the fourth technique. Rates were significantly faster in experiments with oxygen excluded, probably because oxygen destroys free radicals. The free radicals produced in the original polymer irradiation have been preserved for three months at room temperature. Polyethylene specimens stored for this period exhibited rapid grafting when immersed in styrene monomer.

Rates of irradiation-induced polymer degradation in solution have been under investigation. Preliminary data on polymethyl methacrylate dissolved in benzene indicate a constant decrease in viscosity up to an accumulated dosage of 90 to 100×10^6 rep; thereafter an equilibrium in viscosity is observed. The rate of degradation appears to be first-order dependent on rate of intensity between dose rates of 338,000 and 500,000 rep/hr.

The dehydrogenation of methylcyclohexane to toluene over an alumina-molybdena catalyst is being studied. After control conditions have been firmly established a study will be made of the reaction 1) in the presence of gamma radiation, 2) with neutron irradiated catalyst, and 3) in the presence of gamma radiation with neutron irradiated catalyst.

This project has been assisted in many phases by personnel of the Polytechnic Institute of Brooklyn.

SPECIAL RADIOISOTOPES DEVELOPMENT

Yttrium-90

An apparently successful system has been devised for the separation of this important β -emitting yttrium isotope (about 65-hr half-life) from its long-lived β -emitting strontium parent. The present process gives less than $2 \times 10^{-5}\%$ strontium contamination in the product solution. The resulting milking system should prove simple, convenient, foolproof, and operable over a reasonably long period of time.

Magnesium-28

A study of the optimum methods for production of magnesium-28 by the $\text{Mg}^{26}(t,p)\text{Mg}^{28}$ reaction is part of a broader general study of such triton-induced reactions, of which the $\text{O}^{16}(t,n)\text{F}^{18}$ reaction mentioned below is another example. The tritons, of course, are produced in the reactor by the $\text{Li}^6(n,t)\text{He}^4$ reaction. The element or compound to be bombarded by tritons is intimately mixed or alloyed with lithium or one of its compounds and the whole is irradiated in the nuclear reactor. Some tritons are born with a kinetic energy greater than the threshold energy of the desired secondary reaction, and in colliding with the target nuclide produce an isotope conveniently and in good yield. A total of 6072 microcuries of magnesium-28 have been shipped to users during fiscal 1956. While development work is not yet completed, specific activities of 100 microcuries of magnesium-28 per gram of stable magnesium have been easily obtained, and it appears that activities as high as one millicurie per gram may be procurable.

Fluorine-18

A satisfactory production process for fluorine-18 has been previously reported, which uses the reaction $\text{O}^{16}(t,n)\text{F}^{18}$. In the course of the magnesium-28 work, it was noticed that hollow samples of lithium carbonate produced just as much total fluorine-18 as the solid samples previously irradiated. Less carrier fluoride is therefore required in the process, and the specific activity has been increased by a factor of eight over that guaranteed previously.

Molybdenum-90

A suitable process has been developed for producing molybdenum-90 on a tracer scale. It is believed this process can be scaled up if the demand for this isotope arises.

Iodine-133

The wet distillation process for the production of iodine-133 reported last year has been scaled up to the 1-curie level without any major changes. Minor changes have been introduced by which customers in the New York City area can receive this material less than 24 hr after removal from the reactor, as compared with 40 hr in the past. This time interval is important because the percentage of iodine-133 relative to all other iodine activity reaches a maximum of about 85 to 90% 40 to 50 hr after removal from the reactor.

Tellurium-127

About 6 millicuries of fission product tellurium-127 mixed with about 4 millicuries of tellurium-129 have been prepared for a Research Collaborator investigating the decay scheme of tellurium-127.

METEOROLOGY

Research Program

This program is concerned with the dispersion of matter in the lowest layers of the atmosphere as a function of meteorological parameters. These studies are directly related to the solution of problems involving the discharge of radioactive materials into the air.

Last year's report pointed out the need for a simple means of obtaining oil-fog samples aloft during the important nocturnal temperature inversions. Two types of samplers utilizing semi-Diesel model aircraft motors have been developed. The first model uses a portion of the motor air intake as a source of vacuum for a Millipore filter head (see Figure 5), and the second combines the semi-Deisel motor with a small vacuum pump. Both are very light and have proved quite satisfactory. Six successful runs have been conducted and have provided the first such data obtained at this site and perhaps the first available anywhere. Although the concentration values are not yet adequate for a complete study, they substantiate earlier speculation concerning the behavior of the inversion plume.

Eleven oil-fog tests were completed at ground level in which both densitometers and filters were used. Those which have been processed have shown that fluctuations of 4- to 10-min periods are of major importance. There is, however, considerable variation in the spectra of these runs and it is hoped that these will show some consistent relation with meteorological variables. In anticipation of a probable relation with wind spectra, data from several other AEC sites have been

Figure 5. Airborne sampler, showing locking pliers used in starting and launching.

collected and prepared for power spectrum analysis and comparison with Brookhaven wind data.

The interesting analyses of concentration spectra, and the necessity for future studies of co-spectra and quadrature spectra, have led to the cooperative development with New York University and Remington Rand of new computational programs that will be both more general and more efficient than the present simple spectral program.

Another common problem, the calculation of concentrations from effluent sources having various parameters, has been reduced to a machine operation. This problem comes up in the design of new facilities releasing, or potentially releasing,

radioactivity to the atmosphere. This program is general and can be applied to a wide range of problems.

A cooperative investigation was undertaken in the summer of 1955 with botanists of the State of New York to obtain information concerning the vertical distribution of ragweed pollen. No definite results are available as yet.

A new type of gustiness analyzer has been developed to provide a direct record of gustiness and to simplify the operation of the analytical system.

A climatological study of hourly micrometeorological data, financed by the U.S. Air Force and conducted by the meteorology group, has been under way and is scheduled to be completed by the end of the next fiscal year.

Life Sciences

BIOLOGY

The program of the Department has continued along the lines already established. During the year no new major facilities have been added to the Department, but the existing facilities have been used to capacity.

The research activities of the Department continue to center around the special facilities of the Laboratory. In general, this involves 1) the use of radiations of various kinds in the study of their effects on biological material and as a tool for the study of life processes, and 2) the use of radioactive tracers in studies of life processes.

In the first category, the gamma field continues to be valuable. The abnormalities of the plants grown in the field are still under study and probably will be for a number of years. The thermal neutron facility has been and is being used 24 hours a day, 7 days a week, in order to keep up with the demand.

The summer program has continued to grow and is an important part of the research and educational activities of the Department. This summer (1956) there are 13 scientists and 23 students working in the Department.

GENETICS

It is becoming increasingly apparent that perhaps the most profound effects of ionizing radiations on living tissue are produced in the nucleus of the cell and specifically on the genetic structure contained within the nucleus. Thus, ionizing radiations have been found to be very useful for studies in genetics, and these studies in turn have been valuable in helping to understand the mode of action of radiations on living tissue.

Drosophila Genetics

The fruit fly oocyte undergoes a remarkable growth during oogenesis. During its development in a period lasting 3 days its ovoplasm undergoes a 100,000-fold increase in volume. The development of the egg in the ovariole has been divided into 14 successive stages and the number of eggs in the various stages has been correlated with the age of the female. Thus, it has been possible for the first time to know the exact condition of the egg in a female *Drosophila* exposed to radiation.

With this information a study has been made of radiation-induced chromosome breakage during oogenesis as measured by dominant lethal mutations and X-chromosome losses. Great differences in radiation sensitivity have been noted; there seems to be a very definite correlation between radiation sensitivity and the presence or absence of the nuclear membrane, and also the degree to which the chromosomes are condensed. Gross chromosome aberrations are quickly eliminated, but the more subtle recessive lethal mutations are never completely eliminated from the germ tract. Thus, it appears that not only are the oogonia, the stem cells, much more resistant to radiation than are the more mature forms, but also any abnormalities produced in the stem cells have a much lower probability of producing mature viable eggs.

Radiation Cytogenetics in Plants

Experiments are in progress with the tobacco genus, *Nicotiana*, to investigate both the cytogenetic nature of the systems of genes and chromosomes that distinguish natural species, and ways of altering these systems through experimental techniques. Two closely related species with the lowest chromosome number in the genus are differentiated in the heredity of their floral characteristics mainly by a series of gene blocks, the effective number of which is the product of the number of chromosomes and the average number of chiasmata. From the hybrid between these species new morphological types have been selected which possess novel characteristics transgressing those found in the parent species. The fact that certain of these new types when back-crossed with the parental species form partially sterile hybrids demonstrates that essentially new species can be formed in a few generations through inter-specific hybridization, recombination, inbreeding, and selection. Among recombinants from this same original hybrid, unstable genetic units are occasionally detected, and one of these has been found to be many times more responsive to low dosages of chronic gamma irradiation than a stable locus.

In this genus, the cultivated tobacco is the species having the highest chromosome number. Experiments were carried out to see if fertile viable

types with much higher chromosome numbers could be produced. It was possible to combine into one plant three different species: the cultivated tobacco (of South American origin), a North American species, and an Australian species. The resulting new form originally had three times the number of chromosomes of the cultivated tobacco. Although in succeeding generations from 7 to 17 pairs of chromosomes were lost, distinctly new fertile and vigorous races with high novel numbers of chromosomes for the genus have been established.

A recessive gene which confers on *Nicotiana tabacum* a short photoperiod requirement for flower initiation, when transferred to *N. rustica*, produces a plant which fails to flower even under short photoperiods at usual temperatures. Such a plant when exposed to chronic gamma irradiation was induced to flower. This result confirms and extends similar findings from experiments with *N. tabacum* at the Boyce Thompson Institute and indicates that irradiation alters the physiological state governing flower initiation in these species.

Figure 1. Distorted flower formed on a tobacco plant subjected to chronic gamma irradiation in the gamma greenhouse. This variety of tobacco normally does not flower, but has been induced to do so by radiation. When removed from radiation it produced reasonably normal flowers for a time before reverting to the nonflowering state.

The Physical and Chemical Structure of Chromosomes

It has previously been reported that *Tradescantia* grown in pure culture which is a complete medium except for a deficiency in calcium exhibits a very much higher rate of spontaneous chromosome breakage than normal plants. When *Tradescantia* inflorescences from suboptimal calcium cultures were irradiated with x-rays, the frequency of chromosomal aberration observed was higher than that observed in similarly irradiated inflorescences from optimal calcium cultures. These x-ray effects are independent of the spontaneous effect. Other ions will also influence the spontaneous and x-ray mutation rates, but none are as effective as calcium and it is suspected that most of them function by inhibiting calcium utilization. It has been found that in *Drosophila* larvae a chelating agent, e.g., EDTA, which binds metals such as calcium and thus lowers the calcium ion concentration in the tissues, will increase the frequency of genetic crossing-over. Attempts to change the frequency of crossing-over in adult *Drosophila* by the use of EDTA have so far failed, presumably because the calcium ion concentration cannot be changed appreciably in the adult animal. Attempts to change the frequency of crossing-over in corn have also failed, probably because the corn will not grow properly in a medium sufficiently deficient in calcium to cause this phenomenon.

Simultaneous centrifugation has been used as a method of placing a physical stress on the chromosome during the time it is being subjected to x-irradiation. When the material was treated in air the frequency of chromosomal aberration was found to increase considerably, whereas in a nitrogen atmosphere there was no appreciable change. These experiments are still in progress but they provide an important new method of studying the mechanism of chromosome breakage.

These results have led to a hypothesis concerning chromosome structure which proposes that calcium forms bonds at key sites along the chromosome.

Radiation-Induced Mutations in Plants

When seeds are subjected to ionizing radiation, all known types of mutation are produced in far greater numbers than appear spontaneously. Some of these mutations can be extremely useful from a practical point of view, and studies have been under way for several years to investigate the conditions under which they can best be produced. Specifically, the program seeks to determine the factors responsible for mutations in plants, the ge-

netic nature of induced and natural mutations, the types of mutation that can be induced, the types of radiation or treatment that can most effectively induce mutations, and the most efficient methods for isolating mutations in plants.

A mutation which renders the plant resistant to stem rust can be induced readily in oats, and studies of this reaction indicate that the mutant will breed true indefinitely.

It has been found that seeds irradiated with neutrons are affected much more uniformly than seeds irradiated with x-rays. One of the chief reasons for this appears to be the fact that the water content and oxygen content of the seed are very important in determining its x-ray sensitivity but quite unimportant where neutron sensitivity is concerned. Thus, slight differences in water content between individual seeds are responsible for this phenomenon. This observation indicates that neutrons are much more efficient in the production of mutations in seeds than x- or gamma-rays, since the exact dose can be administered to each seed in the entire population.

A study has been initiated to compare the mutation efficiency of ultraviolet and x-rays for barley pollen. Contrary to expectation very little difference in mutation efficiency was found when these two radiations were given at dosages which caused similar amounts of killing in the pollen. However, at the same dosages, cytogenetic studies indicated that x-rays induced over ten times more chromosomal interchanges than ultraviolet. The interpretation of these results is not yet clear but present indications are that ultraviolet may be useful for producing certain types of mutation and x-rays useful for producing others.

Studies have been under way to determine the nature of the mutations induced by radiation. Most of these mutations are inherited in a simple Mendelian manner. In oats it is of great importance that at least one stem rust resistant mutant be inherited as a dominant mutation. Victoria blight resistance in oats is a recessive mutation. Crown rust resistance in certain oat varieties is closely linked genetically to Victoria blight susceptibility; when Victoria blight resistance is induced in these varieties, crown rust susceptibility almost invariably appears in the progenies. However, this apparently is not a simple all-or-none phenomenon, since the induction of Victoria blight resistance results in varying degrees of susceptibility to crown rust. This finding indicates again that characters which are usually considered to be very simple and controlled by one genetic

Figure 2. Microscopic sections taken through the growing bud apices in carnation plants. A) A plant which had received no radiation. B) An apex 8 days after the plant had received a heavy dose of radiation. The outer (epithelial) cells have been killed but the cells in the deeper portion of the bud are not so seriously affected. C) The plant after 49 days. Regeneration has taken place from the subepithelial cells and therefore all characters of the resulting shoot which arise from the epithelial layers, such as flower color, will be governed by the genetic character of the subepithelial cells. Thus what appears to be a mutation may be an injury phenomenon.

locus may in fact be extremely complex and controlled by a number of different genetic loci.

Carnations, either grown in the gamma field or irradiated with x-rays, have been previously reported to produce somatic mutations for flower color, and an analysis of this phenomenon has shown an extremely high rate of change from white to red but a much lower one from red to white. This finding suggested that factors other than purely genetic ones were operative in the change. One possibility was that the epidermis of the plant had a genetic constitution different from that of the underlying layers and that an injury phenomenon was being observed rather than a true mutation. An anatomical study of the stem apex at various intervals after irradiation revealed that the radiation caused selective destruction of the outer layers of the stem apex, followed by regeneration of a new apex from the deep-seated cells. The newly reconstituted apex was thus genetically homogeneous and produced flower color characteristic of the genetic structure of the underlying tissues, which in this case was red. In the changes from red to white flower color, such a mechanism was not possible; hence these must be considered true mutations.

Radiation-Induced Mutations in Plant Breeding

The cooperative program designed to produce useful mutations in agriculturally important plants and trees continues to expand. Active cooperation with Canadian institutions, begun last year, has resulted in a total of 17 vigorous projects which promise to yield well-analyzed and complete data. During the past year there was considerable correspondence with agricultural scientists from foreign countries, and cooperative projects have been started with scientists in Australia, Italy, Mexico, Pakistan, Peru, the Philippine Islands, Rumania, Thailand, and Venezuela. The program has been called to the attention of the scientific attachés at the different foreign embassies in Washington; the enthusiastic response makes it probable that foreign cooperation will increase considerably in the coming year. The newly activated and calibrated instrument tunnel at the reactor has made it easily possible to keep up with the greatly increased demand for irradiation facilities.

Reports from cooperating institutions have given a much better basis for dosage estimation; future experiments should have a considerably higher probability of success.

In the past year analysis was begun of the material first planted in the irradiation field. Rutgers University removed many of its peach trees and

blueberry bushes, and the New York State Agricultural Experiment Station removed apple trees and grape vines. As these plants slowly recover from the physiological stunting induced by the irradiation, they will be scrutinized for somatic mutations of benefit to the fruit breeder.

A Work Conference held at the Laboratory on May 23 and 24 immediately following the Annual Biology Symposium was attended by about 100 of the scientists cooperating in the radiation mutation program and others interested in this work. All aspects of the program and progress to date were discussed. The proceedings of the conference will be prepared for distribution and should serve as a source book on mutation breeding.

Results reported at this conference were encouraging. Several investigators reported finding mutations in wheat, oats, barley, rice, and peanuts which were resistant to specific diseases. These results indicate that it is possible to induce resistance to many different diseases in a wide variety of plants. Since disease resistance is an extremely important agronomic character in the United States, its induction may be the most important single use of this technique.

In addition to disease resistance, many other interesting and important qualities have been observed in mutants including earliness, winter hardiness, stiff straw, dwarfing, etc. An especially interesting possibility is the use of radiation to break close genetic linkages which apparently cannot be broken by any other means.

These results have been obtained within the past few years, the majority within the past year. They must be subjected to vigorous field trials before their ultimate value can be determined.

It appears now that this technique will be most useful where conventional plant breeding methods have gone as far as possible and a change is still desired in a single plant character. The precision of this tool can be expected to increase as the many practical problems associated with its use are solved and understanding of basic radiobiological processes is extended. The work on this project, therefore, is being closely coordinated with the rather extensive program of basic plant genetics in progress at the Laboratory.

ANIMAL PHYSIOLOGY

Acute Effects of Radiation on Mammals

In mammals the intestine is one of the organs most sensitive to radiation; many acute deaths following radiation can be directly ascribed to

failure of this organ. A study of this phenomenon in hamsters and mice indicates that the radiation blocks the production of viable epithelial cells. Cells which were mature at the time of radiation decay at a normal rate until the population is considerably reduced, although some of them survive longer than normal. When a sufficiently large number of these cells has degenerated, the barrier separating the lumen of the intestine from the peritoneum breaks down and the intestinal contents with high concentrations of bacteria enter the peritoneum. This situation is incompatible with life although the bacterial invasion is apparently not the primary cause of death. The primary reaction seems to be that radiation blocks the production of viable new cells in the intestinal epithelium, but the mechanism of this block is not known.

As a corollary of this study it has been found that the irradiation of a small region in and around the mouth in rats and mice with relatively small doses will lead to the death of the animal. There is no other region of the body of comparable size in which a similar dose can start a fatal reaction. This phenomenon is being actively studied but as yet its cause is unknown.

Effects of Radiation on Animal Metabolism

One of the few things observable about an animal after a large dose of radiation is the fact

Figure 3. Neutron activation analysis of materials separated by paper chromatography. The components of the material, in this case an extract of liver, are separated by paper chromatography, and the paper is then placed in the reactor to receive about 10^{16} neutrons. Afterwards photographic film is placed over the paper and the induced activity in the material is identified by autoradiography.

that it will refuse food. Investigation of the causes of this refusal has revealed a rather profound alteration in the carbohydrate metabolism of the animal. Absorption of glucose from the gut is delayed, and liver glycogen, the storage form of carbohydrate, is elevated. Blood sugar levels are increased and subtle but definite changes are produced in muscle glycogen levels. An analysis of this phenomenon indicates that it is a result of an endocrine imbalance regulated primarily by the pituitary gland and mediated through the adrenal; removal of either of these glands abolishes the effect. This appears to be the normal response of an animal to this particular type of stress. Radiation has been compared to other types of stress such as fasting, exposure to cold, intraperitoneal injection of formaldehyde solutions, subcutaneous injection of epinephrine, and hypoxia. These stresses can be divided into two groups, those in which liver glycogen is preserved or increased, as in x-irradiation and hypoxia, and those in which there is little change from the fasting state. Within the central nervous system there is a mechanism which controls the level of carbohydrate metabolism. Following x-irradiation, this level seems to be set at a value somewhat higher than normal.

