TECHNICAL INFORMATION DIVISION

BROOKHAVEN NATIONAL LABORATORY

Annual Report

July 1, 1955

Associated Universities, Inc.

under contract with the

United States Atomic Energy Commission

Annual Report
July 1, 1955

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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 sixth in a series of unclassified Annual Reports, gives an account of the progress of the Laboratory during the period July 1, 1954 - June 30, 1955, 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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CONTENTS

INTRODUCTION	vii
PHYSICAL SCIENCES AND ENGINEERING	
PHYSICS	1
ELECTRONICS	18
ACCELERATORS	20
CHEMISTRY	29
ENGINEERING	46
LIFE SCIENCES	
BIOLOGY	60
MEDICINE	71
TECHNICAL OPERATIONS AND SERVICES	80
ADMINISTRATION AND OPERATIONS	94
APPENDIX - A. UNCLASSIFIED PUBLICATIONS, JULY 1, 1954 - JUNE 30, 1955	105
B. OFFICERS AND SCIENTIFIC STAFF	121

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The officers of AUI are shown on the organization chart for the Laboratory (Figure 1). AUI has appointed five visiting committees to Brookhaven National Laboratory to provide a continuing independent evaluation of the research program of the Laboratory. These visiting committees cover the fields of biology, chemistry, engineering, medicine, and physics, and members report annually to the Board of Trustees.

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Picture taken at the Cosmotron with a University of Michigan Bubble Chamber. Cosmotron particles, entering from the left, leave tracks of tiny bubbles in the almost boiling liquid. The photograph demonstrates how this recently invented technique may show, in one picture, several collisions and interactions of fast Cosmotron particles with atomic nuclei of the liquid.

INTRODUCTION

This annual report of Brookhaven National Laboratory describes its program and activities for the fiscal year 1955. 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. (The record of publications since 1946 is shown in Figure 2.) Hence the activities of the Laboratory service organizations are treated more fully in this report, whereas research activities are covered in summary.

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.

Unfortunately, the Cosmotron broke down on November 5, 1954 and use of the machine for research did not get under way again until April of 1955. A short circuit developed in the magnet winding of quadrant number 2 and resulted in the melting of some copper on one bar and damage to adjacent conductors. This necessitated practically complete dismantling of the damaged quadrant, the repair or replacement of conductors and their assembly. This misfortune, costly in terms of lost research time, was not without its gains. The enforced shutdown period was used to make modifications which would permit increased usefulness of the machine. Typical of the changes made are modification of the vacuum chamber to permit bringing out an external proton beam, modification of the rf system to provide increased beam intensity, general cleaning up of shielding, and installation of an electrical distribution system for experimental equipment. It is gratifying to report that this major repair job has been completed and that the machine is operating under improved conditions with increased performance.

It was reported last year that the demand for operating time at the Cosmotron was increasing. This is still true. The 6 months' shutdown aggravated the situation. Upon completion of the repairs, operation on a 24-hour, 5-day schedule was initiated. Even this schedule has not satisfied the demand from both Brookhaven scientists and from the many university scientists participating in the high energy research program. The Laboratory is continuing to try to meet this demand through more efficient operation and machine use. The fraction of effective operating time (for research) as measured against scheduled time is now 80 percent and probably cannot be increased substantially. Lack of duplicate equipment and restrictions on space cause excessive down time while rearrangements of experimental equipment are being made. The need for a greater floor area has been recognized (FY 1957 budget request—Cosmotron Target Area). This increase would permit large experimental arrays to remain in place throughout the duration of a given experiment and reduce down time. Also, several compatible experiments could then be operated simultaneously. The effectiveness of the Cosmotron would be greatly increased thereby.

It must be remembered that the Brookhaven Cosmotron and the Berkeley Bevatron are the only heavy particle accelerators now operating in the billion electron volt range in the United States. No other US accelerators will be operating in this energy range before 1959, so that it is imperative that maximum use be made of existing machines. Research priorities will undoubtedly have to be continued.

The Brookhaven nuclear reactor continued its very impressive operational record in supporting work from all of the disciplines represented at the Laboratory. Whereas at the Cosmotron experiments are carried out one, two, or at most three at a time, most of the research activities at the reactor can be carried out simultaneously with essentially no interference. The reactor facilities continue to be used at capacity. Individual projects come and go as program demands change. The reactor operated about 90 percent of the time as contrasted with 83 percent for the preceding year. This is also noted through

a comparison of the 8041 megawatt-days accumulated in FY 1955 and the 7244 megawatt-days in FY 1954.

A proposal has been made to replace the natural uranium fuel now in the research reactor with enriched uranium, in order to increase the available flux. Studies have been under way during the past year directed at the design of a new fuel element which would be suitable for the existing reactor. Present considerations indicate that such a change would be highly desirable; it would give about a five-fold flux increase. At the same time the fan pumping power required would be materially reduced and the operation cost would be lowered. The expense of replacing normal uranium with enriched uranium appears to be economically sound. These studies will continue throughout the coming year. It is anticipated that reloading will start some time near the end of the fiscal year, or early FY 1957.

No substantial modifications have been made on the 60-inch and 18-inch cyclotrons, nor on the research electrostatic accelerator. All these instruments had good performance records throughout the year. It will be necessary, however, to provide permanent housing for the 18-inch cyclotron which was assembled and has been undergoing adaptations to special time-of-flight experiments in the Cosmotron test shack. The 18-inch cyclotron cannot be operated in these temporary quarters for the neutron experiments for which it was designed, since this would interfere with other work in the area and would be radiologically unsafe. Consideration has been given to an addition to the present cyclotron—Van de Graaff building to house the 18-inch cyclotron; all the low energy accelerators would then be consolidated in one general area. It is anticipated that a proposal for such an addition will be made in the near future.

CONSTRUCTION PROGRAM

The alternating gradient synchrotron, project AGS, moved into a construction phase during the report period. From a building point of view the first construction phase involved adding to the capacity of the central heating plant of the Laboratory, in order to provide for the increased load for the AGS complex and for other pending needs of the Laboratory. The oil-fired steam plant capacity is being increased from 40,000 lb to 100,000 lb. The construction

began in March and is expected to be completed by the beginning of the heating season in 1955. This addition provides for the elimination of the old low pressure plant and will put all the central area of the Laboratory on one heating system, except for the temporary barracks which still have individual units.

Designs have been completed on the AGS Service Building which will house the offices, laboratories, shops, motor generator control room and other services required for the machine. The site clearing was started in June 1955 and the final details, plans and specifications will be put out for bids in August. This building has some 55,000 sq ft of floor area and will be located to the north and slightly west of the reactor and southeast of the AGS complex.

The construction of the electron analogue of the AGS was completed during the year and operational tests were undertaken. The characteristics and performance of this machine are discussed later in the Accelerators section.

A proposal for the construction of a permanent medical center on the southerly side of the site was made to the AEC and subsequently to Congress in FY 1955. The congressional approval for its inclusion in the FY 1956 plan has been received and construction is expected to begin in the spring of 1956. The AEC has engaged the architect-engineers firm of Eggers and Higgins to proceed with the design of the Medical Center itself. This one-story structure of 120,000 sq ft will house a research hospital having 4 units of 12 beds each, an industrial medicine clinic, and laboratories for the Department's research program. In addition the Center will have its own reactor, specifically designed to satisfy the requirements of the medical program. The cost of the project has been budgeted at \$6,000,000 exclusive of design costs.

The Laboratory had a subcontract with the Nuclear Development Corporation of America for a study of the preliminary design of a reactor suitable for medical purposes. The NDA report, submitted in February 1955, outlined a basic reactor design based on discussions with the Laboratory and upon the ideas prevailing in the summer of 1954. After further consideration of the problem by both medical scientists and reactor engineers at the Laboratory, Brookhaven undertook to settle its requirements so that detailed design could go forward. A Laboratory Medical Reactor Project Committee was charged

ASSOCIATED UNIVERSITIES, INC.

ORGANIZATION CHART

AUGUST, 1955

Figure 1.