Effects of Radiation on Aging

When young animals are subjected to an ionizing radiation such as x-rays, their life span may be markedly shortened. Mice receiving 525 r of x-rays at 8 weeks of age die on the average at about 12 months of age, whereas the controls live about 18 months. Death apparently results from the same causes in both cases. The irradiated mice lose weight at the time of irradiation but soon start to gain again; however, they never reach the weight of the controls. Mice were subjected to forms of stress other than radiation, such as massive doses of typhoid toxin or nitrogen mustard. They were more acutely ill than the x-rayed animals, but soon gained weight to equal that of the controls and lived as long as the controls. Thus x-rays seem to increase the normal rate of aging and in this respect differ markedly from other forms of stress.

Mice subjected to x-rays when young are not as able to withstand a second stress when they are 12 months old as are the controls. The stresses used were a second dose of x-rays or a large dose of typhoid toxin. This finding indicates that x-rays produce a true acceleration of the aging process and do not produce their effects solely by increased tumor production.

Figure 4. Effect of radiation on aging as shown by survivors of two groups of nine mice each at 12 months of age. The group on the right received a large but not fatal dose of radiation at two months of age; the group on the left received no treatment. The treated mice exhibit all the symptoms of old age and senescence, whereas the control mice are still vigorous and healthy.

Leucocytes in Antibody Production

Attempts are being made to determine the cells involved in the production of antibodies and to define the conditions under which these cells are active. Attention is directed particularly to the role of the eosinophil cell, which is known to be related to allergic reactions, parasitic infections, and foreign body reactions, but which has not been studied in relation to antibody formation.

The experiments to date have led to the following conclusions. There is a close correlation between the accumulation of eosinophils at the site of antigen inoculation and the production of antibody in mice. Eosinophil accumulation is at its maximum during the secondary response of immune animals, when antibody production is also at a maximum. The increase in eosinophils is not due to a hypersensitivity reaction, to a local combination of antigen and/or antibody, or to nonspecific inflammation; it appears to occur only when antibody is formed and in organs or tissues forming antibody. Both antibody formation and eosinophil accumulation are inhibited by massive doses of cortisone or by whole-body irradiation given immediately prior to the antigen injection. If the irradiation is given 12 to 24 hr after the antigen injection, neither the antibody synthesis nor the local accumulation of eosinophils is prevented. However, the mononuclear cells are markedly inhibited.

These and other related studies have led to the suggestion that the period of accumulation of

eosinophils is the radiosensitive stage of antibody formation. During the radioresistant phase eosinophils have already accumulated and are apparently resistant to the effects of irradiation.

The Role of Endocrines in Radiation Damage

Studies made at the Laboratory several years ago indicated that the radiation syndrome in animals has important endocrinological aspects. Investigation of one aspect showed that removal of the thyroid gland plus a large dose of radiation will produce a tumor of the pituitary which is transplantable and is specific to the cells of the pituitary responsible for the production of thyrotropic hormones. A tumor is also produced by removal of the thyroid plus irradiation of the body without irradiation of the head or the converse, i.e., irradiation of the head with the body shielded. Furthermore, removal of the gonads plus irradiation produces a pituitary tumor specific to the cells producing gonadotropic hormone. Experiments are under way to determine the time relations of these phenomena, which may be very important in elucidating their fundamental nature. These experiments give radiation an essential but nonspecific role in tumor production. They also raise the important question of whether the carcinogenic action of radiation may result from production of the toxic substance at some distant point in the body. The alternate hypothesis is that radiation is acting as a nonspecific, generalized type of stress. Animals are being subjected to stress

in various ways in conjunction with thyroidectomy or gonadectomy to determine whether this hypothesis has any foundation in fact.

Salt and Water Metabolism of Fish

A study has been undertaken to determine the mechanism which enables the fish, *Fundulus*, to live in both fresh and salt water. One theory is that in fresh water the fish takes in water and dilutes the salt in its tissues to bring the salt concentration closer to osmotic equilibrium with the environment. Careful measurements of the salt concentration in the blood and tissues have shown that the concentration does not change as the fish goes from salt to fresh water, and the fact that the fish does not change its total water content in making the transition confirms this finding.

It has been found that in concentrated salt solutions (sea water) the animal is able to excrete via the kidneys salt which has been taken in through the gills or the intestine, and thus to maintain the body fluids at constant salt concentrations. In very dilute salt concentrations (very fresh water) the kidney is not able to excrete a dilute enough salt solution to compensate for the water taken in through the gills. To achieve compensation, the fish swallows rather large amounts of water and is able selectively to absorb salt from the intestinal tract so that the kidney can maintain a constant salt concentration in the blood without the necessity of excreting a very dilute urine.

There is evidence that special cells in the gill structure of this fish are responsible for transporting ions either in or out in order to maintain the osmotic equilibrium of the animal. An autoradiographic study of these cells is being made, and at the same time a study of the drinking habits of this fish is being made with isotopically labeled media. Contrary to the currently accepted view that only marine fishes drink in order to obtain water to compensate for osmotic dehydration, these studies have shown that this fish in fresh water also drinks water and extracts the salt from it in order to maintain osmotic equilibrium.

Kidney Function

The kidney of the frog has been chosen for a study of the mechanism of excretion and reabsorption by the tubules of substances of physiological interest. The frog kidney is especially adapted to such studies since it has two overlapping circulatory systems: an arterial system which supplies the glomerulus and tubules, and a portal system which supplies only the tubules. Thus it is possible to set up perfusion equipment which will distin-

Figure 5. Schematic drawing showing the method of perfusing frog kidneys. Fluid can be perfused either through the arterial system, which perfuses both glomerulus (Bowman's capsule) and tubules, or through the portal system, which perfuses only the tubules. In this way glomerular and tubular function can be differentiated.

guish between glomerular and tubular function in the kidney. By use of various labeled substances it has been shown that when a substance is introduced in only one system the tubules can excrete only about half as much of it as when it is introduced simultaneously into both blood supplies. The present provisional interpretation is that there are areas of the tubules which receive primarily one type of fluid, either arterial or portal, and that there is relatively little overlap in the two systems. This concept is somewhat contrary to the currently accepted picture of kidney tubular function.

Immunological Studies with Labeled Antigen

Although a large body of practical information about immunization to disease has been amassed, the basic question of how the immunizing agent, antigen, stimulates the production of antibody and then is destroyed by it is still unanswered. In this study the problem has been approached by trace-labeling a suitable antigen, diphtheria toxoid, and following its distribution and destruction in the experimental animal, particularly in the lymph tissues known to be a site of antibody formation. Such small amounts of antigen are involved that quantitative information could be obtained only by use of tracer techniques. When these data were correlated with measurements of the antibody concentrations in the same tissues, the results showed that: a) the largest percentage of antigen destruction occurred at the site of antibody formation; b) there was no direct relationship between the amount of antigen present and the amount of

Figure 6. Measurement of radioactivity in a guinea pig following an injection of radioactive diphtheria antibody. In this way the distribution and metabolism of the antibody can be followed throughout its stay in the body.

antibody produced; and c) an intermediate was required for the synthesis of antibody.

To complete the kinetic analysis of these data it was necessary to measure the rate at which diphtheria antibodies were destroyed in the blood. Diphtheria antibodies labeled with I^{131} were prepared by iodinating guinea pig immune serum,

specifically precipitating the antibodies with antigen, and then redissolving the tagged antibodies by an exchange reaction with unlabeled antibodies. This preparation was injected intravenously into guinea pigs and the antibody-bound activity was followed as a function of time. The half-life, that is, the time in which half the antibody was destroyed,

was found to be 5.7 days. Control experiments with unlabeled antibody analyzed by immunological methods gave a value of 5.9 days. The good agreement between the control and experimental data indicated that the labeling did not significantly alter the properties of the antibody. When the experiment was repeated in irradiated animals, a half-life of 5.8 days was obtained. Thus it was evident that x-irradiation had no effect on the tissues involved in the destruction of antibody. Since the half-life of guinea pig gamma globulin was known to average 4.5 days, it was concluded that the modified gamma globulin which was diphtheria antibody was more resistant to the normal process of enzymatic breakdown.

Veterinary Medicine

Studies have been under way for several years on a number of animal diseases. These include: 1) a histologic study of the retina in hereditary blindness of Labrador dogs; 2) blindness in collies; 3) optic degeneration in collies due to canine distemper; 4) thiamine deficiency in cats; 5) myositis in guinea pigs; 6) pathologic studies of the inner ears of white mink with hereditary deafness; 7) retinal atrophy in swine caused by hog cholera virus; 8) serositis in ducks; and 9) hepatic cirrhosis in sheep. Pathologic descriptions of these diseases are either complete or in progress.

BIOPHYSICS

Effects of Radiations on Large Molecules

The Brookhaven 60-inch cyclotron has been used in two investigations. The first is a comparison of the effectiveness of particle beams of widely different energy transfer properties in inactivating dry preparations of T1 bacteriophage. The process of energy transfer to secondary electrons transports energy forward along the primary particle track and radially away from it. Since the dry virus preparations are very thin and can be assayed at moderately high resolution, some of these effects can be tested with them. Electrons near minimum ionization are about 40% less effective than cyclotron protons of 25-fold higher energy transfer per unit length of track. The effect appears to result from lack of equilibrium of the electron beam with forward-moving energetic secondary electrons. Similar effects are found at the limit of detection for 40-Mev alpha-particle bombardment. Alpha-particles of this energy show effectiveness within 5% of that of 1.8-Mev protons, which are quantitatively the same in linear energy transfer but qualitatively different. In this system a difference in radial migration of energy from the primary particle

Figure 7. Equipment for measuring the film pressure exerted by a protein monolayer spread on the surface of a support solution. An analytical balance, with sensitivity increased 100- to 1000-fold by the addition of simple electronic components, is used to measure the pull of the liquid meniscus upon an immersed glass coverslip (attached to the long Lucite rod in the left portion of the photo). The coils used for the electromagnetic control and measurement of the force can be seen enclosing the mid-portion of the rod, whereas the photoelectric unit for the end-point determination is in the right upper background. This is a very delicate test for changes in proteins taking place as a result of irradiation.

track does not change the effectiveness of the track. At this energy transfer level the events along the tracks are not close enough together to make the track structure important for the virus inactivation.

In the second project making use of the cyclotron, the enzyme xanthine oxidase has been bombarded and assayed with respect to two rather different activities, hypoxanthine oxidation and formaldehyde dehydrogenation. The interest of this work is in the general finding for enzymes of

large target masses within which one ionization event inactivates the catalytic property. The target masses are too large to be identified with substrate binding sites. Bombardments at various energy transfers have failed to separate the properties of xanthine oxidase, so that quite different substrates have not led to different target masses. The seat of primary radiation sensitivity in this enzyme does not appear to be related to the specificity of substrate binding.

Both the structure and the stability of enzymes have been studied by irradiating them in different physical situations. Irradiations carried out in dilute aqueous solution are providing information about the size of molecular surface structures necessary for biological function, whereas the effect upon protein stability of factors such as physical state has been determined from irradiation of enzyme monolayers. Trypsin has been found to lose all its activity once it is in the "gaseous" state. In "solid" (i.e., very viscous) monolayers ultraviolet inactivation was a one-hit event, whereas in very fluid films inactivation appeared to require multiple hits.

Neutron Irradiation Facilities

For several years the thermal column has provided facilities for irradiation of biological material with both fast and slow neutrons. The calibration of this facility has proved to be a rather difficult measuring problem but seems to be reasonably well completed now. The neutron spectrum in the fast neutron facility is very close to that of a fission spectrum, and the gamma contamination and slow neutron contamination in this facility are quite small. Tissue-equivalent ionization chambers have been constructed, and measurements have been made in both facilities. These measurements coincide rather closely with computations for the known radiations present within the facility; hence it is possible to express dosages either in terms of tissue-equivalent exposure or in absolute physical terms.

The thermal column has been in use almost constantly for the last several years and often the demand exceeds the availability. For this reason, one of the tunnels under the reactor has been converted into a neutron radiation facility which can absorb some of the work normally done in the thermal column. In this facility sufficient shielding has been added so that gamma contamination is very low, but it is impossible to add enough graphite to thermalize the neutrons completely. Consequently, the exposures are to a mixture of thermal, epithermal, and fast neutrons. For the

production of mutations no difference has been found between the effects of thermal neutrons and fast neutrons if the dosage is carefully controlled. The tunnel has been calibrated against the thermal column from a biological point of view; thus, for routine production of mutations in seeds, scions, etc., the tunnel can be used as readily as the thermal column, and the latter is freed for more precise experimental work.

BIOCHEMISTRY

Enzyme Chemistry

The work in enzyme chemistry has centered around two main problems: a) the mechanism in certain fundamental physiological activities such as carboxyl activation and muscle action, and b) the study of the enzymes themselves to ascertain the source of their potent catalytic activity.

The work on peptide formation using the O^{18} isotope is an illustration of one type of study. ATP hydrolysis energy is known to be used in the formation of peptide bonds, but the way in which the energy is transferred from the ATP to the carboxyl group is obscure. One possibility is that the ATP energy is transferred indirectly, first to the protein molecule and from there to the amino acid. This mechanism would be analogous to coiling a spring and then using the coiled spring as the energy source for a second reaction. A second possibility is a series of substitution reactions in which the phosphate of ATP is shuttled like the cars on a railroad train until the final products are obtained. This hypothesis was tested in the formation of the vitamin pantothenic acid by making O^{18} -labeled pantoic acid and mixing it with enzyme, ATP, and beta-alanine. When the pantothenic acid was formed the O^{18} was found exclusively and quantitatively in the adenylic acid produced as a by-product. This finding showed that the second of the two possibilities listed above was correct. Moreover, the generality of the conclusion was strengthened by similar results in the formation of another naturally occurring peptide, glutamine. The results give valuable clues to the mechanism of formation of these compounds and also to the way in which living systems synthesize their proteins.

Hemoglobin Synthesis

Hemoglobin, the oxygen-carrying pigment of red blood cells, is made up of three components: globin, a protein; protoporphyrin, a nitrogenous organic base; and iron. While in bone marrow, the cells that are to appear in blood as red cells manu-

facture the protein and porphyrin from certain starting materials. The cells take up iron from the surrounding fluid and add it to the porphyrin to make heme, which then joins the globin to give hemoglobin.

The structure and formation of the protein component of hemoglobin are as well understood as those of most other proteins. Much is known about the units from which the porphyrin is made and about the steps involved in its production. Relatively little is known about how the iron gets into the cell and how heme is formed. It is these latter processes that are under study.

Iron uptake by red cells taken from x-irradiated animals falls to a very low level because the irradiation stops cell formation in bone marrow, and consequently no new cells enter the blood stream. The red cells in the blood at the time of irradiation age normally and lose their ability to take up iron. However, at any given time after irradiation, those cells that still take up iron retain the ability to make heme. In contrast with iron uptake, formation of heme from iron and porphyrin by the broken-cell preparation of red cells changes less after irradiation. Presumably, the capacity of the cells to form heme decreases less with age than their ability to acquire iron.

Carbohydrate Metabolism

A project dealing with the control of mammalian carbohydrate metabolism by various hormones has been continued in collaboration with a group at the New York University Medical School. A number of facts have been established by the use of techniques involving the tagging of the blood glucose by administration of extremely minute (by weight) amounts of C^{14} glucose.

The lowering of blood sugar by insulin injected into the fasting normal animal is almost entirely the result of an increased rate of glucose uptake by the tissues; however, there is a concomitant transient decrease in the rate at which glucose is supplied to the blood by the liver. Recovery from insulin-induced hypoglycemia is due to a several-fold increase in the rate of glucose supply by the liver.

The hypophysectomized dog (one which has had its pituitary gland removed surgically) has no growth hormone. It also has no adrenal cortex stimulating hormone (ACTH), and hence is deficient in the adrenal cortical hormones affecting carbohydrate metabolism. Such an animal is extremely sensitive to the blood sugar lowering action of insulin. It has been discovered that one reason for this insulin hypersensitivity is the failure

of the liver to respond to hypoglycemia with an abundant outpouring of glucose. This failure is at least as important as the previously well-established exaggerated tissue uptake of glucose in response to injected insulin.

In spite of its high sensitivity to insulin, the hypophysectomized dog has been found to have a lowered tissue uptake of glucose in the fasting state; the conclusion drawn from this observation is that the dog has adjusted its endogenous insulin secretion to a very low level.

Cortisone therapy in the hypophysectomized dog has been found to restore the ability of the liver to respond to hypoglycemia, as was expected from previous knowledge. On the other hand, the liver of the adrenalectomized dog (which has no adrenal cortical hormones) has been found to be only slightly deficient in its response to hypoglycemia. A pituitary factor evidently can compensate for the missing adrenal cortical hormones.

PLANT PHYSIOLOGY

Comparative Biochemistry of Photosynthesis

A study has been completed of the phylogenetic distribution and structural association of several enzymes concerned with CO_2 fixation and reduction in photosynthesis. A direct investigation of isolated chloroplasts from spinach showed that the enzyme responsible for the primary fixation of CO_2 by plants was bound to the chloroplasts. A series of experiments was done in which the chloroplasts of both algae and higher plants were removed by the action of metabolic analogs or radiation. In all cases it was shown that the first two enzymes concerned with sugar synthesis from CO_2 were removed with the chloroplasts. A survey of plant, animal, and microbial organisms was undertaken to study the distribution of the photosynthetic carboxylation system in nature. It has been found to be associated primarily with photosynthetic organisms but a few striking exceptions have been noted. These exceptions indicate, for the first time, the potential importance of the carboxylation of pentoses by other than photosynthetic organisms.

Plant Metabolism

A study of the pathways of carbohydrate metabolism has been under way for several years. The problem has been attacked by the labeling of intermediates and by the isolation and identification of the enzyme systems responsible for the reactions involved.

One of the important recent findings is that cell-free extracts of yeast convert ribose to ethyl

Figure 8. An apparatus for the continuous growth of algae under controlled conditions. The flasks are gently rocked in a constant-temperature water bath while being illuminated from below. The nutrient and gas content of the medium can be rigidly controlled.

Figure 9. A new technique for detecting disease-resistant mutants in grain. The grain seed is treated with a toxin from the disease organism which is grown in mass culture. As the seed germinates on moist filter paper the toxin kills all susceptible seeds but allows resistant seeds to grow normally. Resistant seeds can be separated from the rest and grown to maturity. A) Normal seeds treated with toxin; no seeds germinated. B) Toxin-treated seeds from an irradiated plant; one disease-resistant mutant can be seen. C) Control: normal seeds not treated with toxin; 100% germination.

alcohol and CO_2 by converting the pentose to a hexose which in turn is converted to the end products via classical yeast glycolysis.

The developmental age of a plant tissue has been found to affect the pathway of respiratory metabolism. Immature tissues respire glucose entirely or largely by the classical glycolytic scheme; but, as the tissues age and differentiate, use of an alternative pathway becomes increasingly pronounced, and in many mature tissues it accounts for at least 50% of the respiration.

Morphogenesis in Higher Plants

The initiation of root growth on the stem of the Lombardy poplar has been shown to be a light-controlled process. Light of relatively low intensity (150 ft-c) will completely inhibit the growth of roots if administered for only 15 min daily. A series of very brief intermittent exposures inhibits growth much more effectively than a single daily exposure to the same total amount of light. Action spectrum studies have revealed that the red portion of the spectrum is responsible for the inhibition. The photoreceptor pigment appears to be present in the root primordium rather than in the tissues of the bark, as determined indirectly by experiments in which parts of the cutting were shielded. A growing root apex is most readily inhibited by light on the third or fourth day following removal of the cutting from the tree; it is relatively insensitive to light before and after this critical period.

The growth of these light-sensitive roots is also dependent upon internal factors relative to the physiological activity of the tree as a whole. Roots appear over the entire surface of cuttings taken from dormant trees but are restricted to the extreme basal end of cuttings taken from actively growing trees, although the light reaction of both types of material is identical.

Trees have been brought intact into the greenhouse during their period of winter dormancy. Such forced trees will have precociously active growth accompanied by an out-of-season change from the nonpolar to the strongly polar root distribution.

Growth substances are known to be transported only from the apex to the base of the cutting and to accumulate at the base; therefore it seemed that the basal (polar) growth of roots could be associated with the high concentration of endogenous auxin in that area. The lack of roots elsewhere in the cutting seemed to imply a suboptimal concentration of auxin in actively growing stems. Accordingly, auxins were added to cuttings from

actively growing trees, and roots were induced to grow along the entire length of these cuttings.

Radiation Plant Pathology

Studies have been undertaken of the relationship between plant parasites and host plants, and the ways in which radiation can be used to elucidate this relationship. The parasites used were rust fungi, and the hosts included wheat, oats, and flax. The first of these studies sought to determine the radiation sensitivity of various plant disease organisms and the conditions under which it can be altered. Techniques for the processing of spores and evaluation of survival were developed as part of the study. Since the rust fungus is an obligate parasite, survival was based on the number of infections produced on host plants inoculated with a given amount of irradiated urediospores.

Preliminary response curves have been obtained for urediospores of flax rust (Race 1, *Melampsora lini*) and wheat stem rust (Race 15B, *Puccinia graminis tritici*) exposed to ultraviolet, x-rays, gamma-rays, thermal neutrons, and fast neutrons. Similar determinations were made for oat crown rust (Race 202, *P. coronata avenae*) and oat stem rust (Race 7A, *P. graminis avenae*) exposed to two of these radiation sources. Flax rust was easily the most radiosensitive, the LD50 being approximately 30,000 r for x-rays at 55% relative humidity and 7.0×10^{13} neutrons/cm² for thermal neutrons. The corresponding LD50 values for wheat stem rust, as representative of the three other rusts mentioned, were approximately 75,000 r and 11.7×10^{13} neutrons/cm². The latter figures denote a high degree of resistance to radiation injury, particularly to that from neutrons.

Of the several variables studied for x-rays, the relative humidity of the air (control of spore moisture content) during irradiation was the most important. The greatest resistance to radiation was apparent at zero percent relative humidity; at humidities above 75% the sensitivity increased sharply and reached a maximum at 98%. Relative humidity was less important in neutron irradiation.

A number of cultures have been screened for radiation-induced mutations. Mutations for virulence probably constitute an important source of pathogenic variation in rusts in nature, but experimental evidence of this has been lacking.

A high frequency of mutation from avirulence to virulence was obtained in a preliminary experiment involving x-ray treatment (LD50) of flax rust urediospores. Two of the rust gene loci being studied differed greatly in mutation frequency, a factor which may be of direct concern to the plant

breeder in evaluating the usefulness of the corresponding genes for resistance in new flax varieties.

In addition to the pathogenic mutations a white-spored culture of flax rust has been obtained from x-rayed spores of a normal orange-spored culture. Such color-aberrant types are of value as markers in certain fundamental studies.

A change of rust reaction has been accomplished by exposure of the host plant to chronic gamma radiation or to acute x-ray doses. This is a physiological response and is being exploited as a means of studying the complex and little-understood nature of resistance in the host plant.

Seedling plants of some wheat varieties resistant to a particular race of stem rust became moderately susceptible following irradiation at doses from 3000 to 5000 r, the lower figure sufficing for an acute x-ray dose. All plants were correspondingly stunted, but the rust reaction change is apparently gene controlled, since the resistance breakdown did not occur in all the resistant varieties tested and some varieties responded differently to two races of the rust. Both the injury and the rust response were most manifest in young leaf tissue, in actively dividing or enlarging cells. Oat plants responded similarly to infection by crown rust and stem rust. In flax the reverse trend occurred; resistant varieties remained resistant and the susceptible varieties became moderately resistant. The results on flax are preliminary, but it appears that the observed effect is essentially an inhibition of the rust fungus rather than an alteration of host response. Partial-plant exposures have shown that this changed rust response is initiated not in the leaves but in the shoot apex area; possibly the root-shoot transition area also is involved. The exact location of the sensitive region and the nature of this response remain to be determined.

CYTOLOGY

Radiation Cytology

During the past year cytological investigations have been directed toward a study of the relationship between chromosome duplication and chromosome breakage. When cells are irradiated at certain stages of nuclear division, bridges with "side-arms" appear at the following anaphase. This type of aberration has been interpreted as evidence of breakage of strands below the chromatid level. The study is still in progress; detailed analyses of chromosome behavior as late as three cell divisions following exposure to irradiation should show whether or not this interpretation is correct.

Figure 10. Plant tumors on a tobacco plant grown in a nutrient solution containing radioactive phosphorus. The radioactivity is incorporated into the plant tissue and acts on it to produce a tumor. Many tobacco plants, such as this one, eventually are composed almost entirely of tumor tissue.

Investigations on plants with high chromosome numbers have continued and have confirmed earlier work showing that a major factor influencing the tolerance of plants to ionizing radiation is the number of hereditary units (chromosomes) per cell. Chromosome number, which in these studies varied from 8 to 384, is a significant factor in determining radiosensitivity, especially within closely related plant species, but it is by no means the only factor.

Studies of radiation-induced tumors in certain plants (tobacco hybrids) have continued. These experiments have shown that chronic irradiation from an external source (Co^{60}), from an internal isotope (P^{32}), or from acute x-ray treatment produces a great increase in the frequency of tumors and an earlier onset than is observed in control plants. During the past year experiments have been directed toward elucidating the nature of the process of tumor induction and its possible relationship to other known physiological or morphological abnormalities which result from ionizing radiation. These experiments include cytological, histological, and morphological studies as well as studies of tumors grown under controlled conditions in sterile culture.

Cytochemistry

It is generally believed that the substance responsible for the transmission of hereditary characters is desoxyribonucleic acid (DNA) and that each hereditary character (gene) is represented by a different form of DNA. According to this theory DNA must be capable of self-duplication from its precursors during the process of cell division. The theory postulates further that DNA in some way forms ribonucleic acid (RNA) which then diffuses out into the cytoplasm of the cell where it in turn is capable of synthesizing the enzymes which finally regulate the growth and metabolism of the cell. Thus, all living processes are regulated by DNA.

This theory of growth and reproduction is tenuous at best and needs verification at many points. Several phases of this general picture are being investigated cytochemically primarily by use of the autoradiographic technique. Living material is grown on various isotopically labeled precursors, and after incorporation of the isotope into the nucleic acids the tissues are fixed and processed. By means of certain extraction procedures, the various labeled substances are selectively removed from tissue sections so that only the nucleic acid remains. After exposure of the section to a photographic emulsion, the autoradiograph is observed under the microscope and sites of activity are correlated with various cellular structures. Information on the rate of synthesis is obtained by counting the silver grains over a particular structure.

To date, emphasis has been on the extraction procedures and it appears possible selectively to remove labeled substances in such a way that only RNA and DNA, or only DNA itself, remain in the tissue. Isotopic phosphorus in the form of phosphate ions has been incorporated into the DNA of onion root nuclei. Other nucleic acid precursors, such as adenine, orotic acid, and thymidine, labeled with C^{14} or H^3 are being studied. Substances labeled with H^3 show particular promise, since the resolution obtained with this isotope is very much better than that obtained with almost any other isotope.

MEDICINE

On June 26, 1956, ground was broken for the construction of the new Brookhaven Medical Center. This new building will provide facilities for the forty-eight research scientists called for by the long-range medical program approved some years ago. The new center will have a forty-eight bed research hospital and a reactor designed spe-

cifically for medical and biological work. The reactor will employ fuel elements of the "swimming pool" type, ordinary water as a coolant, and an air-cooled graphite reflector. The Department looks forward with pleasant anticipation to occupying its new quarters in early 1958. Further details on the construction of the new building are given in the Introduction to this report under Construction Program. The Joint Committee on the Accreditation of Hospitals gave the hospital full accreditation after a survey of its facilities.

Thirty-six staff scientists together with thirty other scientists, who were research collaborators, guests, or consultants, from twenty-four institutions, and nine students from nine different colleges and universities, shared in the year's activities.

Research in a medical center is directed basically toward the alleviation of human suffering. The problem is approached at many levels ranging from efforts to develop immediate and practical therapy based on established principles to basic research aimed at increasing our understanding of the activities of living organisms. The knowledge gained in the basic research program serves continually to open up new areas for the application of scientific principles to medicine.

CANCER

Radiation and many of the problems of cancer are intimately related. Radiation can induce malignant growth. On the other hand, radiation is often the only useful therapy for a malignant growth which has so infiltrated normal tissue that surgery is no longer effective. Unfortunately, the same radiation which arrests the growth of a tumor may also injure normal tissue, and an understanding of the nature of this injury is essential for the intelligent application of radiation therapy and the utilization of nuclear reactions for therapeutic purposes.

Several years ago this Department began an investigation of neutron capture therapy. Neutron capture therapy is based on the following principles: that capture of thermal neutrons does not occur with the same readiness for all elements; that by proper selection of a target element neutron capture can result in immediate production of energetic heavy particles whose effects will be sharply localized; that a differential in concentration of target element can be obtained between tumor tissue and normal tissue; and that by limited exposure of a region the desired reaction can be further localized. For the experimental trial of this procedure boron-10 was selected as the best target element as compared with lithium-6 and

uranium-235. The energy of boron-10 nuclear disintegration is transmitted through an alpha-particle and an energetic lithium particle, the maximum range of the particles being about 10 microns. The assumption is made that thermal neutrons are relatively innocuous to biological systems in the numbers required for the therapeutic procedure. This form of therapy seems promising in the case of the highly malignant brain tumor, glioblastoma multiforme, for which there is no satisfactory treatment. Neutron capture therapy is particularly suitable for the treatment of brain tumors. When borate is injected, the blood-brain barrier allows only small amounts of borate to pass from the blood into the normal brain tissue; presumably within brain tumors there is no blood-brain barrier, thus the boron moves promptly from the vascular system to the intra- and extracellular space of the tumor at a rate sufficiently rapid to produce an appreciable increase in the concentration of boron in the tumor tissue, soon after the borate injection.

Nineteen patients have been treated at Brookhaven for glioblastoma multiforme with neutron capture therapy. This number has been sufficient to yield encouraging results and to indicate certain problems which need further intensive study in order to permit the development of a practical and successful procedure.

During the last fiscal year primary attention has been devoted to studies in placement of the target atom and to evaluation of results thus far attained. In addition, by experimental studies in animals it is hoped that parameters can be set for neutron exposure and boron concentration leading to tumor elimination. These studies are being made in preparation for a new series of patients to be admitted during the latter part of the coming fiscal year.

Because a radiation dermatitis developed in some patients following neutron capture therapy, the factors involving skin have been studied by exposing swine under conditions similar to those used for the treatment of patients. Following a control radiation with neutrons to one side of the head, animals were injected intravenously with a borax-glucose solution and irradiated on the opposite side of the head. These studies suggest that the main factor in producing the dermatitis was the $B^{10}(n,\alpha)Li^7$ reaction. In other studies on skin, experiments have been carried out with P^{32} -labeled phosphate as a tracer, aimed at establishing the severity of a radiation skin burn immediately after radiation and prior to the appearance of superficial skin lesions.

The general pattern of slow neutron penetration in tissue was further studied by the use of foil activation techniques in phantoms having absorption characteristics similar to those of tissue. The relative biological effectiveness of radiation delivered by boron and lithium in the capture process has been estimated in animal studies (with mice) in terms of mortality for a 30-day period and the amount of weight lost by the testes, spleen, and thymus.

By the LD50 estimate (30-day mortality), the relative biological effectiveness of the radiation resulting from the capture of thermal neutrons by boron was found to be 1.7 compared with that of cobalt-60 gamma radiation, and 1.1 compared with that of 250-kvp x-irradiation. Markedly shortened survival time has been observed in normal mice receiving both boron and thermal neutron irradiation, compared with that in normal mice receiving neutron irradiation, cobalt-60 gamma radiation, or x-irradiation alone.

An additional capture element, lithium-6, has been studied. The apparent relative biological effectiveness of recoil alpha and tritium particles from lithium has been found to be higher than that of those from boron.

The viability of mouse brain tumor following neutron capture irradiation has been studied in the following way. Each animal of a group of mice received a tumor transplant which was allowed to grow for about two weeks. The mice were then divided into four groups. Group A was exposed to thermal neutrons; Group B received only an injection of boron-10 (in the form of sodium tetraborate decahydrate); Group C was given no treatment; and Group D was injected with boron-10 and then exposed to thermal neutrons. Immediately after the treatment all the mice were sacrificed, and the tumor tissue from each was transplanted into 10 normal recipient mice. Data on mortality due to tumor growth and on longevity were then collected during a 60-day observation period. (These mice received no further treatment.) Mortality was as follows: mice receiving tumors from Group A, 92%; from Group B, 93%; from Group C, 93%; and from Group D, 35%. The results indicate that treatment with boron-10 plus thermal neutron irradiation decreases tumor viability, since transplants from mice treated in this way (Group D) caused a much lower mortality among recipients. A new boron compound, sodium pentaborate decahydrate, is being used in similar experiments in order to compare it with sodium tetraborate.

In other studies with mice, the distribution of boron in muscle, tumor, and normal brain was determined at various times after the administration of borate solutions. Five minutes after intravenous injection, the ratio of boron concentration in tumor to that in normal brain was 6.5 for sodium pentaborate and 3.5 for sodium tetraborate; this finding demonstrates a more favorable distribution in the case of the pentaborate. The effectiveness of sodium pentaborate as a capture compound is under study.

In the clinical studies up to 3.3 g of boron have been administered as borax intravenously to single patients at one dose. The most striking symptoms observed have been intense gastro-intestinal stimulation and a violaceous discoloration of the skin accompanied by a mild peripheral vascular collapse. The symptoms have not seriously interfered with the therapy. However, since it would be desirable to give even more boron, extensive studies on the effect of large doses of boron in experimental animals have been undertaken.

In animals the intravenous administration of therapeutic doses of boron produced a transient lowering of blood pressure followed by an extended rise, reduced the respiration rate and amplitude, and caused the electrocardiogram to show an inversion of the T wave and a depression of the ST segments.

Studies of the distribution of borax and three boron-containing dyes in brain tumors of mice following intravenous injections were made by mounting tissue slices on photographic emulsions and exposing the preparations to slow neutrons. The results indicate that the uptake of boron dyes by the tumor is rapid and that the dyes appear in the highest concentrations at the growing edge of the tumor, with a high differential in uptake between the tumor and the normal brain. Studies are continuing on the water solubility of a number of boron-containing organic compounds.

Studies of neutron capture therapy will definitely be facilitated by the reactor installation in the new Medical Center. The flux at the treatment point will be increased from a range of 3 to 15×10^8 neutrons/cm² to a range of 1 to 10×10^{10} neutrons/cm². The principal advantage will be the shortening of the exposure time so that the exposure can be limited to the period in which the ratio in boron concentration between the tumor and normal brain is optimal. Modifications in the reactor design will also permit experimentation with beams of epithermal neutrons. In addition, having the reactor facility attached to the hospital will greatly

facilitate transport of patients, personnel, and equipment.

The critical experiments group of the Nuclear Engineering Department has set up a prototype for the proposed reactor design and has determined the critical mass and temperature coefficients. Experiments to evaluate the quantity and quality of the radiation which will be delivered by the reactor have begun, along with studies of moderators and shielding. The final design will provide a uniform and clear treatment area, 8 inches square.

When a tumor undergoes rapid proliferation, there is a concomitant increase in nuclear activity associated with the synthesis of large amounts of deoxyribose nucleic acid. While a good deal of information is available about the origin of the purine and pyrimidine base of deoxyribose nucleic acid, little is known about the source of the deoxyribose. A study of the metabolic precursors of deoxyribose has been started.

There have been several reports that humans can produce antibodies to their own tumors. If so, the detection of such antibodies and studies of their tissue specificity will become a major field of cancer research. An isotopic tag for such antibodies would be a very useful tool. Such antibodies might serve as vehicles for carrying short-lived isotopes to tumors where they might deliver lethal amounts of radiation. Astatine-211, a short-lived isotope, has many qualities which make it suitable for both purposes. Astatine-211 has been prepared by bombarding bismuth with the beam of the sixty-inch Brookhaven cyclotron. It has a half-life of 7.5 years, and emits alpha-particles with energies of 5.9 and 7.4 Mev. From the track of these alpha-particles, its precise intracellular location can be determined by radioautographic techniques. Techniques for the isolation of astatine from cyclotron targets have been improved. Astatine-tagged antibody globulin is now being made by reacting the protein with previously astatinated organic carriers such as the acid chloride of astato-benzenesulfonic acid. Astatine can be incorporated into gamma globulin by this procedure without appreciable denaturation of the protein. Albumin and fibrinogen have also been labeled; this indicates that the procedure is of genuine applicability and can be used for precise location of a number of biologically important macromolecules within tissue.

THE BIOLOGICAL EFFECTS OF RADIATION

Various effects of radiation injury are being investigated. These include the effect of radiation

on bone marrow, gut, and connective tissue, on immunochemical responses, and on the incidence of cancer in an exposed animal population. Interest in the effects of radiation on the bone marrow has centered about the platelet. Experiments have been carried out with sulfur-35 labeling to determine the origin and ultimate fate of blood platelets. This information is vital for the treatment of persons exposed to radiation, since the hemorrhage which occurs following radiation is associated with the disappearance of platelets from the blood.

Developmental work on equipment for removing leucocytes and platelets from the blood continues. Methods are being developed to test for antibodies against platelets since formation of such antibodies may be a problem in patients receiving multiple injections of whole blood following radiation injury. Ten patients with idiopathic purpura were studied, but no agglutinins against platelets could be detected.

Another important aspect of acute radiation injury is the destruction of the lining in the intestinal tract. Studies of the effect of radiation on the physiology of electrolytic transfer from the lumen of blood vessel to the gut are being carried out with isotopic tracers.

Thymus and Peyer's patch tissue from animals immunized with tetanus antitoxin are capable of producing antibodies against tetanus toxin when transplanted into the anterior chamber of the eyes of cobalt-60 gamma irradiated mice. The morphology of the aging thymus has been correlated with its increasing ability to produce antitoxin under these conditions.

The study of the cancerogenic action of local beta radiation and graded doses of whole-body gamma radiation has continued. No lesions have developed at the site of the beta burns. However, the incidence of breast tumors is approaching 100% in the rats which have received 400 rep of total-body radiation.

Heavily encapsulated Type 3 cells of *D. pneumoniae* were found to be more sensitive to gamma radiation than the corresponding rough, unencapsulated form. A dose of 25,000 rep was required to produce an LD50 in the unencapsulated cells compared to a dose of 10,000 rep in cells surrounded by capsular material. If the encapsulated cells were treated with an enzyme which hydrolyzed the capsular material, the organisms then had the same radiation sensitivity as unencapsulated pneumococci.

Studies continue on the effects of radiation on enzymes in their physiological environments. Plas-

ma, red blood cells, and the brains of rats were lyophilized and exposed to cobalt-60 gamma radiation. From the rates of inactivation of the acetylcholinesterase in each tissue, the sizes of the radio-sensitive targets were calculated. There was a striking difference between the sensitive volume of brain and red blood cell acetylcholinesterase, which indicates that these two enzymes which functionally appear to be almost identical have certain differences *in situ*.