Table 1

ORGANIZATIONAL EXPENDITURES - FISCAL 1953, 1954, 1955
(Includes Operating, Services to Fixed Assets, and Work for Others)

		Salaries, Wages, Insurance		Travel	Material & Supplies	Research & Development Subcontracts	Special Power	Miscellaneous (Net)	Total Organizational Costs	% of Total	Man-Years		
		Staff	Consultants & Temporary Appointments								Scientific (Incl. Guests)	Others	Total
Physics & Chemistry Research	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
	1953	1,400,795	70,383	45,662	382,064	74,337	34,318	(1,986)	2,005,573	21.0	148.0	119.0	267.0
Biology, Medicine & Biophysics Research	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
	1953	815,604	27,949	32,190	178,230	-	-	(8,802)	1,045,171	10.9	64.0	124.5	188.5
Engineering Research	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
	1953	582,085	19,219	20,289	288,555	25,086	-	-	935,234	9.7	54.5	56.5	111.0
Radiation Protection	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
	1953	222,398	1,844	3,059	50,758	-	-	(1,028)	277,031	2.9	19.5	33.0	52.5
Supporting Scientific & Technical Services	1955	1,587,949	8,298	9,373	262,648	-	462,376	(175,040)	2,155,604	20.1	31.0	276.5	307.5
	1954	1,471,086	6,685	11,225	240,434	-	404,202	(122,273)	2,011,359	20.2	31.5	260.5	292.0
	1953	1,545,752	4,448	6,365	224,642	-	420,636	(122,751)	2,079,092	21.7	36.5	279.0	315.5
Security & Plant Protection	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
	1953	537,227	-	52	6,358	-	-	-	543,637	5.7	-	122.0	122.0
Miscellaneous (including Lighting, T & T, Heating Fuels, Special Maintenance, etc.)	1955	-	-	1,394	72,923	-	-	483,685	558,002	5.2	-	-	-
	1954	-	-	-	54,226	-	-	411,554	465,780	4.7	-	-	-
	1953	-	-	-	32,513	-	-	397,862	430,375	4.5	-	-	-
General & Administration	1955	1,925,107	7,520	55,996	238,679	-	-	(146,149)	2,081,153	19.4	5.0	385.5	390.5
	1954	1,916,332	7,523	13,932	200,280	-	-	(116,612)	2,021,455	20.3	5.5	391.0	396.5
	1953	1,930,922	2,507	12,855	240,077	-	-	(98,684)	2,087,677	21.8	6.0	398.0	404.0
Laboratory Total	1955	7,744,504	154,388	177,088	1,532,697	147,448	500,713	138,888	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	451,277	148,270	9,769,820	98.1	357.5	1,116.5	1,474.0
	1953	7,034,783	126,350	120,472	1,403,197	99,423	454,954	164,611	9,403,790	98.2	328.5	1,132.0	1,460.5
AUI Administration	1955	-	-	-	-	-	-	161,400	161,400	1.5	-	-	-
	1954	-	-	-	-	-	-	150,000	150,000	1.5	-	-	-
	1953	-	-	-	-	-	-	150,000	150,000	1.6	-	-	-
Total: AUI and BNL	1955	7,744,504	154,388	177,088	1,532,697	147,448	500,713	300,288	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	451,277	298,270	9,919,820	99.6	357.5	1,116.5	1,474.0
	1953	7,034,783	126,350	120,472	1,403,197	99,423	454,954	314,611	9,553,790	99.8	328.5	1,132.0	1,460.5
Work for Others, Direct Costs Only	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
	1953	8,237	-	181	1,958	4,078	-	-	14,454	.2	-	2.0	2.0
Grand Total	1955	7,787,800	154,453	178,455	1,581,482	200,458	500,713	300,288	10,703,649(1)	100.0	386.0	1,148.5	1,534.5
	1954	7,355,508	161,562	137,350	1,369,603	183,060	451,277	298,270	9,956,630(2)	100.0	359.5	1,119.0	1,478.5
	1953	7,043,020	126,350	120,653	1,405,155	103,501	454,954	314,611	9,568,244(3)	100.0	328.5	1,134.0	1,462.5

(1) \$252,910 of this total was distributed to Fixed Assets and as services to Work for Others.

(2) \$218,978 of this total was distributed to Fixed Assets and as services to Work for Others.

(3) \$172,865 of this total was distributed to Fixed Assets and as services to Work for Others.

Figure 2.

with the job of drawing up detailed specifications for a medical reactor. These specifications introduce some engineering modifications in the reactor itself, but they deal particularly with arrangements of experimental space and equipment introduced for specific medical purposes. Detailed design will be carried out by the architect-engineer firm doing the reactor building and by the several firms supplying the reactor and associated equipments. The construction will be carried out by the general building contractor for the reactor building and the fabricators of the reactor proper and associated equipment under Laboratory supervision. It is not anticipated that detailed design and procurement will be undertaken for the reactor proper until some time in calendar 1956.

Major construction over the next two years will include some of the AGS facilities and the Medical Center, as noted above, starting in FY 1956. Plans for future fiscal years call for the gradual replacement of temporary laboratories with permanent research laboratories in much the same way that the Medical Center has been authorized. Requests are being made for the consideration of a permanent engineering building and the start of permanent physics laboratories during the next fiscal year. Certain spe-

cialized facilities are also required, such as additional space for experimental equipment at the Cosmotron, a permanent hot laundry and reclamation (decontamination) area. Requests for all these are in line with the philosophy of gradually providing permanent facilities both for general Laboratory requirements and for functions which are specific to Brookhaven and its work.

Many minor construction projects were completed during this report period. These are listed in detail under the Architectural Planning section of this report. Two of the projects are of particular significance. The addition of a small annex to one of the existing concrete block buildings near the eastern edge of the site permits the carrying out of criticality experiments with various lattice arrangements and provides for work supplementary to the exponential studies previously done on top of the reactor. The second major item under General Plant Project Additions was the authorization of the construction of a hydrogen liquifier. The liquid hydrogen requirements on the site have been met in the past through the small 3 liter/hr hydrogen liquifier of the Chemistry Department. However, the demands at the Cosmotron for liquid hydrogen targets and bubble chambers made it mandatory that a substantial lique-

Figure 3. The 18-inch cyclotron. The target for the focused proton beam is in the foreground.

Figure 4. The strong focusing magnet assembly for use with high energy beams from the Cosmotron.

faction plant be added to the Laboratory's facilities. The Laboratory has engaged the Bureau of Standards to design and construct a hydrogen liquifier of approximately 50 liter/hr capacity. This unit will be installed in a separate building located in the vicinity of the Cosmotron. It will ultimately serve both the Cosmotron and the new AGS, and provide liquid hydrogen for targets and bubble chambers, as well as for the smaller research demands elsewhere on the site.

A special effort was made in the spring of 1955 to catch up on much of the needed building repairs, especially on the external surfaces of various structures. Effort was directed at the waterproofing of several of the permanent structures, the repair of roofs and roof flashings, and the provision of asbestos siding to avoid the repeated painting of many of the wooden buildings which the Laboratory still plans to use over the next few years. Some structural weaknesses required correction, such as foundation improvements. In addition, the regular spring painting program was carried out. The Laboratory is finding that the maintenance requirements are increasing as the temporary wooden buildings become older. It has been necessary to take more drastic measures in order to preserve them for an additional period of time. The average maintenance program will continue at a higher rate than in previous years and must so continue until a substantial fraction of the site is in permanent quarters.

MAJOR RESEARCH PROJECTS

LIQUID METAL FUEL REACTOR

The use of a liquid metal as a reactor fuel has been under study at Brookhaven for some years. Early work was directed at exploring the basic chemistry and metallurgical aspects of potentially useful fuels. Promising results warranted the extension of these studies to the engineering type of problem. These latter studies have been going on over the past few years as component studies in which the physical, metallurgical and chemical aspects of liquid metal fuel systems have been under investigation. As more and more information has been obtained, the prospects for development of a liquid metal fuel reactor (LMFR) have become more encouraging. It now appears that such a reactor can be developed within a few years to give economical power.

Figure 5. Preparing an experimental loop for insertion into the reactor to study the effects of radiation on materials proposed for the Liquid Metal Fuel Reactor.

The advantages of a liquid metal fuel reactor have been obvious for some time. The fuel is circulated by pumps and can be processed continuously. The reactor structure itself can be relatively simple. High fuel temperatures will give high thermal efficiencies without excessive pressures and the accompanying containment problems. When coupled with a breeding cycle, the reactor could presumably produce as much new U^{233} as it consumed, so that fuel costs would be low.

These potential advantages of the engineering feasibility of LMFR have been confirmed by two independent study groups. Project Dynamo, at MIT in 1953, compared a number of power reactors and concluded that, if certain technical problems could be solved, the LMFR might well produce power at the lowest cost of any of the types studied. Since then some of these problems have been solved and others are on the way to solution. This year, a group of engineers from 17 companies, administered by Babcock and Wilcox Company under subcontract with Brookhaven National Laboratory, studied the

feasibility of the LMFR. They concluded that "the economic potentialities of the LMFR justify efforts to conduct aggressively the necessary research and development work required to bring an operating plant into existence as soon as possible." They also considered an LMFR power plant design using only present technology and concluded that electrical power could be produced at 7-8 mills/kwhr. Further developments should lower this cost.