DISEASES OTHER THAN CANCER

Diseases of Connective Tissue

Connective tissue is found in every organ of the body. It is susceptible to a number of pathological abnormalities, the most common being those associated with rheumatoid arthritis and senescence. Eight patients with rheumatoid arthritis were studied and treated during the last year. One plausible theory concerning the cause of rheumatoid arthritis assumes that the inflammation results from the formation of antibodies directed against antigens normally present in the victim's tissue. Quantitative microprecipitant reactions are being developed to study several naturally occurring antigenic substances as possible factors in this auto-immunization.

Diseases of connective tissue are accompanied by changes in the concentration of collagen, glycoproteins, and mucopolysaccharides in areas in which the disease is active. The protein, collagen, contains hydroxylysine, an amino acid that has been found only in this protein. Tracer studies with carbon-14 indicate that hydroxylysine is formed from dietary lysine, and not from pre-formed, free hydroxylysine. A clue to the possible function of hydroxylysine in collagen is provided by the observation that only a portion of the hydroxylysine residues can be destroyed by sodium periodate, a reagent which would completely destroy hydroxylysine in simple peptides. The significance of this partial masking of hydroxylysine in the organization of normal and pathological connective tissue is being investigated.

Associated with the collagen of mucopolysaccharides of connective tissue are a variety of glycoproteins. These are very difficult to isolate and purify. The plasma, however, contains an alpha-1-glycoprotein which can be prepared in crystalline form. A patient with active rheumatoid arthritis usually shows an elevation in the amount of this material in the plasma. A clear understanding of the chemical nature and physiological function of such glycoproteins may suggest new approaches to

the therapy of rheumatoid arthritis. Previous reports indicate that the glycoprotein is a poor antigen; however, by incorporation of the glycoprotein into Freund's adjuvant, a precipitating antibody has been produced.

An attempt is being made to determine the relationship between the carbohydrate and protein moieties of this material and sialic acid, a unique substance recently characterized in another laboratory. Since alpha-1-glycoprotein is not attacked by conventional enzymes, bacteria were cultured on media containing the glycoprotein. Filtrates of these cultures contain enzymes capable of breaking the glycoprotein into small units much more suitable for chemical investigation.

The metabolism of the sulfated mucopolysaccharides of connective tissue can be studied by injecting inorganic sulfate, labeled with sulfur-35, into an animal. The sulfated mucopolysaccharides of connective tissue then become labeled. However, this labeling is not limited to connective tissue. Other substances, at present unknown, of presumably similar chemical composition also become labeled. One site of intense labeling is the platelet. Another surprising site of sulfur-35 concentration was found to be the proximal convoluted tubule of the rat kidney, where the presence of an insoluble macromolecule containing sulfate within the epithelium was found by radioautographic technique.

Nephrosis

The nephrotic syndrome is characterized by impaired kidney function, edema, and elevations in the lipides and cholesterol of plasma. At the same time there is a depression in the levels of plasma protein, particularly albumin. Peptide moieties of human lipoproteins were labeled with iodine-131, and the metabolism of these proteins studied in non-nephrotic patients and in children with the nephrotic syndrome.

It would appear that a system for the unidirectional conversion of low-density beta-lipoprotein to proteins of higher density containing less lipides is operative. There is a partial failure of this conversion system in children with the nephrotic syndrome, coupled with an overproduction of the high lipide, low-density lipoproteins. An experimental nephrotic syndrome can be produced in rats by the injection of an aminonucleoside from the antibiotic puromycin. In animals so prepared there is a diminished incorporation of carbon-14 into the cholesterol isolated from the plasma, liver, and kidney of the lipemic animal. These results are in accord with the concept that there is an im-

pairment in the ability of liver to remove lipides from plasma.

Experiments with iodine-131-labeled albumin with nephrotic children have indicated that not only is there a large excretion of albumin into the urine but also an increase in albumin catabolism. This increase in albumin catabolism was assumed to be caused by nutritional problems confronting the nephrotic child due to alterations in lipide and protein metabolism. In order to test this hypothesis, some mice were fed diets which would not provide their caloric requirements and others were fed a diet deficient in protein. In neither case was there an increase in the catabolism of albumin. Depletion of carbohydrate, fat, and protein resulted in a decrease in the metabolism of the labeled albumin and labeled globulin rather than an increase.

Hypertension

This syndrome is characterized by elevated blood pressure produced by constriction of the smooth muscle of the arterioles. If a person suffering from hypertension is placed on a low sodium diet, there may be a very significant fall in blood pressure. The reason for this fall is not known. Interviews carried out in the Division of Industrial Medicine with Brookhaven employees indicate that those who salt their food before tasting it and as a group have a significantly higher salt intake than other individuals, also have a significantly higher incidence of hypertension. It is not clear whether salt intake has a primary or secondary effect; therefore, studies have been under way for some time with radioactive sodium and potassium used as tracers to try to determine whether these minerals are handled in any way differently by the hypertensive person. These studies pointed up the desirability of concomitantly observing magnesium. Recently a short-lived isotope of magnesium-28, having low specific activity, has become available which will permit some, but not all, of the desired studies to be carried out on the association between the metabolism of magnesium and that of sodium and potassium. More emphasis is being placed upon the immediate effects of salt restriction. A population of rats rendered hypertensive by a high salt intake is now available. The effect of salt and sea water on the chemical composition and physiological function of the arterioles and aortas of these rats is under way.

Parkinson's Disease

Parkinson's disease is a syndrome characterized by tremor, rigidity, salivation, mask-like features, and a characteristic shuffling gait. These symp-

toms are indicative of injury to the central nervous system. In many instances the cause of the disease is a virus infection or is unknown. However, in certain instances there is a clear association with poisoning by heavy metals, among them manganese. Studies on the metabolism of manganese-56 (half-life 2.59 hr) have been initiated both in patients and in animals. The manganese has been administered both as manganous salts and coordinated with several chelating agents. Manganese is almost completely excreted in the intestinal tract in association with bile salts. Experiments on animals are being continued in order to gain more insight into the normal transport mechanism for manganese and into the variations produced in manganese metabolism by disease.

The tremor and rigidity of the Parkinsonian may be taken as evidence for an abnormal cerebral excitatory state. These patients respond to a number of drugs. The tranquilizer Thorazine

(chlorpromazine) aggravates the tremor, while Parsidol, pyribenzamine, and benadryl suppress it. The action of these drugs *in vitro* on slices of rat cerebral cortex has been studied. Pyribenzamine and benadryl enhance glycolysis, the process by which glucose is metabolized to lactic acid without the consumption of oxygen. Glycolysis is not observed in normal brain that is adequately oxygenated. The inhibitory action of these antihistaminics could be duplicated by omitting calcium from the medium or by adding an excess of magnesium. Present investigations are aimed at correlating the effectiveness of drugs used in the control of tremor in Parkinson's disease with their effects on the glucose metabolism of brain and the distribution of manganese.

Diabetes

The facilities of the Brookhaven Hospital are well suited to studying the nature of the metabolic

Figure 1. Quantitation of the body distribution of Mn^{56} by external scanning. A, Gamma radiation sensing element; B, scaling unit; C, automatic multichannel signal recorder; D, timing signal generator; E, radiation rate meter; F, automatic dose-rate recorder; G, intravenous infusion with 3-way stopcock for blood samples.

lesions in human diabetics. Two questions were of particular interest. First, can the human diabetic obtain a significant net formation of glucose from fat? Second, does the hexosemonophosphate shunt play a significant role in human diabetes? Both of these questions could be answered by analyzing the distribution of carbon-14 in the urinary glucose from two juvenile diabetics and four cancer patients considered to have normal carbohydrate metabolism who had received carbon-14-labeled acetate. While detectable carbon-14 was found in the outer carbons, the labeling of the inner carbons 3 and 4 indicated that glucose formation derived primarily from the intermediates of the citric acid cycle, CO_2 fixation, and reversal of the glycolytic pathway. There was no indication of a significant net formation of glucose from fat and no indication that the hexosemonophosphate shunt was abnormally active in diabetics.

Thyroid Disease

The emphasis has shifted during the last year from studies of patients suffering from malignant diseases of the thyroid to the problem of detecting hyperactivity of the thyroid with a short-lived iodine isotope which gives much less radiation than that given by iodine-131 to the gland during diagnostic tests. The Hot Laboratory has developed procedures for preparing iodine-132, a short-lived beta and gamma emitter with a half-life of 2.33 hours. An attempt is being made to design a convenient diagnostic test using iodine-132 which could be carried out by a physician within six hours.

Within the last few years several new analogues of thyroxine have been recognized as playing important roles in thyroid physiology. Several of these analogues are being studied at Brookhaven. Triiodothyronine has proved five times more potent than thyroxine in preventing goiter in rats fed propylthiouracil, but it is not more potent than thyroxine if the same test is carried out on birds. The acetic acid analogue of triiodothyronine is approximately one-tenth as active as triiodothyronine when assayed in either rats or fowl.

Polycythemia vera

Polycythemia vera is a disease characterized by a hyperplasia of the bone marrow. Abnormal numbers of red cells appear in the blood. As the disease progresses, the number of platelets increases, as well as the number of white cells. The increased viscosity of the blood associated with the increased number of cells favors thrombosis in the extremities, brain, and heart. The treat-

A - NORMAL THYROID

B - THYROID GLAND TREATED WITH IODINE -132

C - THYROID GLAND TREATED WITH ASTATINE -211

Figure 2. An example of the exploratory studies with radioisotopes is shown in these photomicrographs of animal thyroid. Picture A shows the normal thyroid gland filled with functioning follicles. In picture B the central portion of the gland has been destroyed selectively with the beta-particles from iodine-132. Picture C demonstrates the destruction of the entire gland by the alpha-particles from astatine-211. This study indicates that these particles do not differ in their qualitative action on tissues, but that their effects depend upon the quantity of energy released. These animal experiments provide data to assess the capabilities of new isotopes in the treatment of human diseases such as hyperthyroidism and cancer of the thyroid.

ment of choice for this disease is the use of the radioactive isotope of phosphorus, P^{32} , administered as phosphate. Nine patients have been treated in this manner. An attempt has been made to correlate the incidence of thrombosis with changes in the number of circulating platelets and red cells.

Parasitic Disease

Parasitic disease is a serious problem in the United States, and is even more of a problem in the tropics. If isotopic tracer techniques became adapted to studies in parasitology, new avenues of research would be opened of major importance in certain underdeveloped areas of the world. *Trichinella spiralis* larvae have been cultured *in vitro* in nutrient medium containing carbon-14-labeled alanine or glycine. There was a progressive uptake of carbon-14 from the medium during incubation. The experiment produced labeled larvae which could be used in subsequent studies of the life history of these parasites.

Pellagra

Pellagra is a common disease caused primarily by a dietary deficiency in the vitamin niacin. It is unlikely, however, that pellagra represents solely a niacin deficiency since the occurrence of the disease also depends on the nature of dietary protein. The amino acid tryptophane appears to be converted into niacin. Studies in this Department have been directed at clarification of the biochemical mechanism by which this occurs and evaluation of the efficiency of the various steps in the conversion. Both carbon-14 and tritium have been used in these tracer studies.

EUROPIUM-155 FOR DIAGNOSTIC X-RAY

Several samples of europium have been prepared in the BNL reactor. Europium has a half-life of 1.7 years. It decays 60% by 85-kev gamma-rays and 40% by 99-kev gamma-rays. Since it can be prepared in a carrier-free state, a point source is possible. Thus europium-155 appears to be a potential isotopic substitute for a diagnostic x-ray tube. The possibility of preparing larger samples of europium in the material testing reactor in Idaho is being explored.

ADMINISTRATIVE REPORT

The administrative efforts of the Medical Department continue to center around planning for the new Medical Center.

The development of the Research Hospital facility at Brookhaven has always been planned

to provide opportunities for collaborators from other institutions. This has posed a number of operational problems not yet entirely solved. The question of licensure requirement by New York State has been satisfactorily adjudicated after considerable correspondence. The problems of application of AEC requirements of personnel experience and responsibility are still under study, in part because of the relatively recent change in rules concerning this activity. The interrelationship of responsibility of each individual staff physician, his home institution, AUI, and AEC has been found to be more complex than originally estimated. Until at least a satisfactory provisional settlement has been worked out it is not possible to open our hospital services to the broad collaborative effort desired. It is hoped that these problems may be largely resolved during the coming year so that more complete utilization of hospital facilities can be accelerated.

The increasing demands made upon the Medical Department by the growth of the President's Atoms for Peace program, together with certain unique features of the Department's relation to other medical centers in this country, have led to the appointment of an Assistant to the Medical Director to help with the many questions raised by foreign visitors, to coordinate work at Brookhaven with work in other medical centers in this country and abroad which may lack Brookhaven's facilities, and to give continuous study to the role in medical education to be played by the Medical Department.

The total patient days for the hospital in this fiscal year were 4814 compared with 6457 for the previous year and admissions were 80 compared to 79. Of the total patient days, 92% were devoted to the care of research patients. The decrease in total patient days resulted in large part from discontinuance of the service for nephrotic children since inadequate time has passed for the replacing studies to require the same number of patients for study. Out-patient visits of research patients increased from 226 to 378. The research admissions from outside the state of New York decreased from 25% to 8% of the total. Clinical visits to the Division of Industrial Medicine again increased, from 9500 to 9711. Total x-ray visits decreased to 1595 from 1894.

The diorama on neutron capture therapy previously exhibited in Germany and Brazil was displayed at the Trade Fair in Milan, Italy.

Dr. Victor Bond of the Medical Department served as the medical representative in the Colombo Project group which visited fourteen

East Asian countries as a step in planning an Asian Nuclear Center.

During the past year Dr. Irving Serlin was one of the winners in a competition for a travel award by the Federated Societies for Biology and Medicine providing travel expenses to Brussels to present to the Twentieth International Physiological Congress, July 30 through August 4, 1956, a paper entitled "State of Tissue Acetylcholinesterase as Determined by Cobalt-60 Gamma Irradiation."

Dr. Lewis I. Gidez was invited to participate in the Third International Conference on Biochemical Problems of Lipides, sponsored by the Royal Flemish Academy of Sciences in Brussels, July 26-28, 1956, and to present a paper, "Lipide Metabolism in Experimental Lipemia."

Dr. Lee E. Farr participated in the International Conference on the Peaceful Uses of Atomic Energy in Geneva, August 8-20, 1955. He presented a paper on neutron capture therapy with Drs. Robertson and Stickley as co-authors. Dr. Farr was one of the Technical Advisors to the United States Delegation. Following the conference Dr. Farr visited Greece, Egypt, Turkey, and Denmark under the auspices of the U.S. State Department to lecture and confer on medical applications of atomic energy. The proceedings of the Geneva Conference included also papers by Drs. Stoner and Hanks on the metabolism of parasitic helminths and by Drs. Cotzias and Maynard on certain phases of cell dynamic states with short-lived isotopes exemplified by manganese-56 partition studies in organs and intracellular organelles.

Technical Operations and Services

A number of organizational units in the Laboratory provide the technical services and facilities essential to the research programs. Descriptions of their operations follow under appropriate headings.

REACTOR OPERATION

The BNL research reactor has continued to support programs from all the disciplines represented at the Laboratory. The following outside organizations have stationed personnel here as guests of the Reactor Department to carry out programs of research utilizing reactor irradiation and neutron beam facilities: Bell Telephone Laboratories Inc., California Research Corporation, Columbia University, Esso Research and Engineering Company, the Research Laboratory of the General Electric Company, Glenco Corporation, Mine Safety Appliances Company, Monsanto Chemical Company, New York University, Nuclear Development Corporation of America, Rensselaer Polytechnic Institute, and Westinghouse Electric Corporation. Several additional

guest scientists, including one from Sweden and one from Argentina, have participated in the activities of the Reactor Department in order to obtain training and experience in the use and operation of reactors. During the year the shielding program at the reactor was turned over to the United States Air Force's Wright Air Development Center and five scientists, formerly employed by Brookhaven, are now working on it under Air Force administration. Laboratory, office, and shop space at the reactor are now saturated. Counting-room facilities have been set up in a corner of one of the mens' shower-change rooms; the lunchroom has been converted into offices; and laboratory space is at such a premium that consideration is being given to the conversion of partly excavated areas under the present laboratory wings into additional laboratories and offices. Continuous efforts are required to stretch the research facilities beyond originally designed capacity in order to meet the increasing demands for space and access to neutrons. The reactor building, following declassification last December from the security category of a restricted area, has had a steady flow of visitors from all over the United States and many foreign countries.

Except for shutdown time (11%), chiefly for routine maintenance and rearrangement of experimental equipment, the reactor has been operated at an average power level of 23 Mw with no major breakdowns. Startup and shutdown procedures have been modified to provide better temperature patterns throughout the reactor. Improvements in the control and safety system included the development of 1) a safety amplifier featuring automatic testing, 2) a log amplifier to measure the reactor period, 3) a relay on the temperature rate indicator for acceleration when an offscale indication is obtained, 4) modifications in the instrument power supply which will reduce maintenance and decrease the chance of "scrams", 5) modifications in the exit air monitor system, and 6) modifications in the area monitoring system.

New bearings were installed on one of the cooling air fans and the bearings of two others were realigned. Under the five-year maintenance schedule, the emergency control rods were overhauled. The exhaust gas coolers were inspected and cleaned. It is planned to replace several badly

Figure 1. Approved type of new fuel element of enriched uranium, aluminum clad.

corroded sections and to install protection on the exposed steel portions of the coolers to prevent further corrosion.

Fabrication of new fuel-element assemblies has been continued on a need and replacement basis. Shipments of irradiated fuel to Oak Ridge were resumed in January, and 12 shipments have been made since then.

Studies on the plan to reload the reactor with enriched fuel have been continued. Various designs of enriched fuel elements and assemblies have been tested under actual operating conditions. An initial order for 300 fuel-element assemblies of the approved type (see Figure 1) has been placed with Sylvania Electric Products Inc. These units are expected to be delivered and placed in the central core position for further evaluation by early 1957. A hazards report outlining the opera-

ting, safety, and control factors of the reactor when loaded with highly enriched elements has been submitted to the Atomic Energy Commission for review.

ISOTOPE DISTRIBUTION AND SPECIAL MATERIALS

DISTRIBUTION OF IRRADIATED MATERIALS TO OTHER LABORATORIES

The shipment of radioisotopes and materials irradiated in the reactor or in the 60-in. cyclotron continued throughout the year. While the total number of shipments decreased from 1288 in fiscal year 1955 to 1256 in 1956, the volume remained about the same. Five hundred and eighteen shipments were made to 17 hospitals, 292 to 25 uni-

Table 1
Three-Year Summary of Shipments to Users Outside BNL

Source of irradiation or material	Fiscal years					
	1956		1955		1954	
Target conveyor - Unit	673	\$ 31,231.28	894	\$42,907.00	799	\$ 40,899.00
Target conveyor - S.I.	175	7,488.10	—	—	—	—
Pneumatic tubes	39	2,928.06	57	2,990.00	41	1,316.00
Air-cooled holes	39	2,061.00	49	5,914.00	28	6,492.00
Water-cooled holes	77	6,191.00	48	3,591.00	16	1,726.00
Thermal column	3	100.00	12	456.00	6	330.00
Tunnels	8	783.13	2	604.00	—	—
Experimental holes	70	8,032.02	76	13,011.00	42	7,633.00
Liquid nitrogen hole	—	—	4	1,032.00	—	—
South core hole	1	158.00	1	925.00	—	—
Gas facility	1	n/c	2	—	—	—
Fuel channels	1	98.00	—	—	—	—
Top holes	1	190.40	—	—	—	—
Iodine-132	52	5,925.00	27	1,768.00	—	—
Fluorine-18	10	682.50	7	315.00	—	—
Yttrium-90	1	50.00	4	200.00	—	—
Cesium-134	1	70.00	—	—	—	—
Magnesium-28	21	537.50	—	—	—	—
Special irradiations	83	1,200.86	105	1,872.00	36	50.00
Subtotal	1256	67,726.85	1288	75,585.00	968	58,446.00
Multicurie Co ⁶⁰ sources	7	33,560.00	10	50,025.00	3	15,185.00
Rentals at reactor	—	192,489.04	—	71,615.00	—	68,943.00
Subtotal	1263	293,775.89	1298	197,225.00	971	142,574.00
Cyclotron products	16	3,222.50	27	4,762.00	4	275.00
Biology thermal column	6	1,231.60	1	249.00	—	—
Total	1285	298,229.99	1326	202,236.00	975	142,849.00

Figure 2. Isotope distribution and special materials group monthly shipments.

versities, and 476 to 84 industrial organizations and government agencies. Table 1 and Figure 2 summarize this activity during the preceding three fiscal years. The table includes the income from these shipments and also that from the rental of portals at the reactor. The drop in income from the shipment of irradiated materials, due largely to a lower service irradiation charge, is more than compensated for by the large increase in the rental of portals at the reactor. The rate of shipments during the last quarter was about 120 per month.

A new brochure describing the Brookhaven nuclear reactor and detailing the irradiation services at the Laboratory was issued last January and is available upon request together with a schedule of the revised rates.

GAMMA-IRRADIATION SERVICES

Twenty-three different industrial organizations, four universities, four government agencies, and three other research institutions availed themselves of the gamma-irradiation services during the past year. The total income received from off-site users was \$55,827 as compared with \$46,697 for fiscal 1955 (see Figure 3). On-site users were billed for a total of \$66,556 as compared with \$82,815 for fiscal 1955; the decrease in income resulted from new rates established in February 1956 which reduced the cost to on-site users by more than 50%. The total number of gamma-ray

Figure 3. Income and use of gamma-irradiation services by fiscal years.

source days used was 3361; based upon 261 working days in the year and an average of 15 sources available, this represents an 86% utilization of the irradiation facilities.

Seven multicurie cobalt-60 sources were sold for \$33,560 as indicated in Table 1. Six other sources are available for shipment as soon as the customers' facilities are ready to receive them. All sources which have been in the reactor for a year or more have been sold, and are scheduled for shipment in the next few months.

HOT LABORATORY OPERATIONS

DEVELOPMENT

Some recent variations in the routine gamma-radiography service include 1) a considerable number of radiographs *in situ* of one of the pilot plants in the Hot Laboratory and 2) radiography of a test pump while in operation to determine clearance of the pump rotor. A special hydraulically operated portable crane with a source housed in a spherical shield on the end of a boom has been designed and built. A flexible cable arrangement permits the source to be exposed or retracted by remote control, and the boom permits placement

of the source in locations otherwise difficult to reach.

A special 8-mg iridium-192 source having an activity of approximately 40 millicuries was prepared for the Biology Department and was used in a model of the gamma-irradiation field exhibited at the Geneva Conference.

The Brookhaven Mechanical Manipulator Model 3 was modified by conversion of the column rotation from a gear-operated motion to a cable and pulley drive similar to the other motions. This change not only makes the columns rotate more freely but also standardizes more of the parts and thus reduces the cost. A simple clutch was also installed so that the operator can vary the distance between the slave and master columns and can thus work in a more comfortable position than is possible with other types of manipulators when manipulating an object close to the inside of the front shielding wall.

A shielded bench has been set up in the hot area and provided with a 2-curie cobalt-60 source which produces a nearly uniform field of radiation of approximately 4 r/hr at the bench top. This is being used by the Medical Department in some experiments with mice undergoing chronic exposure to relatively low levels of gamma radiation.

LIQUID WASTE OPERATIONS

The figures in Table 2 indicate the magnitude of the liquid waste operations of the past year as compared to that of the previous year. While the total volume of the "F" waste released into the Laboratory's sewer increased, the activity discharged into the sewer system was less. The efficiency of the concentration operation was about the same as in the previous year; the volume handled was less. The status of waste inventory for the past two years is also given in Table 2.

HEALTH PHYSICS

The program of the Health Physics Division has continued along the same lines as in the past, but with gradual increases in volume and variety of work. Such increases have been particularly noticeable at the Cosmotron, at the reactor, and in connection with the waste disposal and decontamination programs. The nine-week summer training program for the AEC Fellows in Radiological Physics will be given this summer as usual. In addition, there have been a number of other training activities for visiting engineers, new members of the Health Physics Division, and a steadily increasing number of foreign visitors.

Table 2

“F” Waste Discharged to the Sewer				
Period	Volume, gal	Average activity level, curies/ml	Total activity, millicuries	
Fiscal 1955	2,837,985	3.10×10^{-11}	332.40	
Fiscal 1956	3,731,620	2.46×10^{-11}	324.5	
Waste Concentration				
Feed, gal				333,675
Average volume reduction				127
Drummed concentrate, gal				2656
Number of drums of concentrate				98
Waste Inventory				
	Fiscal 1955 “D” waste	Fiscal 1955 “A” waste	Fiscal 1956 “D” waste	Fiscal 1956 “A” waste
Volume on hand at beginning of fiscal year, gal	157,340	1758	95,105	2201
Volume received during year, gal	365,650	443	337,880	726
Volume to evaporator, gal	427,885	—	333,675	—
Volume on hand at end of fiscal year, gal	95,105	2201	99,310	2927

Exposure and contamination control problems continue to be acute at the nuclear reactor because of the highly radioactive equipment that must be removed from experimental holes and because of occasional failures of fuel elements. The canal area has been especially troublesome in this respect.

Safety arrangements at the 60-in. cyclotron have been improved by the installation of a photoelectric barrier at the entrance to the experimental vault and a television monitor for the experimental vault area. Operating procedures have been so established that the machine can be operated with a high margin of safety.

RESEARCH AND DEVELOPMENT

A dosimetric study of neutron-irradiation facilities at the pile was completed in cooperation with the Biology Department. Values of fast neutron flux, as well as thermal neutron and γ -ray exposure rates, during use of a uranium converter plate, were obtained.

Facilities for the study of radioactive fallout were improved, and a fairly extensive series of measurements is being made during the spring and summer of 1956. Daily measurements of total fallout have been made as in the past, and the results are shown in Figure 4. In addition, the degree of contamination collecting on typical road and building materials is being measured with a thin-walled flow counter. The time sequence of arrival of activity in rainfall is being determined by means of a rain collector which automatically collects 1-hr rain samples for a period of 24 hr.

A number of special instruments were developed for taking measurements of the dosage rate in the Cosmotron external beam. Since the rates encountered are of the order of 1.5 to 2.0 rep/pulse, it was necessary to use very small chambers with high collecting voltage. A multirange survey instrument has been developed for measuring the wide variety of radiation levels encountered at the Cosmotron.

A diffusion cloud chamber has been obtained for use in studying the nature of the ionization produced by scattered radiation from the Cosmotron in an effort to determine the relative biological effectiveness ratio that should be used in the areas occupied by personnel. The characteristics of

shielding materials for use at the Cosmotron are under study.

Smaller projects include the calibration of an ion chamber for assaying the tritium content of air, tests of the degree to which a variety of floor surfaces can be decontaminated by standard janitorial procedures, construction of a flow counter for detecting tritium on smears, analysis of area monitoring data obtained during the period of a cosmic-ray burst, an estimate of area radiation levels to be anticipated from reloading of the BNL pile, calibration of a radium-beryllium source in a 7-in.-thick lead shield, and a study of the extent to which beta dosage in the canal area is reduced by absorbers.

WASTE DISPOSAL AND DECONTAMINATION

Both the volume of work connected with waste disposal and the radiation levels involved have continued to increase. Considerable effort has been devoted to planning additional facilities. The first unit, a prefabricated metal building, has been completed and will serve as a temporary location for the wet decontamination of fuel storage tubes from the pile. Plans have been made for reclamation and decontamination laundry buildings, as well as for a smaller building to house low-level sorting operations, locker rooms, and sanitary facilities at the waste area. More pavement, trenches, and storage pits have been provided in order to keep pace with the increased volume of large and very active equipment brought down from the pile.

Decontamination work has been continued with the makeshift arrangements at the waste disposal area during the past year, including cleaning of orifice plugs and lead bricks, sandblasting of tools and heavy shields, and decontamination of fuel storage tubes. More and more dismantling of extremely radioactive equipment taken from the pile is being done at this area.

The liquid waste system has been operated as in the past and a summary of data is shown in Table 3. A new weir was installed at the site boundary so that satisfactory flow data can now be obtained even during flood stages of the stream to which the waste effluent from the Laboratory is discharged.

PERSONNEL MONITORING

Table 4 gives a breakdown of the work done by the personnel monitoring group, which has functioned very much as in previous years. Off-site neutron monitoring service, not included in Table 4, is still being provided for contractors of the New York Office of the AEC and a few other

Figure 4. Weekly averages of the rate of fallout of radioactivity at BNL.

Table 3
Summary of Liquid Waste Data

	1955-56	1954-55
Input to filter beds gal/day	362,000	353,000
Output from filter beds, gal/day	306,000	323,250
Net loss in filter beds, %	15.5	8.4
Stream above discharge point, gal/day	999,000	489,500
Stream at site boundry gal/day	1,525,000	952,250
Rainfall, in./mo	4.5	4.45
Activity concentration at input to filter beds, curie/cc	3.5×10^{-13}	5.0×10^{-13}
Activity concentration at output from filter beds, curie/cc	1.3×10^{-13}	1.5×10^{-13}
Reduction in activity concentration, %	63	71
Activity at input to filter beds, millicurie/mo	14.2	20.4
Activity at output from filter beds, millicurie/mo	4.6	5.7
Percent of permissible	11.7	16.8

Figures are averages as indicated for each fiscal year.

Table 4
Use of Personnel Monitoring Equipment

	1955-56	1954-55
Pairs of pocket chambers	963	1082
Regular film badges	1006	960
Visitors' film badges - On-site	113	125
Visitors' film badges - Off-site	176	156
Total film badges	1294	1241
Neutron films used	461	409
Neutron films read	321	286

Figures are weekly averages for each fiscal year.

laboratories. The work load of this service averaged 336 badges per week. There were no cases of whole-body exposure significantly over the three-month limit of 3.9 roentgens equivalent.

The personnel monitoring records have been standardized and the data from the currently active file have been transferred to punch cards preparatory to statistical analysis, which will be carried out later in the summer. Considerable addi-

tional work remains to be done in tabulating exposure data from the inactive file, which includes former employees, before an over-all statistical study of our exposure record can be carried out.

The personnel safety problems at the Cosmotron have been greatly increased by three factors: 1) the machine has been improved considerably and now has an internal beam of the order of 10^{11} protons/pulse, which is about 100 times that available three years ago; 2) a large fraction of the internal beam has been brought out of the machine and projected across the area back of the Cosmotron building in close proximity to another building housing two other accelerators; and 3) the machine has for some time been operating 24 hr/day for five days a week. Improvements in the shielding have not kept pace with the increased beam intensity, so that for full-intensity operation very high levels are encountered in the work areas within the Cosmotron building. Thus far it has been possible to carry out the desired experimental program without over-exposure because of the fact that operation at full intensity has been required only a minor fraction of the time.

Radiation levels in the control room averaged 148 mrem per shift week for the whole year. The average for the 33.5 weeks during which the machine was actually operating was 230 mrem per shift week.

Extensive surveys were made of the radiation levels caused by the external beam. The great range of 3-Bev protons necessitated construction of a dike containing approximately 40,000 cubic yards of earth as a "catcher." This dike effectively protects outlying areas from objectionable levels of scattered radiation. A large area between the machine and the dike, traversed by the beam, has been fenced off, and access to this area is carefully restricted during external beam operation. Levels in the area occupied by the 18-in. cyclotron are extremely high for certain types of Cosmotron operation and work with the two machines has had to be carefully coordinated. The Cosmotron group is planning radical improvements in the shielding and the provision of additional experimental areas in anticipation of further increases in the intensity of both the internal and external beams.

METEOROLOGY

The meteorologists continue to supply to other sections of the Laboratory services such as weather forecasting, special climatological studies, and instrumentation. Forecasting is not a routine aspect

of the work, but is undertaken on special request or in the event of unusual or dangerous meteorological conditions. Climatological studies range from simple computations, e.g., of mean temperatures and degrees days, to complete investigations. An extensive investigation of soil temperature variations was carried out to provide data for the design of the foundation of the new 30-Bev Alternating Gradient Synchrotron. Instrumentation work is concerned primarily with the repair and calibration of meteorological devices throughout the Laboratory.

MECHANICAL ENGINEERING DESIGN AND CONSTRUCTION

NUCLEAR ENGINEERING

The design of equipment for the research staff of a size or type that cannot be easily constructed by individuals is a continuing activity. A number of loops containing flowing metal, static reaction pots, columns, and the like were designed for use with liquid uranium-bismuth reactor fuel, and for experimentation with various methods of extracting both volatile and nonvolatile fission products.

For equipment costing \$100,000 or more the Division prepares specifications suitable for competitive bidding, and has guided several such jobs through contractor's shops to eventual delivery at the Laboratory, where assemblies were made by Laboratory personnel prior to operation of the equipment. Formal engineering designs and formal development of engineering scale equipment have been involved in connection with certain radioactive waste disposal processes, with applied radiation chemistry techniques, and to a marked degree with the proposed experimental liquid metal fuel reactor. The Mechanical Engineering Division, in late 1955, proposed a 4-in. test loop containing components of substantially the same size as required for a 5-Mw experimental reactor. Equipment is being procured from various contractors, and the job is now in the manufacturing stage, at a cost of about \$1,000,000.

Contracts have been let for the development of pumps, valves, graphite, and miscellaneous specialties for U-Bi radioactive service. A preliminary design of an experimental liquid metal fuel reactor was prepared under an engineering assistance subcontract to Sanderson and Porter.

Guest engineers from interested private industries have assisted in the development, testing, and operation of the foregoing facilities.

ACCELERATOR DEVELOPMENT

The design and construction of the electron analogue of the Alternating Gradient Synchrotron in 1955 consumed the entire effort of the designing group, and a large fraction of the time of the engineering staff. With this work completed, the effort of the whole group has been devoted to the design of machine components of the 25-Bev proton accelerator. The service building will be ready for occupancy in October 1956, and Stone and Webster, in collaboration with the Laboratory engineering staff, has essentially completed the designs of the experimental area, the linac building, the magnet enclosure, and the magnet supports. The magnet support is a steel box girder segmented at 22-ft intervals to permit longitudinal thermal expansion, with a type of coupling at each segmented joint that will keep the adjacent members in radial and vertical collimation. Twenty-four surveying monuments are in place in the excavated magnet tunnel enclosure. These monuments are currently used to locate the components of the magnet enclosure and will subsequently be used in making the final precision survey. The instruments and precision tapes that will be used in this survey either have been built or are on order. Shielding in the experimental area will be carried on a heavy concrete mat with a cantilever overhang adjacent to the bending magnets, which will permit the placement of heavy experimental apparatus in close proximity to these magnets.

The following magnet models have been constructed: Model No. 4 with 11-in.-wide pole tips of low-carbon auto-body steel laminates 0.031 in. thick, and Model No. 5 which is a half-scale dc magnet remodeled to newly calculated pole-tip contours. The effort of the design group has been largely concentrated on the 50-Mev linear accelerator. A copper-clad steel tube that will serve both as a vacuum enclosure and radio-frequency conducting surface, with drift tubes attached in a manner permitting alignment by optical methods, has been designed and modeled. Drift tubes will contain quadrupole focusing magnets. An Evaporation pump fabricated by the Consolidated Vacuum Corporation has been extensively tested, and minor faults have been corrected to permit its anticipated use on the AGS machine. Designs of an rf cavity are also complete, and a unit is currently being constructed. In addition to the foregoing, models of the following machine components have been built and are currently being tested: vacuum chamber, vacuum-chamber flanges, precision screw jacks for supporting and

leveling the bending magnets, main exciting coil, magnet water cooling connections, and the bus bars to the main exciting coils.

PHYSICS

With the group located at the Physics shop, where the design of apparatus to be built in the shop is a continuing activity, the anticipated construction of a large hydrogen bubble chamber is a major project. The size of this designing group has been increased to expedite the preparation of drawings of the bubble chamber. At the 60-in. cyclotron building, the construction of experimental apparatus and changes to the machine have engaged the full time of the design group which is located there.

COSMOTRON

A liquid hydrogen generating facility of the high pressure type has been constructed because of the anticipated increased use of liquid hydrogen. The plant, designed by the National Bureau of Standards, is rated at 50 l/hr and has delivered on test at Boulder, 99 l/hr of approximately 90% parahydrogen. About half the equipment is surplus from Los Alamos. The building is equipped with blow-out windows in the north and south walls, and includes a cryogenic experimental laboratory, with a ventilation system that provides a complete air change every two minutes in all parts of the building. An external hydrogen gas holder of the dry seal type provides a storage reservoir on the suction side of the compressor.

Two small models of hydrogen bubble chambers have been designed, built, and operated in collaboration with members of the Physics Department. Liquid hydrogen vessels with target areas 6 in. in diameter and 6 to 8 in. long have been constructed of Styrofoam. One model of Styrofoam target has been constructed with Mylar windows 0.5 mil in thickness, the beam entering and leaving through a total of six layers of the Mylar film. A 4-in. safety vent has been installed in the roof of the Cosmotron building as a precaution against a sudden loss of hydrogen from the experimental targets.

On the Cosmotron machine, two sets of shaped iron shims have been installed to shield the emergent external beam from the fringing magnetic field. Extensive structural supports are required to hold these shims rigidly in place in the pulsed magnetic field. A small electromagnet is used to bend the emergent beams along a common path.

Two vacuum chamber quadrants were removed while repairs to the motor generator set were in

progress and new gaskets and Myvaseal blankets were installed. The entire vacuum system is now in excellent shape, with essentially clean gasket materials in all four quadrants. A device to permit the retraction of the ejector magnet while under vacuum has been installed in the south straight section. A pulsed liner to compensate for energy droop, and electrostatic strong focusing lenses have been designed for the Van de Graaff injection system. A testing manifold has been installed at one quadrant of the Cosmotron to permit the rapid detection of a water leak in the main exciting coil, and similar ones will be installed at the other three quadrants.

A large fraction of the time of the resident engineering group continues to be spent on the development and alteration of experimental apparatus, in addition to work on machine components. Two additional 18×36-in. analyser magnets are currently being built. Plans have been made to increase the cooling water available for experimental magnets to 500 gpm. The original installed capacity of 30 gpm has already been increased to 90 gpm.

CENTRAL DESIGN

The following reactor components and apparatus used in connection with the reactor have

Table 5

Mechanical Engineering Division Personnel

	1954	1955	1956
Engineers	11	17	18
Designers and Draftsmen	30	33	39
Secretaries and Clerks	3	3	3
Total	44	53	60

Localities Where Staff is Currently Working

	Engineers	Designers and Draftsmen	Secretaries and Clerical
Accelerator			
Development	9	14	1
Central Design	2	7	1
Cosmotron	4	4	—
Nuclear Engineering	3	8	1
Physics	—	5	—
Reactor Operations	—	1	—
Total	18	39	3

been designed during the past year: handling equipment for enriched fuel rods, a neutron spectrometer, a neutron chopper now located on the roof of the pile, a thermal column and shutter for the slow neutron chopper including a hole bored in the graphite of the pile to provide a beam of higher intensity, redesign of a uranium slug chopper for the reactor canal, and a BF_3 multiple counter for installation in the beam of the fast neutron chopper. Plant inoculation chambers, a separation centrifuge, and a "mouse hotel" have been made for the Biology and Medical Departments. Various component parts have been designed for the medical reactor that will be located in the new medical center.