The development status of the LMFR is as follows. A suitable fuel, uranium dissolved in bismuth, is available. The requirements of a container material seem to be satisfied by low chrome steels, which are now routinely used in boilers. In certain experiments, uranium-bismuth solutions containing inhibitors have been circulated in test loops for more than 2 years without serious corrosion. A process is under development which removes rare earth fission products from the fuel by extraction into fused salt. Since June 3, a loop has been circulating the fuel in the Brookhaven reactor. This has already demonstrated that gaseous fission products are removed from the fuel stream. A blanket consisting of a thorium-bearing bismuth slurry has been developed which has the properties required for a breeder blanket material. Some progress has been made towards a blanket processing scheme.

Several problems still need to be solved before a full scale reactor can be built. The Laboratory is recommending that the AEC support a substantial increase in development work in FY 1956. The accelerated program should include theoretical and exponential studies to determine core parameters, kinetics and control. In metallurgy, the container problem needs further study to ensure that mass transfer, uranium-graphite reactions and corrosion can be adequately controlled under conditions involving radiation. While the major features of the chemical process have been tested, process control and removal of impurities need further study. Heat exchange equipment developed by others will require testing. Development and testing of pump devices for circulating liquid bismuth and fused salts must be continued. The Laboratory hopes to increase substantially its development effort along these lines to recommend that the AEC consider the design and construction of an experimental LMFR within the next year or two.

ALTERNATING GRADIENT SYNCHROTRON

As reported last year, the Atomic Energy Commission authorized the Laboratory in January 1954 to go forward with the design of an accelerator and its associated buildings and services. This accelerator,

Figure 6. The electron analogue. The circular chamber enclosing the electron orbit is shown in the background, the control console in the foreground.

to operate at an energy of about 25 Bev, or more, will employ the "strong focusing" principle. During the past year, design and development of the various AGS components was carried on; this work is described in detail in the Accelerator section of this report. The design is roughly 50 percent completed and it is expected that machine design will be nearing completion in approximately another year. As noted above, construction of the service facility has already started. The electron analogue was successfully completed during the report year and an electron beam was circulated for the first time in March of 1955. This analogue has been constructed in order to study specifically the beam orbit behavior under conditions of strong focusing. Several problems arise in the type of machine to be constructed, and it was deemed desirable to build an analogue device which would allow one to determine experimentally the effect of various parameters on such problems as resonance and phase transition.

One problem encountered in the construction of the electron analogue arose from the fact that fabricators were unable to deliver guide lens assembly components within specified tolerances. An analytical technique was developed to determine a stacking order that averaged out misalignments to a satisfactory degree. This technique is now available to determine the stacking order for the AGS magnet sectors.

Optimum injection parameters for the analogue have been established, the pickup electrode system extended, and kicker electrodes installed. Reliable operation has been achieved. Resonance conditions have been investigated by changing the betatron wavelength. The inter-resonance spacings found are in excellent agreement with the theoretical predictions. The effects of nonlinear field components are still being studied. While the experience gained indicates that design of the AGS will have to include many facilities to correct equilibrium orbit displacements, it has nevertheless demonstrated that the earlier theoretical considerations have been sound and that full scale accelerators utilizing the strong focusing principle can be built. On the basis of the analogue and magnet model studies, it has been possible to design the magnet lattice structure for the AGS, i.e. the arrangement of focusing magnets, correcting magnets, and straight sections. The usefulness of the electron analogue has already justified its cost.

The present studies of resonance conditions with the coasting beam and the effects of nonlinear field components will soon be completed. Acceleration of the beam will then be undertaken and passage of the beam through the phase transition region will be studied to determine which of several proposed techniques is both effective and economical in achieving this transition.*

At the end of the fiscal year it was possible to review the design of the AGS accelerator in the light of the last 18 months of theoretical and experimental work. A revised set of parameters has been developed. No alteration of the preliminary basic parameters which were reported last year has been necessary. However, the information and experience gained made it evident that it would not be most efficient to build a machine of a nominal 25 Bev energy as a first step, with a later increase to about 35 Bev as was originally contemplated. Consequently, a new proposal was made to the AEC for the construction of an accelerator of approximately 30 Bev to be built in essentially one step. This proposal was also evaluated with respect to costs and official approval by the AEC of the revised program is momentarily expected.** The present specifications are therefore for the construction of an alternating gradient accelerator having a proton radius of 280 ft (circumference of approximately one-half mile including straight sections) and accelerating protons to a maximum energy of approximately 33 Bev. The new cost estimates for such a machine total \$26,000,000 which includes a ten percent contingency.

GENEVA CONFERENCE

In his speech to the United Nations on December 8, 1953, President Eisenhower appealed to the nations of the world to put the atom to work for peaceful purposes. In furtherance of his proposal, an Atoms for Peace Conference will be held in Geneva in August, 1955 under the auspices of the United Nations. Brookhaven is most happy to have a number of its staff members participate in this Conference and to be able to help the Atomic Energy Commission and the United States in the preparation of exhibits and published material to be used at that time.

* Passage of the accelerated beam through the transition region has since been achieved.

** AEC approval was received early in August.

Figure 7. Exhibit prepared for the National Academy of Sciences by the Biology Department to illustrate studies of the effects of radiation on plants. A similar display was erected at the Geneva Conference.

Twenty Brookhaven scientists have been invited to attend the Conference. Of these, 16 are scheduled to give papers. Titles and authors of these papers are given in Appendix A. In addition to these scientists, Dr. L. J. Haworth, Director; Dr. R. W. Dodson, chairman of the Chemistry Department; and Dr. D. H. Gurinsky, head of the Division of Metallurgy, have been invited to attend as delegates. Brookhaven is supplying a special exhibit illustrating the effects of radiation on the production of mutations in plants. Dr. S. Shapiro, of the Biology Department, will be in charge of this.

The Laboratory has cooperated in the gathering of information and the publication of much of the textual material to be presented by the United States delegation in addition to exhibit material and the scientific papers mentioned above. This includes the assembly of data and the preparation of charts and drawings for the most up-to-date neutron cross sections compilation, by Drs. D. J. Hughes and J. A. Harvey, the editing of a hot laboratory equipment catalog by L. C. Stang, Jr., and D. Puleston, the preparation of a chapter on the Brookhaven research reactor, and miscellaneous photographic and editorial assistance on other items.

Brookhaven is prepared to participate, not only in the Geneva Conference, but in other aspects of the Atoms for Peace plan. The Laboratory is most anxious that the participation in its program by visiting scientists be extended to include foreign scientists

as conditions warrant. These wishes are being made known to the Atomic Energy Commission. While visitors in the past have come primarily from the United States, the ideas and criticisms contributed by the few senior foreign visitors, with their quite different backgrounds, have proved most stimulating and have greatly benefitted Brookhaven's own programs. Consideration has also been given to appointments limited to one, or at most two years, for younger scientists from other countries who are just embarking on careers in the nuclear energy field. Brookhaven is also ready to offer help in the way of formal courses should its special facilities and staff warrant such courses being given at the Laboratory. However, its most effective role in the Atoms for Peace program is believed to lie in a natural extension of its present program, in which the visiting scientist plays such an important role.

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;
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. A few samples of research in progress and of significant advances made in the above categories will be noted here.

FUNDAMENTAL STUDIES OF NUCLEI

Studies of atomic nuclei, the particles which constitute them, and the forces involved are carried out in the Physics Department, the Cosmotron Department and the Chemistry Department. These studies extend from the range of energies available with the Cosmotron down to essentially zero energies at which the static properties such as spins and masses of the nuclei are measured. However, emphasis on research with the high energy beams from the Cosmotron continues to increase. This machine has been operating on a 24-hour, 5-day week basis since the middle of May. While two hours daily are reserved for inspection and adjustments, the scheduled research demands are being met, on the average, about 80 percent of the time. With strong focusing magnets, the following types of particles are now available in well defined beams: 10^6 protons of 3-Bev energy within an area of 1/4 in. by 1/2 in.; a focused beam of 10^4 positive K-mesons per cm^2 per pulse, which, although contaminated with about one hundred times as many pi mesons, is useful for K-meson emulsion and counter experiments; and a focused beam of either positive or negative pi mesons with energies up to 2 Bev and numbering 30 to 40 per cm^2 per pulse. Efforts are under way to bring out and focus the internally circulating beam of protons.*

The trend away from exploratory investigations and toward more quantitative experiments has required improvement in instrumental techniques. Cerenkov counters are supplementing the more common scintillation counters for many purposes. Since

the Cerenkov counters respond only to particles moving with nearly the speed of light, the background due to particles of lower velocity is greatly reduced. Bubble chambers have been brought to Brookhaven for use at the Cosmotron by the University of Michigan and Columbia University. With them it is possible to record a number of nuclear interactions on a single photograph, as illustrated in the frontispiece. The Laboratory is constructing several of these bubble chambers for the purpose of studying in particular the nature of the various heavy mesons and hyperons and their modes of decay.

Collaborative research with scientists at other institutions has continued to increase. The largest number of visiting experimenters work with emulsions; several, however, are working with counters. The cloud chambers from Harvard, Yale, Columbia and MIT have been operated by groups from these institutions. While about 20 regular staff members and 5 graduate students resident at Brookhaven spend a major part of their time on research with the Cosmotron, there are some 50 physicists and 44 graduate students at other institutions who are carrying out research based on data obtained from the Cosmotron beams. Most of the latter group have spent some time at Brookhaven in acquiring the photographs or other data with which they are working.

For attacking the problem of the nature and structure of atomic nuclei, basic information is obtained by investigating what happens when protons collide with protons or with neutrons—in the scattering of nucleons by nucleons. The energy and momentum of the incident bombarding particle is known and, by means of magnetic analyzers, cloud chambers, emulsions and counter arrays, information can be obtained with regard to the energy, momentum and direction of flight of the particles resulting from the collision. This information is useful in the formulation and testing of theories of the structure of nuclei and of meson production. If none of the kinetic energy of the colliding particles is transformed, the collision is an elastic one. If, however, the collisions are sufficiently energetic, some of the kinetic energy may be transformed (inelastic collisions) and transitory particles called "mesons" and "hyperons" are produced. There are a variety of mesons with masses lying between that of the electron and that of the proton. Hyperons are somewhat heavier than protons and, indeed, are sometimes regarded as excited states of either protons or neutrons. The determination of the

* This has been achieved since this writing.

characteristics and behavior of these short-lived particles is one of the major objectives of high energy research.

Investigations of the scattering of nucleons by nucleons have continued here during the past year. Elastic scattering predominates when the incident protons or neutrons have energies less than 0.4 Bev. Above this energy, inelastic collisions begin to occur in which some of the kinetic energy of the incident nucleon is transformed and pi mesons appear. Pi mesons are short-lived particles having a mass of about 270 electron masses; they may be positively or negatively charged or neutral—i.e., carry no charge. The charged pi mesons disintegrate into mu mesons and neutrinos; the neutral ones, into gamma rays. As the energy of the incident particle increases, the probability of these inelastic collisions rises to twice that for elastic collisions. Pair production of these mesons also increases and their angular distribution becomes more concentrated in the forward direction. The region in which these interactions take place has a radius of approximately 10^{-13} cm and is partially transparent.

The results of the experiments can be compared with certain theoretical considerations. Fermi's statistical theory of meson production predicts certain multiplicities and charge distributions. Another approach assumes that intermediate excited states of nucleons are produced which decay almost immediately with the expulsion of mesons. Experiments with 9.9-, 1.5-, and 2.7-Bev protons on protons and with 1.5- and 2.2-Bev neutrons on protons indicate that the statistical model is not applicable to these energies but that many features of the excited state model do apply. Relative multiplicities in the production of pi mesons predicted by the statistical model disagree with the experiments by factors of up to 30. In proton-proton collisions at 2.7 Bev, a number of cases of triple meson production have been observed. Statistically, triple meson production should be negligible at this energy. At the higher energies (1.2 Bev and up) heavy unstable particles are also produced. Both hyperons (decaying into a nucleon and a meson) and K-particles (heavy mesons that decay into other mesons or lighter particles) have been found.

The scattering of pi mesons by nucleons has also been investigated. As in the case of protons, elastic scattering predominates when positive pi mesons at energies less than 0.4 Bev collide with protons. In contrast, however, experiments performed with 1.0-,

1.4-, and 1.8-Bev negative pi mesons on protons and with 1.4-Bev negative pi mesons on neutrons (in deuterium) seem to be more consistent with the statistical picture as far as multiplicities and charge distribution in the pi meson production are concerned. Pi mesons at 1 Bev and above produce heavy transitory particles rather copiously. Both hyperons and K-particles are found. Perhaps the most significant achievement to date has been to establish beyond all reasonable doubt the existence of so-called associated production in this energy range. That is, there are a number of experiments which are consistent with the production of a hyperon only in conjunction with a heavy meson, and there is no evidence for any other mode of production.

Investigations of the characteristics of positive and negative K-mesons have been made and are being actively pursued. Within experimental error, the positive, negative, and neutral K-mesons have the same mass as the meson of 965 electron masses. About 50 negative K-mesons have been observed to be captured by nuclei of emulsions and to result in several tracks emanating from a single point. In about one-half of the stars so produced, a fast pi meson was emitted, and in about one-fifth of the captures, one of the emitted particles was either a charged hyperon or an excited fragment heavier than a deuteron. The negative K-mesons appear to interact strongly with nuclei, as do pi mesons, rather than weakly, as do mu mesons.

While 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, the 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 overall yield of different nuclides to more specific studies of particular processes. Among the latter are investigations of the relative abundance of the new nuclides produced at different energies of bombardment, their ranges and their angular distributions. A survey for about 30 products of proton bombardments of lead and bismuth has been completed. At proton energies of 3.0 Bev, the yield data indicate high production of nuclides that have mass numbers of 20 to 80 below that of the target nucleus. Very large energy transfers from the proton to the target nucleus are thus indicated. This is consistent with a

mechanism of energy deposition developed earlier by which in these bombardments mesons are created, scattered and reabsorbed within the nucleus in which they are produced. The absorption of this energy causes the nucleus to "boil off" nucleons and light nuclides, and leave a remnant nuclide that is usually radioactive and of considerably less mass than that of the original nucleus.

It has been previously observed that in the bombardment of bismuth nuclei by 340-Mev protons, there was a peak production of nuclides containing an excess of neutrons and having masses about one-half that of bismuth. Experiments performed with protons at 3.0 Bev revealed no such production peak. Apparently this type of fission becomes relatively less probable as the spectrum of energy deposition in the target nucleus moves to higher values with increasing bombarding energy. In contrast, the yields of neutron-deficient medium mass products, mass number 15 to 40, increase sharply at the higher energies. The probability of the production of tritium increases markedly in bombardments with 2-Bev protons as the target nucleus increases in mass from carbon to lead.

In the range of much lower energies, some elastic scattering experiments have been carried out to determine nuclear radii. The results obtained using 40-Mev alpha particles against heavy elements agree with the theory of Blair for small scattering angles and with the theory of Ford and Wheeler for larger scattering angles. The scattering from light elements, aluminum and copper, shows pronounced diffraction. On the assumption that the nucleus acts as an opaque disk, a value of 5.7×10^{-13} cm was obtained for the sum of the radii of the alpha particle and aluminum nucleus. The scattering of 1.7-Mev neutrons by iron has also been investigated with neutrons from a zirconium tritium target bombarded by 2.5-Mev protons from the 18-inch cyclotron. The results agreed with theoretical expectations.

However, in the range of these low energies, the physicists have been primarily engaged in determining the energy states that are associated with various nuclides. The values and distributions of these energy states are characteristic properties of various nuclei. The data obtained concerning them is of great value to the theoretical physicists who are seeking to develop successful theories of nuclear structure by study of the radiations that are emitted as the nuclei pass from one energy state to another. A number of

systematic relations that seem to govern these energy states have been previously reported. New regularities have been established. The energy spacings of excited states of nuclei with even numbers of protons and neutrons have been examined. Between the spherical nuclei with filled shells which have high first excited states and the greatly distorted nuclei which show rotational states with low excitation energies, there are many nuclei with medium excitation energies, ranging from 300 to 1200 kev, which had hitherto escaped interpretation. Empirical regularities have been found in the ratios of the energies of the first and second excited states of these nuclei, ranging in mass number from 60 to 180. A theoretical treatment based on the Bohr-Mottelson model of the nucleus in the region of weak to moderate coupling accounts for the regularities found and predicts other levels that can be verified experimentally.