PERSONNEL

The expanding facilities of the Laboratory have produced an increase in the size of the Division staff. The growth of the staff and its present distribution are shown in Table 5.

MACHINE SHOPS

In the past year over-all shop operations have been more effective. A satisfactory manpower level has been attained, as well as a more efficient distribution of individuals within the various job classifications. A closer association between the scientists and the craftsmen is gradually being achieved.

A study of the desired machine-tool complement for a consolidated central facility will be completed early in fiscal year 1957 and will provide a comprehensive plan for machine-tool procurement and retirement which should result over a five-year period in a central facility specially de-

signed to meet the demands peculiar to the work of the Laboratory.

A new layout was tried on a plant basis for one of the three major locations of the shop facilities. Six months' experience with this layout has proved its general workability and acceptability to the machinist staff.

A detailed study of the internal system of record keeping has yielded a much simplified system capable of giving more information more quickly and accurately and with less work.

Approximately 4% more productive man-hours were worked during fiscal year 1956 than in fiscal year 1955, almost 91,000 hr in 1956 as against slightly more than 87,000 hr in 1955. The distribution of workload between the groups of the Shops Division remained about the same as previously. A sharp rise occurred in the man-hours of short-order work done, an increase of 19.5%; however, short-order work still accounts for less than 10% of the total shop workload. The breakdown by major shop groups is given in Table 6, with a comparison of this year's experience against that of the last fiscal year.

Table 7 shows the relative contribution of the several departments to the Shops Division workload. Of the major users during fiscal year 1955, only the Nuclear Engineering and Physics Departments showed increased workloads, 16.9% and 57% respectively. These increases were more than offset by marked decreases in workload from the Reactor, Accelerator Development, and Cosmotron Departments.

The high level of the backlog existing in the spring of 1955, over 20,000 man-hours, was substantially reduced during the first half of this year. The backlog has since leveled off at around 15,000

Table 6
Comparison of Intra-laboratory Requisition Workloads by Shop Groups, Fiscal 1956

	No. of jobs		% of total jobs		No. of man-hours		% of man-hours	
	1955	1956	1955	1956	1955	1956	1955	1956
Heavy and special equipment shops	708	623	60.5	63.0	60,247	65,955	69.0	72.7
Sheet metal and welding shop	437	366	37.3	37.0	19,216	18,063	22.0	19.9
Maintenance	26	—	2.2	—	2,158	—	2.5	—
Intra-laboratory requisitions, total	1171	989	100.0	100.0	81,622	84,018	93.5	92.6
Additional short-order jobs					5,722	6,838	6.5	7.4
Total					87,344	90,856		

Table 7
Departmental Contributions to Shop Workload, Fiscal 1956

	% ILR man-hours fiscal year 1955	% ILR man-hours fiscal year 1956	% Change in workload
Major users			
Nuclear Engineering	37.8	44.2	+16.9
Reactor	18.8	13.4	-28.7
ADD	13.6	4.9	-64.2
Physics	10.0	15.7	+57.0
Cosmotron	9.0	6.3	-30.0
Percent of workload	89.2	84.5	
Minor users			
Chemistry	4.1	6.6	+61.0
Biology	4.0	2.7	-32.5
Medical	1.7	2.5	+47.1
Instrumentation and Health Physics	0.4	0.5	+25.0
Miscellaneous	0.6	3.1	+417.0
Percent of workload	10.8	15.4	

man-hours, which represents slightly more than eight weeks' work. The experience of the past year indicates that, with the present lag between the time a job is received and the time it can be released to the floor, a backlog of this level is appropriate.

TECHNICAL INFORMATION

As a result of the Civilian Application Program of the AEC, which is making a large amount of technical information available to U.S. industry, there has been a shift in the workload of the Technical Information Division. An extensive review of classified reports, in line with the recently liberalized AEC Declassification Guide, has shown that about 10,000 of Brookhaven's report holdings require downgrading or declassification. As declassified reports are turned over to the Research Library, its workload is increasing; whereas an opposite trend is noticeable in the classified documents group due to the decreasing volume of new reports being received.

To date 3000 documents have been processed for declassification or downgrading. In addition, a large amount of Brookhaven-originated material, such as drawings, correspondence, and laboratory notebooks, is being declassified after review by two representatives of the AEC's Declassification Branch. Review of all such Laboratory material is expected to be completed next spring.

The recent declassification of the Reactor Building has made it necessary, according to security regulations, that classified documents formerly in files throughout the premises be safeguarded in one central location; therefore, an extension of the Classified Library was established in that building.

With the increased acquisition of documents in the Research Library, the reference section is now operating under its heaviest workload. There has also been an increase in the demand for bibliographies; during the review period 35 were completed, noteworthy among which is "Radiation Effects on Blood and Blood-Forming Tissues in Man," exhaustively covering the period 1900 to 1956. The reference staff has also taken part in the translation of articles from Russian scientific journals, mainly in the field of high energy physics. The burden of this work grew so heavy that the cooperation of the University of California Radiation Laboratory, Argonne National Laboratory, and Technical Information Service, USAEC was enlisted in a "share-the-load" plan, coordinated at Brookhaven. However, this service has been less in demand since commercial translation agencies started providing complete translations of the most important Soviet physics journals. Acquisition and circulation statistics both indicate the growing use of the library facilities. The expanded cataloging program begun during the year has been of considerable assistance to users during the evenings, when the library staff is not on duty. An

additional staff member was engaged for the summer months to meet the increased use of the library by summer visitors.

The publication group has edited and otherwise processed for publication 48 major technical documents originating within the Laboratory, including 14 classified reports. In addition, 3 reports were edited and published for the Health and Safety Laboratory, New York Operations Office of the AEC.

The Division also processes all technical manuscripts originating from Brookhaven-sponsored research for publication in the scientific and technical journals. During the year, 393 such papers (including published abstracts of speeches) have been processed, a decrease of 25 from last year's total.

The distribution lists for the Laboratory's unclassified reports continue to grow. Standard distributions are made as prescribed by the AEC, and, in addition, all bona fide requests from within the national atomic energy project and from cooperating government agencies and universities are honored. Satisfactory exchange arrangements have been made with a number of other organizations, both in the United States and abroad. Also, 300 copies of all such reports are made available for public sale at a nominal cost from the Office of Technical Services, Washington, D.C.

PHOTOGRAPHY AND DUPLICATING

The personnel of this Division now stands at 34, an increase of one in the duplicating group, and activity continues to increase. Production figures for the photography group are given in Table 8.

A gas-discharge point light source with exposure times of 10 to 80 μ sec has been constructed by the Instrumentation Division and is proving most useful in the photomicrography of highly motile organisms. A borescope camera for right-angle and oblique photography of cavities has been acquired.

Predictions of next year's film consumption by bubble and cloud chambers indicate that a continuous processing machine for 35- and 70-mm film will be needed, and a study of suitable equipment has been started. The practicality of negative-positive color materials is being investigated.

The capacity of the existing nuclear emulsion processing facility has been increased from 1858 to 7433 cm^2/week . Construction has been started on a new laboratory for nuclear emulsions, which, to-

Table 8

	Fiscal '54	Fiscal '55	Fiscal '56
Photographs	3,227	4,218	4,552
Photomicrographs	1,435	1,837	1,770
Lantern slides	4,489	5,788	6,283
Prints	30,302	36,008	36,351
Photostats, Xerox	22,226	18,969	19,925
Ozalid prints	233,821	276,968	332,451
Recording film processed	13 mi.	13.6 mi.	14.6 mi.

Table 9

	Fiscal '54	Fiscal '55	Fiscal '56
Offset pages	3,819,809	4,036,991	4,574,215
Offset negatives	4,445	5,035	5,479
Offset plates	1,125	1,066	1,677
Mimeo impressions	1,702,165	1,850,795	1,517,156
Stencils cut	1,176	1,992	1,497
Stencils run	8,312	10,168	10,084
Sheets collated			
and bound	1,324,089	1,377,050	1,637,145
Report copies issued	30,419	40,304	67,155

gether with new equipment, will provide for more accurate control of the process and increased output.

The Joint Congressional Committee on Printing approved the rental of an Intertype Fotosetter, a machine for setting copy directly on film, and it will be installed in the fall of 1956. The addition of this major device, the first to be installed in an AEC laboratory, will greatly increase the efficiency of text composition by eliminating several steps in the offset process. Also, the Laboratory's reports will have a more professional appearance, as all required characters will be available and margins will be automatically aligned.

The Division has also produced certain reports for the New York Operations Office of the AEC at their request.

Production figures for the printing group are given in Table 9.

The illustration section has been active in preparing displays and exhibits, and has completed 3010 drawings for publications and slides.

SCIENTIFIC COMPUTATION

The scientific computation program offered approximately the same services in its second year

Table 10
Distribution of Time by Departments

	409-2R Computer	Univac
Physics	35.0%	10.5%
Reactor	27.0	-
Nuclear Engineering	20.0	66.5
Biology	14.0	-
Cosmotron	1.5	-
Medical	1.0	-
Chemistry	1.0	-
ADD	0.5	22.0
A.U.I.	-	1.0

of operation as it did previously. Both the AEC's New York University Univac and the on-site Remington Rand 409-2R electronic punch card computer were available to the scientific staff. The 409-2R computer was operated jointly by the computer group and the tabulating section of the Fiscal Division. About 25% of total machine time was allotted to the tabulating section, and the rest to scientific computations and maintenance operations.

A number of the Laboratory's large-scale problems were placed on the NYU Univac using 375 hr of computing time. Table 10 shows the distribution of the Univac usage by departments.

During this fiscal year the local computing facility served eight departments and performed a total of 1024 hr of computation. About 2279 hr of auxiliary operation were required for processing cards prior to and during computation. About 278 hr of computer time were allocated to pre-

ventive and emergency maintenance. Most of the programming effort was provided by Computer Center personnel, but the amount performed by others increased toward the end of the period. Table 10 shows the distribution of computer time by departments.

The computation load on the local facility grew steadily until it reached the saturation point late in the spring. All indications pointed to further warranted load increases and, therefore, an increase in computer group personnel was planned and a second Remington Rand 409-2R computer ordered.

The computer study group, formed in the preceding year for the purpose of determining what type of computer would best meet the needs of this Laboratory, conducted a survey of available medium-scale commercial computers and visited several national laboratories to examine the nature of the computational load, the facilities offered by the computer used, and the approximate cost of computer duplication. It became evident that the cost of duplicating a high-speed, large-scale machine was not much greater than that of purchasing a commercial medium-scale, slow-speed computer. After careful examination of the programming facilities, memory capacity, speed, and electronic design characteristics of each machine, the study group recommended that a copy of the new Los Alamos computer, Maniac II, be built by Brookhaven. In June the AEC provided funds which enabled engineering personnel to gather the necessary technical data required for beginning the project. The summer months will be occupied with project planning and in the fall actual construction will commence. The estimated time for completion of the basic computer is between 1.5 and 2 years.

Administration and Operations

Included in this section are reports on the personnel, business, and other operational activities of the Laboratory. The following administrative changes occurred during this period. Assistant Director R.A. Patterson relinquished his responsibilities for scientific personnel and university liaison on December 31, at which time Dr. R.C. Anderson was transferred from the Chemistry Department to the Director's Staff to assume these duties. Mr. L.R. Swart, Director of Personnel, resigned from the staff to accept a position in industry on March 2. Mr. Julius Hanoach, who replaced Mr. Swart, also resigned for other employment in May, and Mr. W.H. Fields Jr., Assistant Director, assumed his responsibilities pending the appointment of a new Head of the Personnel Division. Mr. E.A. Macy has accepted this appointment and will join the staff this summer. Mr. Fields has been given the responsibility for administrative operations of the Laboratory and will become Associate Director for Administration on July 1.

PERSONNEL

SCIENTIFIC STAFF

While the over-all size of the scientific staff remained relatively constant, certain new trends may be noted in its composition as shown in Table 1. The number of regular staff members on May 31 dropped from 290 in 1955 to 281 in 1956 as contrasted with 273 in 1954. This static condition belies a vigorous turnover rate, inasmuch as 35 additions to the regular staff and 44 terminations occurred during the period from June 1, 1955 to May 31, 1956.

A review of the appointment policy resulted in creation of a new category, that of Assistant Scientist, which appears in the analysis for the first time. Of the 20 Assistant Scientists, 12 were appointed directly and 8 promoted from Junior Scientists.

Research Associates, who hold appointments of limited periods similar to postdoctoral fellowships

Table 1
Scientific Staff on May 31, 1955 and 1956

	Regular staff		Salaried		Visitors	
	1955	1956	1955	1956	No compensation	
					1955	1956
By Appointment Category						
Senior Scientist	35	37	1	2	11	12
Scientist	74	76	—	4	57	82
Associate Scientist	149	129	3	4	48	53
Assistant Scientist	—	20	—	1	—	12
Research Associate	—	—	20	27	2	6
Junior Scientist	30	17	—	—	8	4
Junior Research Associate	—	—	10	13	7	27
Research Assistant	2	2	—	—	11	7
Total	290	281	34	51	144*	203**
By Academic Degree						
PhD or MD	178	178	22	37	91	133
Master	43	34	11	13	27	50
Bachelor	64	63	1	1	24	18
No Degree	5	6	—	—	2	2

*113 of these appointees work intermittently at BNL.

**134 of these appointees work intermittently at BNL.

Table 2
Classification of Visiting Scientists Participating in
BNL Program for Period of One Month or More, June 1, 1955–May 31, 1956

	More than 3 months		Less than 3 months		Total	
	Salaried	Guest	Salaried	Guest	Individuals	Institutions
University staff	11	17	36	55	119	59
Thesis students	14	12	2	6	34	14
Student Research Assistants	3	2	97	25	127	52
Total	28	31	135	86	280	86 different
Industry	1	24	—	14	39	28
Other institutions	1	19	—	26	46	26
Total	30	74	135	126	365	140 different

Table 3
Foreign Visitors, July 1, 1955 to June 30, 1956
Appointed to Staff for Various Periods (Weeks to a Year)

Country	Field						Total
	High Energy and Theoretical Physics	Other Physics	Chemistry	Biology	Engineering	Medicine	
Britain		4	1	1		1	7
Belguim		1	3		2		6
Japan	3	1	2				6
Germany		2	1	2			5
China	2	3					5
India	2	2		1			5
Canada			2	2			4
Italy		2				1	3
France	1		2				3
South Africa			1	1			2
Egypt			1		1		2
Sweden		2					2
Norway		2					2
Netherlands				1			1
Israel			1				1
Argentina					1		1
Turkey		1					1
Peru				1			1
Denmark		1					1
Australia	1						1
Austria				1			1
Total	9	21	14	10	4	2	60

and who add measurably to the population of younger scientists working full time on research, are included for statistical purposes under the heading of visitors. Their number has increased from 22 in 1955 to 33 in 1956 and significantly now includes a few foreign scientists. As might be expected, the turnover here is quite high. Twenty-six new Research Associates were appointed while 15 others completed their work and terminated during the year.

The major increase in the number of persons using the Laboratory's facilities has occurred on the visiting staff, the total going from 178 in 1955 to 254 in the current year. Not only has there been a general increase, but there has been a marked increase in visitors at the levels of Scientist and Junior Research Associate, the latter being graduate students working on their theses.

The numbers of visiting scientists by classification who worked at the Laboratory for a period of one month or more between June 1, 1955 and May 31, 1956 are set forth in Table 2. Two hundred eighty individuals from 86 different colleges and universities participated in the Laboratory program as compared with 238 from 69 different institutions in the preceding year. Those from industrial and other organizations, such as government agencies, numbered 85 as compared with 52 in the preceding year. The number of graduate students engaged in doctoral investigations was 34 as compared with 27; nine of these completed the research required for their degrees.

With the increase of visitors has come an increase in foreign scientists. Table 3 shows not only that these scientists have come from a wide variety of countries, but that they are working in almost every one of the Laboratory's Departments. For the most part, the foreign visitors are supported by their own institutions or governments; a few have received grants-in-aid from philanthropic organizations or U.S. Government agencies other than the Atomic Energy Commission. The sixty listed were all actively engaged in scientific research or in advanced training by research participation, and do not include the more numerous visitors who spend only a few days observing the operations and activities of the Laboratory. The presence of the foreign scientists has proved very stimulating. Their interaction with the regular staff, bringing as they do fresh viewpoints and markedly different backgrounds, has resulted in much cross-fertilization of ideas and experimental techniques. Not only is the number of the foreign visitors increasing, but the time each one spends at the Laboratory is becoming longer. The latter fact is impor-

Table 4

Consultants' Services

Item	1954	1955	1956
Total contracts in effect June 30	94	81	72
No. consultants used	54	52	41
No. of man-days of service	580	535	443

tant because an initial orientation is necessary before the collaboration between visitor and staff members results in scientific productivity.

Finally, the man-days of service rendered by consultants are shown in Table 4, in which comparisons are made between the current report year and the two previous fiscal years.

SUMMER PROGRAM FOR 1956

Arrangements have been made for 100 faculty members from 49 different educational institutions to work for up to three months during the summer of 1956.

The summer student program, now in its fifth year, has also been continued. In January, announcements were sent to about 125 schools in the northeastern region of the United States. From 115 different colleges and universities, 400 applications were received and 108 appointments were offered. Of these appointments, 85 have been accepted by 44 undergraduates and 41 graduate students representing 49 different institutions.

Including 14 Radiological Physics Fellows, who have completed the first part of their training at the University of Rochester, and 20 additional graduate students who will be brought to the Laboratory by faculty members to work as their research assistants, the scientific staff will be increased by 226 additional workers. This is close to the 230 accommodated during the summer of 1955 and represents about the maximum number that can be handled with the present laboratory and on-site housing facilities.

EMPLOYMENT

There were 1598 people employed by the Laboratory as of June 30, 1956, excluding guests, research collaborators, and temporary appointees. This total represents a net increase of 65 in the number of employees over the total for the previous year. The ratio on June 30th of 1 scientist to 3.8 non-scientists is similar to the same ratio for

Table 5

Staff Data

Turnover Data	Fiscal 1955			Fiscal 1956		
	1533*			1598**		
	Total numbers	Annual rate (%)	Average monthly rate(%)	Total numbers	Annual rate (%)	Average monthly rate (%)
Accessions	277	18.64	1.55	285	18.20	1.52
Separations (turnover)	190	12.59	1.05	220	14.05	1.17
Net Accessions	87	6.05	0.50	65	5.69	0.47
Replacements (net turnover)	185	12.26	1.02	196	12.51	1.04

*Not including 135 temporary appointees.

**Not including 147 temporary appointees.

the last two years. Pertinent personnel statistics are set forth in Table 5.

Recruitment remained a difficult problem because of the continuing need for employees with specialized training, e.g., chemistry and electronics technicians, for projects such as LMFR and AGS.

The Laboratory continued its effective policy of informal training of technicians and internal promotion whenever possible.

LABOR RELATIONS

Maintenance and Service Employees

A new collective bargaining contract was signed with the Federal Labor Union No. 24426, AFL-CIO on August 3, 1955, which is to expire on December 31, 1956. Wage rate increases were granted in two steps, effective July 1, 1955 and April 2, 1956.

Patrolmen

A new contract was negotiated with the Long Island Guards Union, Local 37, International Guards Union of America, representing the Laboratory patrolmen, which will expire in January of 1957.

EMPLOYEE BENEFITS PROGRAM

The Group Medical Insurance Program instituted in the fall of 1954 continued without major modifications. Some minor adjustments in the plan were made including an increase to \$10,000 in the maximum coverage, making children eligible for coverage from birth under the major expense benefit portion of the basic policy, and broadening the maternity coverage to include

certain charges for the baby. Experience under the plan for this year has been such that no change in the present premium rates has been necessary.