Studies of the deuterium-proton reactions in gold, silver and copper have given information about the density of excited states of the compound nucleus, and in general theoretical expectations have been confirmed. The Van de Graff accelerator has been used in a number of studies of the energy levels in light nuclei. Both proton and deuteron beams have been used at energies up to 3.5 Mev.

Closely associated with the studies of nuclear energy states have been the investigations of the interactions of neutrons with various nuclei. Active use has been made throughout the year of both the choppers and neutron spectrometers at the reactor. These instruments make it possible to study the effects that result from the capture of neutrons of different energies. When a nucleus captures a neutron, the excited nucleus may emit another neutron or gamma rays, or it may in the case of a few nuclei go through the process of fission. These effects are pronounced for certain narrow ranges of neutron energies called neutron resonances. The total widths in energy of these resonances are measurable and it is possible to deduce from such measurements the probabilities of the two or three different types of transition through which an excited nucleus may go. During the past year, these probabilities have been determined for some 200 resonances from 2 to 700 electron volts for about 20 heavy nuclei of mass number greater than 90. The results show that the probability of a given excited nucleus emitting gamma rays varies only a little from one resonance to another (~ 20 percent). This is attributed to the large number of possible

Figure 8. The blue luminescence produced in air by the 40-Mev beam from the 60-inch cyclotron. The divergence of the beam is due to scattering by air molecules. In the vacuum tube this beam remains well focussed. Bombardment of a bismuth target produces the man-made radioisotope, astatine. Medical researchers are incorporating astatine in antibodies in an effort to determine the distribution and behavior of antibodies in animals. The scattering of such beams by targets of different elements is also used to determine the radii of different nuclei.

Figure 9. Clay beads containing radioactive yttrium. Their size is shown by comparison with the eye of a needle. When clay and yttrium oxide are mixed together and then fired, beads are formed. After irradiation by neutrons in the reactor, the yttrium becomes radioactive. Similar beads as small as one micron in diameter can be formed by passing the mixture through an oxygen gas flame. These radioactive beads are being used in exploratory medical research.

Figure 10. The arrangement of atoms in pyrite as revealed by x-ray diffraction studies. Larger spheres represent sulphur atoms. The smaller black ones are iron, cobalt and nickel atoms. The interatomic distances have been precisely determined.

gamma ray transitions to lower energy levels in the excited nucleus. In contrast, the probability of neutron emission varies greatly from resonance to resonance due to the fact that there is only one mode of decay. The capture of neutrons of energies up to 40 electron volts by uranium-235 has been studied for some 50 resonances. Analysis of these measurements has shown that while the probability of gamma ray transitions is nearly constant from resonance to resonance, the probability of fission varies considerably, but not as much as for neutron emission. This is interpreted as indicating that there are many fewer modes in which the nucleus can decay by the fission process than by the emission of gamma rays.

Considerable improvement in the beams available for research from the 60-inch and 18-inch cyclotrons has been obtained during the past year. Focused beams of 5.0 μ amp of 10-Mev protons, 20-Mev deuterons or 40-Mev alpha particles are now available from the 60-inch cyclotron. These beams have been piped into the experimental laboratory some 25 ft from the machine and are focused in an area of 1 sq cm. Pulsed operation has also been improved. One-milliamper burt, 0.5 μ sec wide, of 22-Mev deuterons are available for external targets at a repetition rate of 1600 per second. The proton beam from the 18-inch cyclotron has been partially focused on a 3/4 in. square area at the end of a 15 ft pipe. Proton currents up to 150 μ amp have been obtained. With 2.5-Mev protons on a zirconium-tritium target, elastically scattered neutrons have been observed with a signal-to-background ratio of at least ten to one. Neutron cross sections as low as 0.1 barn can be detected here.

EFFECTS OF RADIATION

The effects produced by the irradiation of materials and of organisms are important in themselves. Moreover, the study of these effects can frequently reveal characteristics of the material or throw light on the internal processes of organisms. For example, radiation damage of a cell may destroy it or transform it, but a study of damaged cells may lead to a better understanding of cell development. The physical, chemical and biological effects of radiation are all under investigation.

Materials are being studied both for changes in their fundamental physical properties, such as thermal conductivity or electrical resistance, under neutron radiation, and for their engineering application

as suitable materials for use in high neutron and gamma radiation fields. Extensive studies on the behavior of graphite and of various alloy materials of special interest to the Brookhaven liquid metal fuel reactor program, under varying conditions of irradiation, have been under way. The concentration of lattice defects introduced into graphite by reactor irradiation has been determined by means of long wavelength neutron transmission experiments. The neutrons are scattered isotropically by the point defects when their wavelengths are sufficiently long—too long for Bragg diffraction. The fraction of displaced atoms found in graphite after exposure to neutrons was in excellent agreement with theoretical prediction. Post-irradiation annealing experiments for 1 hr at 500°C reduced the defects by 70 percent. No defects could be detected after similar annealing at 900°C.

Studies of the decomposition of water by radiation have been continued. The hydrogen gas and peroxide yields were found to be functions of the nature and concentration of added solutes. The hydrogen yields from copper sulphate and potassium nitrite solutions and peroxide yields from neutral and potassium bromide solutions were decreased as the solute concentration was increased.

It has been shown that certain organic compounds can be labeled directly with either carbon-14 or tritium by neutron irradiation of suitable target systems. The petroleum and pharmaceutical industries are interested in such labeled compounds for research purposes. If a suitable nitrogen-containing organic compound is irradiated at room temperature in a high thermal neutron flux, 3 to 5 percent of the C^{14} nuclei formed from nitrogen nuclei are found in the target molecule. By the use of carrier techniques, a smaller fraction of C^{14} atoms is found in the carbon analogue of the irradiated molecule. Two interesting facts have emerged. The target material is labeled in a roughly uniform manner with a low but usable specific activity, and the carbon analogue molecules are specifically labeled by a process which can be represented as a displacement of a N^{14} nucleus by an energetic C^{14} nucleus. The production of radioactive organic compounds with recoil tritons has been found to be equally promising with the Li^6 -to-tritium reaction. This technique has been used to label sugars, aromatic acids, and steroids.

Investigations of the biological effects of radiation have been continued. The cooperative program that

seeks to produce useful mutations in agriculturally important plants and trees has expanded. More than 100 institutions now participate, including a number in Canada. The irradiations are performed at Brookhaven. The individual institutions that initiate the projects grow the material and screen it for desired mutations. The facility at the reactor which makes slow neutrons available for irradiations has been used to capacity, and an additional facility is planned to take care of the demand. Samples of rust-resistant varieties of wheat and flax, a strain of tobacco with a different flowering response to light and higher yield, and a barley variety with considerably stiffer straw have been produced and are under still further investigation.

Bacteriophages are aggregates of complex molecules that have the capacity to destroy bacteria. Under irradiation some of them lose their power to do this. The ability of radiation to inactivate these molecules has been thought to depend upon the density of its ionization—that is, upon the number of ions that it produces per unit length of its path. This idea has been further tested by using beams of alpha particles, deuterons and protons from the 60-inch cyclotron. When the energies of these different particles were so adjusted as to produce the same density of ionization, the measured effects upon the bacteriophage were the same. At other energies, when the different particles had different densities of ionization, the inactivation of the phage was a linear function of the ionization density over quite a wide range. These results confirmed the idea that radiosensitivity depends to a large degree on the density of ionization produced by the radiation.

Last year it was reported that a toxin had been found for the first time in the blood of rats subjected to radiation. This result has been further confirmed here, as well as at another laboratory. This toxin reaches its highest concentration in the blood about 48 hours after the radiation; it is destroyed on standing for 30 min at room temperature, but will keep overnight at 0°C. Its effects in mice produce symptoms that are qualitatively similar to those produced by radiation.

Some light has been thrown on the origin of the deficiency in the synthesis of hemoglobin that follows radiation injury. Hemoglobin is the oxygen-combining complex molecule that constitutes about 30 percent of the composition of red blood cells. Reticulocytes, the parents of mature red blood cells,

are found in the bloodstream. In duck blood, two types of reticulocytes have been found, Class I and Class II. Those of the younger type, Class I, appear to develop into Class II, which in turn become mature red blood cells. After x-irradiation, the supply of Class I reticulocytes is reduced. Apparently the mechanism which gives rise to these reticulocytes has been injured. Experiments with radioactive iron atoms as tracers have indicated that the hemoglobin originates in cells in bone marrow that become Class I reticulocytes. These facts clarify to some extent the events that take place after irradiation in the system that gives rise to red blood cells, and explains in part the anemia characteristic of radiation injury.