More than 730 claims were processed under the Medical Insurance program, and a total of more than \$107,340 was disbursed in payment of medical claims in the past fiscal year, representing approximately 83% of the total medical expenses incurred.

Under the Group Life Insurance Program provision was made to extend life insurance coverage to employees while on leave of absence.

The Retirement Plan continues without modification, with about 70% of the total staff participating.

RESIDENCE SERVICES

The housing facilities on the site – apartments, guest houses, and dormitories – have been operating at an almost full occupancy level during the past fiscal year.

The contract for the apartments in Stony Brook was renewed last spring for three more years. A slight increase in the rent was introduced to cover the addition of storm windows, and the utility charge was increased by a small amount.

It was necessary to secure more than ten off-site summer rentals and hotel accommodations for families and individuals who could not be accommodated in the on-site facilities. Included in this group were 23 professors from engineering colleges who were provided housing at the Wyandotte Hotel in Bellport.

A recent review of rentals in the area does not indicate any definite increase; therefore rentals for the on-site housing facilities have not been changed.

SAFETY ENGINEERING

The personnel safety record for the past year has remained at a favorably low level, as indicated in the following summary:

FREQUENCY AND SEVERITY RATES

	Fiscal Year 1955-1956	Five Years (1951-1955)
Frequency*	0.9	1.86
Severity**	6.7	36.39

*Number of disabling injuries per million man-hours worked.

**Days lost per million man-hours worked.

Special attention has been given to the problems introduced when handling liquid hydrogen in the Cosmotron. A special committee was assigned to formulate standard procedures for handling liquid hydrogen, and was also charged with the responsibility of insuring that the experimental equipment brought into the Cosmotron building complies with safety requirements.

With respect to fire-protection engineering, work has progressed on the installation of automatic sprinkler systems in the AGS service building; plans were drawn up for the installation of automatic alarm systems in the AGS target building, the Linac building, and the magnet tunnel itself; and an automatic fire protection system has been agreed upon for the new research hospital.

The fire-loss ratio for the past year (in which only one major fire was reported) was low: \$0.0009 per \$100 of assessed valuation. This figure may be compared with an average fire-loss ratio of \$0.0023 per \$100 of assessed valuation throughout other AEC facilities in the same period, and an average of \$0.03 per \$100 for industry in general.

EMPLOYEE ACTIVITIES

The Brookhaven Employees Recreation Association (BERA) sponsored during the year more than twenty cultural, recreational, and social activities. The cultural activities included a series of five concerts, several plays produced by the Theatre Group, and, under the auspices of the Film Study Group, motion pictures monthly during the winter and weekly during the summer. A photography competition open to all employees was sponsored by the Camera Club.

A total of 272 employees participated in the annual bowling championship. Soft ball and tennis were popular. The swimming pool was open daily throughout the summer.

SECURITY AND PLANT PROTECTION

The Security Office is concerned primarily with security clearance of personnel, safeguarding of restricted data, control of entry into and exit from the site and all restricted areas, and the administration of the operations of the police and fire groups.

During this report period the downgrading of certain classified information resulted in less emphasis on the security program. Many of the physical security restrictions have been removed. The most significant change has occurred at the Reactor, which is now declassified and can be visited by the general public, subject to the usual safety precautions.

Individuals can now be employed on unclassified work without formal security clearance, and there has been an increase in the number of alien employees and visitors.

Table 6

Admissions to the Site

	Fiscal 1955	Fiscal 1956
Regular visitors	19,893*	22,507**
Conference visitors	2,498	2,452
Alien visitors	832	1,179
Subcontractor employees	16,362	17,610
Total	39,585	43,748

*Includes 5,415 visitors during two open house days.

**Includes 6,611 visitors during two open house days.

These changes have resulted in a 10% reduction in police and security personnel; the number is now 53, a minimum consistent with adequate plant protection and security.

Table 6 provides comparative data for the fiscal years 1955 and 1956 on the admission of visitors to the Laboratory.

Fire group activity has been about the same as in the two previous years. Comparative figures are given below.

FIRE GROUP	1954	1955	1956
Responses on site	75	65	80
Responses off site	3	9	5
No response—investigation	18	12	11
Total	96	86	96

ARCHITECTURAL PLANNING

The types of activity and areas of responsibility of the Architectural Planning Division have not changed significantly during the past fiscal year. In addition to the professional application of architectural and engineering skills to the solution of facility problems, the responsibilities of this Division include concern for the long-range aspects of Laboratory growth, liaison on scientific requirements of the various Departments, estimations for budget purposes, and collaboration with the Brookhaven Area AEC office.

Early in June a ground-breaking ceremony was held to signal the start of construction on the Medical Research Center, a more than six-million-dollar project being accomplished under Prime Contracts by the Atomic Energy Commission. This undertaking, significant in the growth of the Laboratory, represents the culmination of effective collaboration between the AEC Area Manager's Office and their Architect-Engineers, the Medical Department, and this Division in the investigation and development, over a period of years, of the established design.

As a result of similar collaboration, construction was started during June on the Engineering Works Area, another AEC Prime Contract which, when complete, will provide a versatile industrial type of building having a high ceiling, for the development and testing of large equipments. This project will cost about one-half million dollars.

During the year more than 100 projects of varying size and complexity were the subject of engineering study in collaboration with the various Departments of the Laboratory concerned. From these preliminary investigations more than 60 jobs were undertaken, which required working drawings and specifications, bid invitations, contract administration, and field supervision by this Division. A representative list of such major undertakings, with approximate costs, includes:

Steam plant improvement and alterations	\$ 49,700
Applied chemistry laboratory	23,500
Power (dc) for Cosmotron beam ejector	21,700
Reactor canal water treatment facility	41,900
Hydrogen liquefier laboratory	135,000
Nuclear emulsion process laboratory	52,000
Waste disposal area improvements	69,500
Voltage regulation, 2.3- and 13.8-kv substations	88,400
Steam line manhole improvements (Cornell Avenue)	29,200
Chemistry laboratory modifications	12,500

External proton beam trap (north of Cosmotron)	22,900
Cosmotron cooling water for experimental magnets and high pressure hydrogen vent	11,800

The maintenance of "Record Drawings" and related basic data for all structures, utility systems, and site surveys is also a responsibility of the Architectural Planning Division.

The Division continues to assist the Director and his staff in periodic review and study of long-range plans for the Laboratory's growth, in the preparation of descriptive brochures used with facility budget requests, and in the preparation of individual proposals for facility improvements.

PLANT MAINTENANCE

Considerable restoration of both permanent and semipermanent buildings was necessary during the past year. The work involved waterproofing, interior and exterior painting, minor alterations, and the installation of asbestos shingles on eleven semipermanent wooden buildings. The total cost of both normal and special maintenance including wages and salaries of regular employees, materials, and subcontract obligations was about \$1,500,000.

Service activities included the building of models of the AGS magnets and service building and the review of plans for both the AGS and medical building with recommendations relative to the use of specific materials in the interest of long-range economical maintenance.

A Communications Service was established which provides better Laboratory mail service and telephone, telegraph, and teletype service.

Total heating fuel costs for FY 1956 exceeded those of FY 1955 by approximately 20% because of higher fuel costs coupled with an unusually severe winter. The number of degree days during FY 1956 exceeded the average for the past five years by 933 or 16%.

BUSINESS OPERATIONS

FISCAL

During the period under review the Fiscal Division began an extensive reprogramming of accounting and statistical applications on the electronic computer. This was possible because an additional computer was acquired which is devoted exclusively to accounting and general

administrative problems. Moreover, experience gained with the jointly used computer in previous years indicated many interesting improvements which could be made in programming the present applications. The largest application reprogrammed has been in connection with inventory records and inventory management.

Laboratory capital equipment records were converted to punched cards during FY 1956.

SUPPLY, MATERIEL, AND INVENTORY MANAGEMENT

Immediate provision of materials for the research units of the Laboratory requires the warehousing of approximately 16,000 items of inventory which are subject to Machine Records Control, plus 6000 items classified as "common use," i.e., items of low unit price. The common use items are issued without formal papers.

Continued efforts, through cooperation between Inventory Management and the Laboratory's users, have effected a further decrease in active inventory investment both in dollar total and in number of months for which supplies are on hand

(see Table 7). As the Laboratory grows it may be necessary to increase somewhat the dollar investment in inventory to satisfy larger demands. Turn-over however should remain at three to four times a year. Active advisory committees of users have helped immeasurably in keeping the inventory adequate and in balance.

The Supply and Materiel Division is also responsible for the newly developed Office Machines Utilization Program. The servicing and repair, and the standardization where practicable, of all office machines throughout the Laboratory constitute the major aspects of this program.

Centralization in this Division of the Excess Property Disposal Program has provided desirable control. A reclamation section for all used material and equipment no longer needed by the original requisitioning unit has been established to make such items available to all departments.

PURCHASING

Purchasing activities of the last three fiscal periods are set forth in Table 8. A buying group has

Table 7

Inventory Changes

Type of Inventory	Fiscal Year		
	1954	1955	1956
ACTIVE INVENTORY			
Opening active inventory July 1	\$418,609	\$396,564	\$274,574
Net of purchases, stores issues, adjustments, additions to inventory, and transfers to excess	- 22,045	- 121,990	- 13,428
Closing active inventory June 30	396,564	274,574	261,146
No. of months' investment in active inventory June 30	6.5	4.1	3.8
EXCESS INVENTORY			
Opening excess inventory July 1	154,198	0	45,026
Net of transfers from active inventory, dispositions, and adjustments	- 154,198	45,026	- 40,699
Closing excess inventory June 30	0	45,026	4,327
TOTAL INVENTORY			
Opening total inventory July 1	572,807	396,564	319,600
Net of purchases, stores issues, adjustments, transfers to excess, and dispositions	- 176,243	- 76,964	- 54,127
Closing total inventory June 30	\$396,564	\$319,600	\$265,473

Table 8

	FY 1954	FY 1955	FY 1956
Number of Purchase Orders and Change Orders	15,977	16,965	16,425
% Increase over FY 1954		7%	3%
Total dollars	\$2,513,546	\$2,736,449	\$3,543,332
% Increase over FY 1954		9%	40%
Personnel strength	16	21	22

been established for the procurement of all inventory items. Another group was established for the LMFR program of the Nuclear Engineering Department. In both cases, present personnel were utilized. These buying groups are similar to the one established for the Alternating Gradient Synchrotron during the previous period.

A new administrative tool, The Standard Operation Procedure Guide for Purchasing, was prepared and distributed to all members of the Purchasing Division. The Guide outlines the procedure for all purchasing activities including the duties and responsibilities of the personnel concerned.

Eight excess sales were conducted during the year, a decrease of five compared to the number in the previous year. The sales produced a gross return of \$22,548.

Purchases of excess made during the year amounted to \$4,108 plus transportation. The Government acquisition cost was listed as \$16,992.

PUBLIC INFORMATION

The expanding interest in the peacetime possibilities of nuclear energy again resulted in increased activities for the Public Information Office during the fiscal year. In accordance with the aims of the AEC, Brookhaven participated in the dissemination of information about uses of atomic energy both in this country and abroad.

The public relations office dealt with 100 members of the press (domestic and foreign), supplied material for scenes in five motion pictures about various phases of atomic energy research, assisted seven foreign newspaper reporters to write feature articles about BNL, supplied various background material and pictures for 25 magazine articles, and assisted writers of textbooks and encyclopedias with written and visual material.

The Voice of America recorded at the Laboratory interviews with scientists, both BNL staff members and visitors, to be broadcast and televised in many parts of the world.

Appendix A

UNCLASSIFIED PUBLICATIONS, JULY 1, 1955 — JUNE 30, 1956

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 publication is designated by (In press).

GENERAL PUBLICATIONS

Annual Report, July 1, 1955. BNL 364 (AS-9).
 Quarterly Progress Reports:
 July 1 - September 30, 1955. BNL 367 (S-27).
 October 1 - December 31, 1955. BNL 375 (S-28).
 January 1 - March 31, 1956. BNL 388 (S-29).
 April 1 - June 30, 1956. BNL 406 (S-30).
 Conference Report:
 Brookhaven Symposia in Biology No. 8. Mutation. BNL 350 (C-22).
 Weekly Bulletin 8, No. 50-52; 9, No. 1-49.
 Weekly Selected Reading List 8, No. 18-52; 9, No. 1-17.

STAFF PUBLICATIONS AND ABSTRACTS

Accelerator Development Department

Blewett, J.P. Linear accelerator injectors for proton synchrotrons. *CERN Symposium Proceedings*, pp 159-66, Geneva, June 1956.
 Christofilos, N.C. Calculations of drift tube shapes for linear accelerators. (A) *Bull. Am. Phys. Soc. Ser. II*, 1, 290 (1956).
 Christofilos, N.C. (See Cottingham, J.G.)
 Cottingham, J.G., Christofilos, N.C., Plotkin, M., Raka, E.C. and Rheume, R.H. Electron analogue - Electrical system. (A) *Bull. Am. Phys. Soc.* 30, No. 7, 42 (1955).
 Cottingham, J.G. (See Spiro, J.)
 Courant, E.D. (See Green, G.K.)
 Courant, E.D. (See Spiro, J.)
 Courant, E.D. (See Raka, E.C.)
 Courant, E.D., Kassner, R.R., Raka, E.C., Smith, L. and Spiro, J. Electron analogue - Performance and interpretation: II. (A) *Bull. Am. Phys. Soc.* 30, No. 7, 42 (1955).
 Gould, C.L. (See Jacobus, D.D.)

Green, G.K., Courant, E.D., Haworth, L.J. and Snyder, H.S. The electron analogue. (A) *Bull. Am. Phys. Soc.* 30, No. 7, 41 (1955).
 Green, G.K. Phase transition in the alternating gradient accelerator. *CERN Symposium Proceedings*, pp 103-5, Geneva, June 1956.
 Grisoli, J.J. (See Jacobus, D.D.)
 Haworth, L.J. (See Green, G.K.)
 Jacobus, D.D., Gould, C.L., Grisoli, J.J. and Polk, I.J. Electron analogue - Construction. (A) *Bull. Am. Phys. Soc.* 30, No. 7, 41 (1955).
 Kassner, R.R. (See Raka, E.C.)
 Kassner, R.R. (See Spiro, J.)
 Kassner, R.R. (See Courant, E.D.)
 Laslett, L.J. (See Raka, E.C.)
 Plotkin, M. (See Raka, E.C.)
 Plotkin, M. (See Cottingham, J.G.)
 Plotkin, M. A 25 billion electron volt proton synchrotron. Presented at Nuclear Eng. Sci. Congr., Cleveland, Dec. 1955.
 Polk, I.J. (See Jacobus, D.D.)
 Raka, E.C., Kassner, R.R., Plotkin, M. and Spiro, J. Acceleration through phase transition in the Brookhaven electron analogue. (A) *Bull. Am. Phys. Soc. Ser. II*, 1, 177 (1956).
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 Spiro, J., Cottingham, J.G., Courant, E.D. and Kassner, R.R. Electron analogue - Initial setup. (A) *Bull. Am. Phys. Soc.* 30, No. 7, 42 (1955).
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Architectural Planning Division

Rideout, S.S. (See Lamarsh, J.R. - Nuclear Eng.)

*Also included are those listings from the last Annual Report (BNL 364 (AS-9)) for which complete reference information was not then available.

- Ruddy, J.M. Radioactive liquid waste control. *Plant Eng.* (In press).
 Ruddy, J.M. Radioactivity laboratories. Submitted to *Plant Eng.*

Biology Department

- Anderson, L.F. (See Steffensen, D.)
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 Berg, G.G. Ascending chromatography of polyphosphates. Submitted to *Anal. Chem.*
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 Cantino, E.C. and Horenstein, E.A. The stimulatory effect of light upon growth and CO₂ fixation in *Blastocladiella*. I. The S.K.I. cycle. Submitted to *Mycologia*.
 Curtis, H.J., Person, S.R., Oleson, F.B., Henkel, J.E. and Delihass, N. Calibrating a neutron facility for biological research. *Nucleonics* **14**, No. 2, 26-9 (1956).
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 Dropkin, V.H. Determinations of phosphorus content of golden nematode and root-knot nematode. (A) *J. Parasitol.* **41**, 39 (1956).
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 Gibbs, M., Sokatch, J.T. and Gunsalus, I.C. Product labeling of glucose-1-C¹⁴ fermentation by homofermentative and heterofermentative lactic acid bacteria. *J. Bacteriol.* **70**, 572-6 (1955).
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- Konzak, C.F. and Randolph, L.F. Radiation and iris breeding. *Bull. Am. Iris Soc. No.* **142**, 68-74 (1956).
- Konzak, C.F., Borlaug, N.E., Acosta, A. and Gibler, J. Stripe rust resistant mutants obtained from irradiation of Gabo wheat. *Phytopathology* **46**, 525-6 (1956).
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- Koshland, D.E., Jr. Isotopic exchange criteria for enzyme mechanisms. *Discussions Faraday Soc. No.* **20**, 142-8 (1955).
- Koshland, D.E., Jr. (See Herr, E.B., Jr.)
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- Langer, L. (See Kowalsky, A.)
- Lewis, L. (See Nims, L.F.)
- Melnick, I. (See Krueger, R.C.)
- Moses, M.J. and Taylor, J.H. Desoxypentose nucleic acid synthesis during microsporogenesis in *Tradescantia*. *J. Exptl. Cell Research* **9**, 474-88 (1955).
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- Nims, L.F. and Geisselsoder, J.L. Responses to whole-body x-irradiation in the starved rat. *Radiation Research* **5**, 58-64 (1956).
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- Pond, V. (See Sparrow, A.H.)
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- Reichard, S.M., Edelmann, A. and Gordon, A.S. Endocrine influences upon the uptake of colloidal thorium by the reticulo-endothelial system. *J. Lab. Clin. Med.* **48**, 431-41 (1956).
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- Saunders, L.Z., Jubb, K.V. and Coates, H.V. The intra-ocular lesions of canine distemper. *J. Comp. Pathol. Therap.* (In press).
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- Sparrow, A.H. (See Kuhl, O.A. - Nuclear Eng.)
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- Steele, R., Wall, J.S., deBodo, R.C. and Altszuler, N. Carbohydrate metabolism of hypophysectomized dogs as studied with radioactive glucose. *Am. J. Physiol.* **187**, 25-31 (1956).
- Steele, R., Altszuler, N., Wall, J.S. and deBodo, R.C. Effect of cortisone on carbohydrate metabolism as studied with C^{14} glucose in hypophysectomized and adrenalectomized dogs. (A) *Federation Proc.* **15**, 3 (1956).
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- Steele, R., Wall, J.S., deBodo, R.C. and Altszuler, N. Studies with radioactive glucose of insulin hypersensitivity in the hypophysectomized dog. (A) *Federation Proc.* **15**, 196 (1956).
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Technical Information Division

- Comstock, M. The literature of instrumentation for radiological studies. *I.R.E. Trans. Professional Group on Nuclear Sci.* **NS-3**, 15-17, (June 1956).

Appendix B

OFFICERS AND SCIENTIFIC STAFF

Leland J. Haworth, *Director*
Gerald F. Tape, *Deputy Director*

Robert A. Patterson, *Assistant Director*

William H. Fields, *Assistant Director*

Leland J. Haworth, *Chairman*, Accelerator Development Department
Howard J. Curtis, *Chairman*, Biology Department
Richard W. Dodson, *Chairman*, Chemistry Department
George B. Collins, *Chairman*, Cosmotron Department
J.B.H. Kuper, *Chairman*, Instrumentation and Health Physics Department
Lee E. Farr, *Chairman*, Medical Department
Clarke Williams, *Chairman*, Nuclear Engineering Department
Samuel A. Goudsmit, *Chairman*, Physics Department
Marvin Fox, *Chairman*, Reactor Department
J. Georges Peter, *Architectural Planning Director*
H. Russell Cort, *Budget Officer*
Lewis R. Burchill, *Controller*
Charles F. Dunbar, *Legal Counsel*
Laurence R. Swart, † *Personnel Officer*
Julius Hannoch, * *Personnel Officer*
Frederick H. Williams, *Security Officer*

Accelerator Development Department

Leland J. Haworth, *Chairman*
Roger R. Adams
Robert D. Baldwin, Jr.
Richard A. Beth
John W. Bittner
John P. Blewett
M. Hildred Blewett
Hugh N. Brown
Vernon J. Buchanan
Nicholas C. Christofilos
Theodore Constant
James G. Cottingham
Charles E. Falk
Robert J. Gerrity
Salvatore T. Giordano
Charles L. Gould
George K. Green

†Terminated March 2, 1956.

*Terminated before June 30, 1956.

John J. Grisoli
Donald W. Huszagh
David D. Jacobus
Michael Karelitz
David A. Kassner
Ralph R. Kassner
John D. Kiesling
Glen R. Lambertson*
(*on leave from Univ. of California*)
Calman Lasky
Walter W. Markle
James P. Palmer
Robert H. Phillips
Martin Plotkin
Irving J. Polk
Eugene C. Raka
Raymond H. Rheaume
Everett J. Rutan
Albert P. Schlafke, Jr.
Edward E. Shelton
Maxwell M. Small

*Terminated before June 30, 1956.

Lloyd Smith*
(*on leave from Univ. of California*)
Julius Spiro
Lincoln D. Stoughton
Arthur M. Vash*

Biology Department

Howard J. Curtis, *Chairman*
Leroy G. Augenstine
John A. Bergeron
Irwin Berman*
(*on Natl. Research Council Fellowship*)
Florence G. Buch
(*graduate student from NYU*)
Phelps P. Crump
Elwood Dollinger*
(*on US Public Health Service Fellowship*)
Francis M. Dwyer*
(*on leave from Brown Univ.*)
Abraham Edelmann*

*Terminated before June 30, 1956.

Marilyn L. Fleischer
(graduate student from NYU)
Donald J. Fluke
Frederick Forro, Jr.*
Rufus C. Fuller
Martin Gibbs
Monroe Glitzer*
(on leave from Syracuse Univ.)
Earl B. Herr
(postdoctoral appointment)
Otto Kandler
(on leave from
Univ. of Munich, Germany)
Robert C. King
James R. Klein
Calvin F. Konzak
Daniel E. Koshland, Jr.
Marian E. Koshland
Arthur G. Kowalsky*
(postdoctoral appointment)
Myron Levine
Newton Meiselman*
(graduate student from Rutgers Univ.)
Leslie F. Nims
Lynn M. Paegge
(assigned from Frankford Arsenal)
Henry Quastler
George H. Reazin
Sherwood Reichard*
(graduate student from NYU)
Yoneo Sagawa
(postdoctoral appointment)
Leon E. Saunders
Erwin A. Schwinghamer
Seymour Shapiro
Frederick G. Sherman
Willard R. Singleton*
Harold H. Smith
(on leave from Cornell Univ.)
Arnold H. Sparrow
Robert Speirs
(on leave from Univ. of Wisconsin)
Robert Steele
Dale M. Steffensen
Otto L. Stein
(on leave from Univ. of Minnesota)
Robert E. Swanson
Raymond R. Walsh*
Philip S. Woods

Chemistry Department

Richard W. Dodson, *Chairman*
Augustine O. Allen
R. Christian Anderson
Elizabeth W. Baker
Nathaniel F. Barr
(postdoctoral appointment)
Jacob Bigeleisen

*Terminated before June 30, 1956.

Lee G. Carpenter*
(graduate student from Columbia Univ.)
Albert A. Caretto, Jr.*
(postdoctoral appointment)
David R. Christman
Lester M. Corliss
James B. Cumming
Raymond Davis, Jr.
Nancy E. Day*
Israel Dostrovsky
(on leave from Weizmann Inst. of Science)
Norman Elliott
Arthur M. Feibush
(graduate student from Syracuse Univ.)
Simon Freed
Gerhart Friedlander
Lewis Friedman
Richard Glick*
(postdoctoral appointment)
Barry M. Gordon
(postdoctoral appointment)
Floyd T. Gould
(graduate student from Columbia Univ.)
Walter C. Hamilton
(postdoctoral appointment)
Garman Harbottle
Julius Hastings
Ralph A. Horne*
(postdoctoral appointment)
Jerome Hudis
Adolph P. Irsa
Masomi Izawa*
(on leave from
National Inst. of Health, Japan)
Seymour Katcoff
Henry Linschitz
(on leave from Syracuse Univ.)
Samuel Markowitz
(graduate student from RPI)
Donald G. Miller
(postdoctoral appointment)
John A. Miskel*
Elinor F. Norton
Brian D. Pate
(postdoctoral appointment)
Morris L. Perlman
Russell W. Pierce
(graduate student from Columbia Univ.)
Carol S. Redvanly
Peter Riesz*
(postdoctoral appointment)
Walter G. Rothschild
J. Keith Rowley
William Robinson
Edward V. Sayre
Oliver A. Schaeffer
Robert H. Schuler
Harold A. Schwarz

*Terminated before June 30, 1956.

Rodman A. Sharp
(postdoctoral appointment)
Patricia R. Sisler
Morris Slavin
Raymond W. Stoenner
Norman Sutin
(postdoctoral appointment)
Sydney O. Thompson
Milton M. Wald
(postdoctoral appointment)
Joan P. Welker*
Ralph E. Weston, Jr.
Alfred P. Wolf
Richard Wolfgang
Max Wolfsberg

Colombo Project

Marvin Fox, *Leader (BNL)*
Dennis Puleston, *Deputy Leader (BNL)*

Field Team

Victor P. Bond
(assigned from
Medical Department, BNL)
Solomon H. Chafkin
(on leave from
International Cooperation Administration)
John F. Hogerton
(on leave from Vitro Corp.)
Harold H. Smith
(assigned from
Biology Department, BNL)
Horace Smith
(on leave from Department of State)
Ralph Strom
(on leave from
Atomic Energy Commission)
Harold B. Tukey
(on leave from Michigan State Univ.)
Amry Vandenbosch
(on leave from Univ. of Kentucky)
Frederick C. Vonderlage
(on leave from
Oak Ridge National Laboratory)

Home Team

George J. Dienes
(assigned from
Physics Department, BNL)
Norman Elliott
(assigned from
Chemistry Department, BNL)

Computer Center

Stuart S. Rideout

Cosmotron Department

George B. Collins, *Chairman*

*Terminated before June 30, 1956.

Alexander Abashian
(graduate student from
Johns Hopkins Univ.)
Robert K. Adair
David A. Barge
(graduate student from RPI)
Mark Q. Barton
(postdoctoral appointment)
David Berley
(graduate student from Cornell Univ.)
Henry Blumenfeld
(graduate student from Columbia Univ.)
Elihu Boldt
(graduate student from MIT)
Theodore Bowen
(on leave from Princeton Univ.)
Walter G. Chesnut
(postdoctoral appointment)
William Chinowsky
Forrest Cookson
(graduate student from Princeton Univ.)
Ernest D. Courant
Edward W. Dexter
Louis Janeau
(on MIT Fellowship)
Kenneth Lande
(graduate student from Columbia Univ.)
Christopher P. Leavitt
Lawrence B. Leipuner
(postdoctoral appointment)
Isador J. Livant
Robert A. Loper
Richard Madey
Robert L. Mills*
(postdoctoral appointment)
William H. Moore
Robert Motley
(on leave from Princeton Univ.)
Stuart L. Ridgway*
(postdoctoral appointment)
Edwin J. Rogers
Marc H. Ross*
(postdoctoral appointment)
Melvin Schwartz
(postdoctoral appointment)
Walter Selove*
(on leave from Harvard Univ.)
Lyle W. Smith
Rudolph Sternheimer
Clifford E. Swartz
Guido Tagliaferri
(on leave from Princeton Univ.)
Gyo Takeda
(on leave from Kobe Univ., Japan)
Clarence M. Turner
Daniel Willard*
(postdoctoral appointment)
Lee Young
(on leave from Harvard Univ.)

*Terminated before June 30, 1956.

Luke C. Yuan

Instrumentation and Health Physics Department

J. B. Horner Kuper, *Chairman*
Luther C. Barcus
Donald S. Beard*
Maurice M. Beebe
William Bernstein
Richard H. Boutelle
Robert L. Chase
Frederick P. Cowan
Ahmed M. Elnasher*
(on leave from Shams Univ., Egypt)
Edward H. Foster
Lee Gemmell
Martin H. Graham
John S. Handloser
Mortimer B. Heller
William A. Higinbotham
Byron E. Kenne*
Clifford J. Konnerth
Stella E. Lax*
Lionel Lewis*
Casimir Z. Nawrocki
Lloyd Nevala*
Leigh F. Phillips
Seymour Rankowitz
Francis X. Rizzo
Richard C. Roth
Robert J. Spinrad
Charles F. Stearns
Robert M. Sugarman
Jerome Weiss
Max M. Weiss

Medical Department

Lee E. Farr, *Chairman*
Johan K. Basson*
(on leave from Council for Scientific and
Industrial Research, Union of South Africa)
Victor P. Bond
Donald C. Borg
(postdoctoral appointment)
Robert D. Campo
(graduate student from St. John's Univ.)
Robert A. Conard
George C. Cotzias
Eugene P. Cronkite
Lewis K. Dahl
Ruth M. Drew
Edward T. Dunham*
Otho D. Easterday
Lewis I. Gidez
Lawrence V. Hanks
Walter L. Hughes
John James*
(postdoctoral appointment)

*Terminated before June 30, 1956.

Paul G. LeFevre
Charles G. Lewallen*
Stuart W. Lippincott
Robert A. Love
Myles Maxfield
Lawrence S. Maynard*
Carleton M. Neil
(postdoctoral appointment)
Robert B. Painter
William H. Perkins*
Edwin A. Popenoe
James S. Robertson
Herschel Sandberg*
Irving Serlin
Claire J. Shellabarger
Walton W. Shreeve
Lawrence Silver
F. Marrott Sinex
Elmer Stickley
Richard D. Stoner
Geronimo Terres, Jr.
Donald D. Van Slyke
Richard I. Weller
William Wolins

Nuclear Engineering Department

Clarke Williams, *Chairman*
Seymour Adler
Theodore Auerbach
David S. Ballantine
Hampden O. Banks, Jr.
Wendell E. Bent
(assigned from Long Island Lighting Co.)
George F. Bierman
(assigned from Gilbert Associates Inc.)
Allan K. Booth, Jr.
(assigned from American Metal Co.)
Merwyn B. Brodsky
Joseph S. Bryner
Jack Chernick
Joe G. Y. Chow
Noel R. Corngold
Robert F. Doering
Kenneth W. Downes
Lauren B. Doyle*
Orrington E. Dwyer
James J. Egan
Charles L. Feldman
Harmon L. Finston
Joseph A. Fleck
William S. Ginell
Althea Glines
David H. Gurinsky
Laranus P. Hatch
Leonard R. Heintze*
Joseph M. Hendrie
Raymond J. Heus
Frank B. Hill
Frederick L. Horn

*Terminated before June 30, 1956.

Robert J. Isler
 Jared Jackson*
(assigned from Babcock and Wilcox Co.)
 Richard Johnson
 Jean Juliens
(assigned from Center of Applied Nuclear Energy, Belgium)
 Otto F. Kammerer
 Irving Kaplan
 George Kelcic
(assigned from Jersey Central Power and Light Co.)
 Carl J. Klamut
 Ernest A. Knipp, Jr.*
(graduate student from Yale Univ.)
 Herbert J. Kouts
 Stanley L. Koutz*
(assigned from General Dynamics Corp.)
 Evan C. Kovacic
(assigned from Central Hudson Gas and Electric Co.)
 Otto A. Kuhl
 Lawrence E. Kukacka, Jr.
 John Lamarsh
 Gerald S. Lellouche*
 Theodore M. Littman
 Bernard Manowitz
 David B. Marsland
(graduate student from Cornell Univ.)
 Michel Melice
(assigned from Center of Applied Nuclear Energy, Belgium)
 Donald J. Metz
 Robert A. Meyer
 Francis T. Miles
 William E. Miller*
(assigned from Dow Chemical Co.)
 Daniel Milsom
(assigned from Cities Service Research and Development Co.)
 Donald F. Molino*
 Bernard Mozer*
 Donald E. Neil
(graduate student from RPI)
 Paul J. Nicholson
 Sophie Oleksa
 Dwight R. Patterson
(assigned from TVA)
 James P. Phelps
(assigned from Glenn L. Martin Co.)
 Carl Pierce
 Glenn A. Price
 Chad J. Raseman
 William H. Regan, Jr.
 David M. Richman
 Corwin Rickard
 Arthur E. Roswell
 Jerome Sadofsky

*Terminated before June 30, 1956.

Cesar A. Sastre
(assigned from Atomic Energy Commission, Argentina)
 Clifford H. Scarlett
 George T. Schnurer*
(assigned from General Dynamics Corp.)
 Donald G. Schweitzer
 Donald H. Sengstaken*
(assigned from Long Island Lighting Co.)
 Rudolph Sher
 Yoshio Shimamoto
 Melvin Silberberg*
 John L. Speirs
 Kenneth T. Spinney
(assigned from Atomic Energy Research Establishment, England)
 Louis G. Stang, Jr.
 Graham Stoner
(assigned from Dow Chemical Co.)
 Gerald Strickland
 Herbert Susskind
 Robert J. Teitel*
 Robert A. Tidball
(assigned from Griscom-Russell Co.)
 Belden S. Tucker
(assigned from C.H. Wheeler Manufacturing Co.)
 Walter D. Tucker
 Bernard Turovlin*
(assigned from Combustion Engineering, Inc.)
 Charles H. Waide
 William E. Weaver
(assigned from Griscom-Russell Co.)
 John R. Weeks
 Clarence B. Whims*
 Frank Wills
(assigned from US Metals Refining Co.)
 Edward Wirsing, Jr.
 Richard H. Wiswall, Jr.
 Samuel A. Zwickler

Physics Department

Samuel A. Goudsmit, *Chairman*
 James Abel
(assigned from Picatinny Arsenal)
 David E. Alburger
 John J. Antal
(assigned from Watertown Arsenal)
 Frederick Ayer II
 Charles P. Baker
 Marietta E. Blau
 Stewart D. Bloom
 Ernest M. Bolze
 John L. Brown IV
(graduate student from Univ. of Michigan)
 Keith A. Brueckner

*Terminated before June 30, 1956.

Robert S. Carter
 Eugene L. Church
(assigned from Frankford Arsenal)
 David D. Clark*
 Victor W. Cohen
 Rodney L. Cool
 James W. Cronin
(postdoctoral appointment)
 Arthur C. Damask
(assigned from Frankford Arsenal)
 Charles C. Damm
 Horace R. Danner
(on leave from Pennsylvania State Univ.)
 Edward der Mateosian
 George J. Dienes
 James E. Draper
 Russell W. Dreyfus
(assigned from Picatinny Arsenal)
 Lila M. Eisberg*
 Robert M. Eisberg*
(postdoctoral appointment)
 Edward L. Fireman
 B. Chalmers Frazer
(assigned from Westinghouse Electric Corp.)
 John D. Garrison*
(on leave from Yale Univ.)
 John B. Gibson
(postdoctoral appointment)
 Donald A. Gilbert
 G. Norris Glasoe
 Richard E. Glick*
(postdoctoral appointment)
 Gertrude S. Goldhaber
 Maurice Goldhaber
 Lee Grodzins
(postdoctoral appointment)
 William M. Harris*
 John A. Harvey*
 Edward L. Healey
 John Hornbostel
 Donald J. Hughes
 George Igo*
 David T. Keating
 Henry W. Kendall
(on MIT Fellowship)
 Vincent P. Kenney*
(on leave from Fordham Univ.)
 Ottmar C. Kistner
(graduate student from Columbia Univ.)
 Walter L. Kosiba
 Saul Krasner
(assigned from Picatinny Arsenal)
 Karl Erik A. Larsson
(assigned from Atomic Energy Establishment, Sweden)
 Paul W. Levy
 Seymour Lindenbaum

*Terminated before June 30, 1956.

Robert S. Margulies
(graduate student from Cornell Univ.)
Bruce H. McCormick
(postdoctoral appointment)
Andrew McReynolds*
Kirk W. McVoy, Jr.
(postdoctoral appointment)
Donald Meyer
(on leave from Univ. of Oklahoma)
Michael J. Moravcsik
(postdoctoral appointment)
Thomas W. Morris
(postdoctoral appointment)
Henry T. Motz
Carl O. Muehlhause
Robert Nathans*
(on leave from Univ. of Pennsylvania)
Harry Palevsky
Simon Pasternak
(assistant editor of *The Physical Review*)
Martin Perl*
(on leave from Univ. of Michigan)
Oreste Piccioni
Stanley J. Pickart
(assigned from United States Army)
Valter E. Pilcher
Charles E. Porter, Jr.
Lew F. Porter
(assigned from US Steel Corp.)
David C. Rahm
Ralph R. Rau
Tormod Riste
(assigned from Joint Establishment for
Nuclear Energy Research, Norway)
Hyman Rosenwasser*
(assigned from Picatinny Arsenal)
Edward O. Salant
Robert B. Schwartz
Mary J. Scott
(graduate student from
Johns Hopkins Univ.)

*Terminated before June 30, 1956.

Frederick G.P. Seidl*
Kamel Seth
(on leave from Univ. of Pittsburgh)
Gen Shirane
(on leave from Pennsylvania State Univ.)
Clifford Shull
(on leave from MIT)
Ralph P. Shutt
Harvey P. Sleeper*
Joseph E. Smith
Lincoln G. Smith
George A. Snow*
Hartland S. Snyder
Andrew W. Sunyar
Leon Tenzer
(on Belgian-American
Education Foundation Fellowship)
Alan Thorndike
Bert J. Toppel
George H. Vineyard
Walter W. Wada
(on leave from
National Research Laboratory)
Harvey Wegner*
Joseph Weneser
William L. Whittemore
Robert L. Zimmerman
Gus T. Zorn

Reactor Department

Marvin Fox, Chairman
Raymond E. Benenson
John E. Binns
John A. Dooley
Anthony N. Fasano
(assigned from
Wright Air Development Center, USAF)
John J. Floyd
Hugie L. Foote, Jr.*

*Terminated before June 30, 1956.

Fred P. Harries*
(assigned from
Westinghouse Electric Corp.)
Gerald C. Kinne
Harry H. Landon, Jr.
Walter Lones
Harvey Marshak
(postdoctoral appointment)
Miles J. McGoff
(assigned from
Mine Safety Appliances Co.)
Lowell McLean
James A. Moore
(on leave from Columbia Univ.)
Charles L. Osborne
Jack E. Phillips
G. dePuyster Pitcher
Robert W. Powell
Edward Prince
(assigned from Bell Telephone Co.)
Alonzo C. Rand*
Joseph A. Roll
(assigned from
Westinghouse Electric Corp.)
Brice M. Rustad
(on leave from Columbia Univ.)
Vance L. Sailor
Robert D. Schamberger
Arthur Z. Schwarzschild
(on leave from Columbia Univ.)
Ralph E. Segel
Ferdinand J. Shore
Irving A. Singer
Maynard E. Smith
Isaac Van der Hoven
(assigned from US Weather Bureau)
Edward W. Wiederhold
(assigned from Monsanto Chemical Co.)
Walter Winnowski*
(assigned from
Westinghouse Electric Corp.)

*Terminated before June 30, 1956.