The Medical Department has continued its investigation of the application of neutron capture therapy to destroy brain tumor glioblastoma multiforme, described last year. Extensive studies of the pharmacology and toxicity of boron have made it possible to administer much larger doses of this element. Modifications in the facility at the reactor have provided a higher flux of thermal neutrons. A second series of patients have been treated, with encouraging results. In general, the life span for this series of patients was almost double that observed in the first series of patients. Progress has been more rapid than might have been expected for such a complex undertaking as this.

USE OF NUCLEAR TOOLS

Extensive use of nuclear tools of research has been made by workers throughout the Laboratory during the past year. Beams of neutrons from the reactor have been applied to the study of the arrangement of atoms, ions and magnetic spin systems in solids. The kinetics of chemical reactions, processes of photosynthesis, metabolism, and medical diagnosis have been investigated with radioisotopes as tracers. Only a few of these numerous studies from different fields will be mentioned here.

The special neutron scattering effects at magnetic transition points have been investigated for a number of materials, both ferromagnetic and antiferromagnetic. In ferromagnetic materials, the magnetic spin systems are all aligned parallel to each other and in the same direction. In antiferromagnetic systems, half are aligned in one direction, half in the opposite direction, to give no resultant magnetic effect. In ferrimagnetic substances, the magnetic spin systems

are lined up, some in one direction and some in the opposite direction, but never to balance each other completely; there is a resultant magnetic effect. Polarized neutrons which have their magnetic spin axes parallel and in the same direction are scattered differently by these different materials. The resulting diffraction pattern is therefore characteristic of the nature of the material. As the material passes through a magnetic transition point, these diffraction patterns are found to change. In ferrimagnetic and antiferromagnetic materials, the peaks found in the diffraction patterns of polarized neutrons consist in general of two components: an elastic part which drops sharply to zero at the transition to the paramagnetic phase, and a diffuse peak which rises to a sharp maximum at the transition point. The diffuse peak demonstrates the existence of a sub-structure of short range magnetic spin order which is maximum at the transition point but persists at higher temperatures after the long range spin order has disappeared.

Neutron diffraction studies of the crystal structure of rochelle salt have also been made. They have established that the crystal has monoclinic pseudorhombic symmetry in its ferroelectric modification. Investigators using x-rays have not detected the monoclinic symmetry, but this is clearly established with neutron data. A number of deviations from orthorhombic symmetry have been found which can be related to the dielectric peculiarities of this crystal. Similarly, the structure of ferroelectric barium titanate cannot be solved uniquely by x-rays. An unambiguous solution is possible with neutrons, however, since the scattering intensities for the different atoms are more nearly equal and they reveal the small displacement from the ideal cubic structure that can be related to the crystal's ferroelectric characteristic.

Attempts have been made to determine the intensities of the cosmic rays to which two meteorites were subjected some time in the past when they were in interplanetary space. This has been done by comparing the amount of tritium found in these meteorites with the amount of tritium produced in iron when bombarded by 2.2-Bev protons from the Cosmotron. The results indicate that the meteorites were bombarded by 10 and 1.5 particles per cm^2 per second, respectively. These values may be compared with 3 particles per cm^2 per second, which was the cosmic ray intensity found in the vicinity of the earth's poles in 1949. From a comparison of the helium-3 and

Figure 11. Preparation of "hot cell" apparatus for an experiment involving highly radioactive material. Previous experiments have contaminated the cell and the equipment in it. This makes protective clothing necessary for the worker on the left.

tritium contents of one of these meteorites, it is also possible to determine what may be called the cosmic ray age of this meteorite—i.e., the time required to build up the He^3 from the tritium. The amount of He^3 in the meteorite was measured after converting it into tritium by neutron bombardment in the reactor. The meteorite's age was thus determined to be about 2 billion years.

An investigation has been under way for several years on the isolation of C^{14} -labeled intermediate substances in plant metabolism, the isolation and identification of the enzyme systems responsible for the reactions involved. A number of reaction pathways have been worked out and reported previously. An interesting recent result is that the pathway for glucose metabolism in the plant depends upon the age of the tissue being investigated. Young tissue in the plants studied so far tends to metabolize sugar via the Embden-Meyerhof glycolytic scheme; and as the

tissue grows older, it tends to shift to the hexose-monophosphate shunt pathway. This is one of the few quantitative observations that has been made which indicates that, physiologically speaking, old tissue is different from young tissue.

A study has also been under way for several years on the fundamental mechanisms of enzyme action as elucidated by tracer techniques. The general approach to this problem is to label substrates in specific places and then by enzymatic degradation and analysis of the degradation products to attempt to determine the exact chemical pathway that the breakdown followed and to deduce the way in which the enzyme was able to effect the breakdown. The principal reactions studied have been those involving phosphorus atoms. As a result of these studies, it has been possible to formulate a tentative theory of enzymatic reactions. This theory essentially implies that no basic change in mechanism occurs on going from simple organic and inorganic catalysis to the action of protein enzymes. It can be shown that this hypothesis can lead to an explanation of changes in enzymatic reactions due to different atomic configurations, and to a generalization relating enzyme specificity to the point of cleavage in hydrolytic reactions.

Studies of the factors responsible for the regulation of carbohydrate metabolism in animals have been continued. In particular, the control exercised by hormones from the pituitary gland and the adrenal cortex have been under investigation. It is well known that insulin produces a profound and long lasting effect when injected into hypophysectomized dogs, i.e. dogs from which the pituitary glands have been removed. With C^{14} -labeled glucose, it has been found that there is a much lower uptake of the glucose by the tissues in hypophysectomized dogs than in normal dogs. The hypophysectomized dogs have smaller glucose pools. Present indications are that a deficient secretion of glucose by the liver in response to low blood sugar is the critical factor in the insulin hypersensitivity of hypophysectomized dogs. In normal dogs, the liver almost instantly delivers extra glucose to the blood when insulin has lowered the blood sugar to only a little less than the normal level.

Before any isotope can be used in radiation therapy, it is necessary to know how it is distributed in the body. Studies of the kinetics of manganese-56 have led to the postulate that there exists in the body a mechanism that quickly diverts the metal in transit

and traps it in a site of high affinity and then releases it gradually. The short life of Mn^{56} permits preparation of the isotope in very high specific activity; thus readily measurable concentrations are found in various animal tissues after administration in amounts well within physiological limits. Moreover, its short life permits observations on the early phases of the distribution when reabsorption, recirculation and redistribution are at a minimum. Experiments on rats have shown that an injection of radiomanganese is rapidly partitioned through the body and concentrates in mitochondria-rich organs. Liver cell fractionation revealed the mitochondria as the main site of intracellular manganese uptake. Since these mitochondria are the tiny chemical laboratories, or respiratory centers, in the cytoplasm of cells, this distribution of manganese is compatible with its functioning as a respiratory co-factor aiding in the take-up of oxygen. The possibility of increasing or decreasing at will the isotope uptake by the liver was explored by coordinating the manganese with certain binding materials, or ligands. The use of the strongest coordinating agent, versene, resulted in high accumulation of manganese in the blood and low uptake by the liver. Conversely, the weaker ligands in this series favored accumulation of the metal in the liver. From the practical viewpoint, these studies point to radiomanganese as a possible therapeutic agent in malignant diseases of liver and pancreas. This short-lived isotope is capable of delivering irradiation at high dose rates to these organs, where it may be concentrated to a high degree. Moreover, the rapid disappearance of radiomanganese from the bloodstream can be further accelerated in order to minimize undesirable effects of irradiation on the blood-forming organs.

Astatine, a cyclotron-made halogen, has a half-life of 7.5 hr and emits alpha particles. It, therefore, has two desirable features. Its precise intracellular location can be determined by radioautographic (photographic) techniques, and the energies of the alpha particles are such as to suggest that it might be therapeutically effective against tumors and microorganisms. It has been found that antibodies can be combined with astatine. The distribution of astatinated antibodies injected into rabbits and mice is now under investigation.

When an animal is infected with trichinae (commonly caused by eating infected pork) the larvae pass from the intestines into the muscles, where they become encysted and remain indefinitely. It has been uncertain whether in the cysts the organisms are entirely dormant or continue active metabolism with exchange of materials with the host. This problem was attacked by feeding infected mice C^{14} -labeled amino acids. The fact that carbon-14 was found to have been incorporated into the larval protein indicates that there is an active metabolism, even in the encapsulated state. This suggests that the encysted larvae may be open to attack by antibiotics.

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. A wide range of studies is pursued. Many of them are directly related to reactor components and the design of reactor systems. Among these are the metallurgy and chemical processing of reactor fuels, container materials, and the heat transfer problems associated with the development of liquid metal fuel reactors. The progress made during the past year has been described on page xiii under the heading of Major Projects. Progress on the problems of radioactive waste disposal has been directed at devising a system that makes use of the adsorption of fission product waste in clays and its fixation through baking of the clay. A pilot process plant based upon preliminary studies has been completed during the past year. Preliminary runs with full strength chemical solutions containing tracers have been made and the results have been satisfactory. Operation of the plant at higher activity levels will be undertaken.

Considerable work has also been done in making available special radioisotopes for the use of researchers, particularly in the medical field. Two processes have been developed for the production of the fission product iodine-133, which has a half-life of 21 hr. Stable yttrium has been successfully incorporated in hard uniform clay spheres 3 to 4 one-hundredths of an inch in diameter. When irradiated in the Brookhaven reactor, these spheres have about

half a millicurie of yttrium-90 per milligram of finished particle. Fluorine-18 has been made available in a physiologically compatible solution with intensities of 1 to 8 millicuries.

The efforts of the research experimentalists to gain deeper understanding of the nuclear processes requires the continual provision of more highly sensitive devices for the detection and measurement of radiation. During the past year, the Brookhaven design of pulse amplifiers has been improved to give a larger output, greater linearity, and better long-term gain stability. A project has been undertaken to construct a new instrument for sorting neutrons into different energy groups depending on their time of flight over a distance of about 60 ft. The new instrument will have 1,024 channels, as compared with the 100-channel analyzer now in use. Different channels will recognize neutrons of different times of flight, or of different energies. Up to 10,000 neutron counts may be accumulated in each of the 1,024 channels. The total of over 10 million bits of information will be stored in 16 cathode ray tubes; there will be a continuous indication of all the data acquired on another cathode ray tube. At the end of a run, automatic circuits will cause the data stored in the memory tubes to be printed on a paper tape or punched on business machine cards for analysis. All parts of the instrument have been designed and tested, and about one-quarter of the circuits have been built.

Biological effects of radiation are primarily due to the ionization produced, and many investigations of these effects depend on a knowledge of the average energy lost by the radiation per pair of ions produced. The accuracy of the generally accepted value of this constant for air has been questioned. It has therefore been remeasured this past year at Brookhaven and at several other laboratories. Measurements were made on air and other common gases under more accurately controlled conditions than heretofore. The new and more precise determinations at the several laboratories are in agreement and have established a new value for the constant for air which is about 5 percent higher than the older measurements had indicated.

BUSINESS AND ADMINISTRATION

A significant organizational change was effected early in the fiscal year in the area of business and plant operation. Mr. William H. Fields, Jr., formerly associated with Controls Systems Laboratory of the University of Illinois and prior to that with Radiation Laboratory of the University of California, joined the Laboratory on July 1 as Assistant Director. In that capacity, he has been placed in charge of Purchasing, Receiving, Warehousing and Distribution, Security and Plant Protection, and Plant Operations. These several functions have been brought together under Mr. Fields in order to provide coordination and centralization in one Director's office representative. Mr. J. G. Peter has continued in charge of the Architectural Planning Division and is serving on the Director's staff in the capacity of Architectural Planning Director. The changes have been effected in order to provide more time and more help to the Director and the Deputy Director for over-all planning purposes. The construction program involving the steady conversion from temporary barracks to permanent laboratories and buildings is becoming more important and requires the full attention of the Architectural Planning Director.

Efforts have been continued toward keeping the inventory content alive and weeding out items no longer of interest to the Laboratory. The results are reflected in the steady downward trend of the inventory investment. At the end of the fiscal year the average monthly investment in active inventory was 4.1 months as contrasted with 7.9 months at the same time two years ago. The total dollar value in active inventory was approximately \$275,000, with some \$45,000 additional excess inventory awaiting disposal on June 30.

Increased attention has been devoted to problems involving capital equipment. The Laboratory has set objectives for the formal establishment of a property catalog, for more effective use of capital equipment on hand, for development of a consistent program of disposal of property no longer of use to the Laboratory, and for the reduction in investment of such property. This program is being pursued with diligence, but progress has been slow.

The purchasing volume for the Laboratory increased over fiscal 1954 both in number of purchase orders written and in total dollar value. This increase reflects in part the increased activity in Accelerator

Development and in general the growth of the Laboratory's research program. The total dollar value of orders purchased in 1955 was slightly over 2.7 million. Several new employees were added because of the increased activity. Procedural changes have been introduced to facilitate efficient handling of paper work. Also, open-type purchase orders, term contracts and broader use of petty cash buying have been introduced to permit rapid acquisition of material without carrying extensive stocks in warehousing.

Mr. Forrest E. James, Assistant Purchasing Agent, retired on December 31, 1954. Mr. George E. Maxey assumed the duties of Assistant Purchasing Agent on January 1, 1955.

Fiscal operations with the punch card machine installation have progressed satisfactorily with increased emphasis on the development of management-type information. Additional work is being placed on the machines on a continuing basis and it is expected that fixed assets records on punch cards will be completed during FY 1956.

Increasing effort has been placed upon the internal audit program of the Laboratory in accordance with the AEC policy of establishing a strong internal audit function in each integrated contractor's organization.

The responsibility for office machines, equipment and furniture was transferred from the Office Services Group to the Supply and Material Division (formerly Receiving, Warehousing and Distribution) on July 1, 1955.

FINANCE

Three program divisions of the Atomic Energy Commission finance the research program of the Laboratory. These three divisions, the Reactor Development Division, the Research Division, the Biology and Medicine Division, each separately finance research activities. However, to carry out these activities it is necessary for the Laboratory to provide general operation and administration and support of the technical activities as well as the direct research in each activity. The operating costs of the Laboratory for the past three fiscal years are shown in Figure 12. These costs have been distributed among the programs supporting the work and also by major categories of expenditure. It is interesting to note that 74.2 percent of all operating expenditures in FY 1955 are accounted for by labor costs. Nonprogram

COST DISTRIBUTION BY PROGRAMS

FISCAL YEAR	PHYSICAL SCIENCES	REACTOR DEVELOPMENT	LIFE SCIENCES	OTHER	TOTAL COST
1955	54.4 %	18.0 %	23.9 %	3.7 %	10,703,649
1954	56.5 %	17.4 %	23.5 %	2.6 %	9,956,630
1953	57.2 %	17.7 %	23.2 %	1.9 %	9,568,244

MAJOR CATEGORIES OF EXPENDITURES

FISCAL YEAR	SALARIES AND WAGES	MATERIALS, TRAVEL, SUB-CONTRACTS	SPECIAL POWER	MISCELLANEOUS	TOTAL COST
1955	74.2 %	18.3 %	4.7 %	2.8 %	10,703,649
1954	75.5 %	17.0 %	4.5 %	3.0 %	9,956,630
1953	74.9 %	17.0 %	4.8 %	3.3 %	9,568,244

Figure 12.

Table 2

Capital equipment expenditures and commitments

	FY 1955		FY 1954		FY 1953	
	\$	%	\$	%	\$	%
Scientific & Hospital	401,494	75.4	318,011	70.8	393,538	72.5
Automotive & Heavy Mobile	36,056	6.8	55,925	12.4	75,378	13.9
Office Machines & Furniture	23,588	4.4	25,734	5.7	19,553	3.6
Shop Equipment	39,116	7.4	26,517	5.9	31,849	5.8
Miscellaneous	32,183	6.0	23,184	5.2	22,706	4.2
Expenditures & Commitments, Total	532,437	100.0	449,371	100.0	543,024	100.0
Proceeds from Sales	(21,770)		(56,369)		(25,617)	
Expenditures & Commitments, Net	510,667		393,002		517,407	

costs include work done by Laboratory organizational units for the construction of plant and equipment and work done for others, such as other government agencies and special work for other Commission programs not included under the normal Laboratory budget.

Detailed expenditures by organizational units are shown in Table 1. The year end total for FY 1955 is \$10,703,649 which includes work done for others (\$197,095) and work done by organizational units for plant and equipment (\$202,338). The direct costs of AGS design and development are not shown in Table 1. The direct costs of work carried out by the research units increased by about \$460,000 over that for FY 1954 while the total operating expenditures of the Laboratory increased by \$747,000. Expressed in another way, the direct research cost accounted for 46.9 percent of the total expenditures in FY 1955 and 46.0 percent in FY 1954. When one includes technical services, these figures become 67.3 percent and 66.5 percent, respectively. Experience in all units which provides routine service is continuing to provide more efficient operation, with accompanying reduction in cost or increase in service. Table 2 gives the capital equipment expenditures and commitments for the past three fiscal years.

The Laboratory Balance Sheet as of June 30, 1955 and June 30, 1954 is shown on page xxxi. Inventories of materials and supplies excluding precious metals and radium were reduced by \$76,964 to \$319,600 at June 30, 1955 which is the approximate level of inventory necessary for Laboratory operations at present budget levels. The increase in Advances, De-

posits, and Prepaid Items was due primarily to a change in financing the Laboratory's group insurance program from a monthly to an annual basis. The Construction in Progress account was increased primarily by expenditures of approximately \$1,167,000 for the construction of the Alternating Gradient Synchrotron during the year ended June 30, 1955.

PERSONNEL

The Laboratory staff on June 30, 1955 numbered 1,533, a net increase of 87 for the fiscal year. This is the largest increase experienced in any year since 1949, and is distributed over nearly all phases of Laboratory operations. The ratio of scientists to nonscientists remains at 1 to 3.7, the same as last year.

The growth of the scientific staff from July is depicted in Figure 13. 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 is also a measure of the average number of scientists present each month. The regular staff increased about 6 percent during the year. Salaried visitors include scientists and engineers on leave from their own institutions, graduate students doing doctoral investigations while on leave from their graduate schools 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 in-

Figure 13.

cluded in the graph. During the fiscal year 1955 over 24 man-months of service were rendered by these consultants.

For the eighth successive year, the number of scientific visitors who worked at the Laboratory has increased. A significant fraction of these visitors who spend periods of from one month to several years away from their home institutions, and participate in the program of the Laboratory, come without salary compensation. Of a total of 391 man-years of scientific effort in the report period, not including the summer student program, 100 man-years were contributed by salaried visitors, guests, temporary employees and consultants. Of these 100 man-years, more than half were provided by guests who received no remuneration from the Laboratory for their services. The continuing increase in the number in the guest category is gratifying and reflects an expanding interest on the part of scientists to make use of the facilities available at Brookhaven.

The formal summer program of participation by graduate and undergraduate students, initiated in 1952, has been continued. The circulation of announcements for the summer of 1955 to universities

and colleges resulted in applications from 382 students. Appointments have been offered to 119 of these applicants and acceptances received from 63 undergraduates and 33 graduate students. In addition to their participation in the Laboratory's activities, the students will be given tours of all the laboratories and informal talks on many phases of the research in progress.

In addition to the above student participation, about 105 faculty members from universities are planning to work at the Laboratory during the summer of 1955. Including 14 AEC Radiological Physics Fellows and about 20 additional graduate students, who will be brought here by visiting scientists to act as their assistants, the influx to the scientific staff will number at least 225, the largest yet experienced for the summer months.

CONFERENCES

The number of informal seminars and colloquia scheduled at the Laboratory increased considerably during the past year. Many of these were conducted by scientists from universities and research organiza-

tions throughout the country and, indeed, a few by scientists from other countries.

Several more formal scientific conferences were held during the report period. The largest was the symposium on Mutations in June, sponsored by the Biology Department. About 330 representatives from educational institutions attended. Other major conferences included a classified information meeting on Reactor Heat Transfer Problems in October, sponsored by the AEC, and a symposium on the Statistical Aspects of the Nucleus in January. A one-day conference in May on the Biological, Physical and Industrial Aspects of Potato Irradiation attracted 124 individuals from 68 different organizations. At the request of the Third Naval District, the Laboratory was again host to a Naval Reserve Research Nuclear Physics Seminar of two weeks' duration in May-June.

As in previous years, a large number of requests have been received from technical societies, educational and civic groups for one-day visits to the Laboratory. During the report period, 1369 individuals, representing 30 professional groups, visited the Laboratory. This was a second or third trip for a few of the groups seeking additional, detailed information on specific phases of the Laboratory's program.

Last fall, the Laboratory instituted a special "Student Visitors' Day" to accommodate the large number of requests from student groups, including high school and undergraduate college students. The first "Student Visitors' Day" was most successful. Approximately 2,000 students were shown through special exhibits and the major facilities of the Laboratory on October 15. The customary "Visitors' Day" was held on the following day; about 3,600 people were here.

Because of the increasing pressure of special projects and the stepped-up tempo of research activities, compliance with requests for talks by staff members was somewhat curtailed. However, whenever possible, speakers were provided for civic, educational and church groups of nearby communities. Many of the requests from more distant communities had to be referred to the New York office of the AEC or to some other suitable organization.

Activities of the public information office also increased during the year to reflect the heightened general interest in "Atoms for Peace." Exhibit material was in demand. Several staff members participated in radio interviews, or appeared in motion picture footage used on television, or in newsreels and educational films.

Figure 14. An overflow audience attending the Biology symposium on Mutations.

BROOKHAVEN NATIONAL LABORATORY

BALANCE SHEET

	June 30, 1955	June 30, 1954
ASSETS		
Cash	\$ 880,868	\$ 469,933
Accounts Receivable	82,217	52,329
Inventories	382,790	462,962
Advances, Deposits and Prepaid Items	181,952	41,095
Fixed Assets (less reserves of \$19,960,883 at June 30, 1955 and \$17,158,648 at June 30, 1954)	37,930,664	39,910,013
Construction in Progress	1,649,714	668,198
Total Assets	<u>\$41,108,205</u>	<u>\$41,604,530</u>
LIABILITIES		
Accounts Payable	\$ 554,696	\$ 346,202
Accrued Payroll	134,924	108,781
Atomic Energy Commission	40,418,585	41,149,547
Total Liabilities	<u>\$41,108,205</u>	<u>\$41,604,530</u>

PHYSICAL SCIENCES AND ENGINEERING

PHYSICS

Research in physics has continued to utilize all the special facilities of the Laboratory. Without regard to the particular facilities used, the program can still be described best under the categories of high energy research, nuclear structure, atomic and molecular physics, neutron physics, and solid state physics.

In addition to carrying out their research programs, the Physics, Cosmotron, and Reactor Departments have responsibilities for the operation and maintenance of the major facilities of the Laboratory. The 18-inch and 60-inch cyclotrons and the electrostatic accelerator (3 Mev) are the responsibility of the Physics Department; the Cosmotron is operated and maintained by staff in the Cosmotron Department; and the reactor is the chief responsibility of the Reactor Department. Reports on the accelerators and the reactor are found in later sections of this report.

During this past year increased emphasis has been placed on high energy research at the Cosmotron. The demands by researchers both at Brookhaven and from cooperating institutions far exceed the time available on this machine, in spite of improvements in its operation and additional operating time. It was unfortunate that a short circuit in the copper winding of one of its magnets caused the machine to be out of service for about six months.

HIGH ENERGY RESEARCH

The study of nucleons together with the particles and fields that are associated with them is an important new branch of physics in which the Cosmotron is playing an important role. The most significant achievement to date has been to establish beyond all reasonable doubt the existence of so-called associated production in the energy range of this machine. There is now a variety of experiments the results of which are consistent only with the production of hyperons in conjunction with a heavy meson; there is no evidence for any other mode of production. This is a situation without parallel in physics and it would

seem to be a symptom of some undiscovered basic law.

The first phase of research, that of searching for any new phenomena, is beginning to be replaced by experiments directed to more specific ends. A year ago most of the work with counters was directed toward exploring new energy ranges by means of total cross section measurements. Now counters are being used to determine the nature of π -meson production and to distinguish between the various types of K-mesons. Cloud chambers were originally used solely to find what kinds of reaction took place between different kinds of particles in the different energy ranges. Now these instruments are used to determine the differential cross section for π -p scattering at 300 Mev and for similar explicit purposes. The same situation holds for photographic emulsions which at the start were exposed to various high energy beams and then examined for any interesting events. Now setups are expressly made to obtain answers to specific questions.

There has been a noticeable improvement in experimental techniques. Several bubble chambers are in use by Brookhaven, Columbia and the University of Michigan, and this type of instrument may to some extent replace conventional cloud chambers because its characteristics are peculiarly suited to use with accelerators. Cerenkov counters are supplementing the more conventional scintillation counters; they respond only to particles moving with a velocity close to that of light, and are thus useful in reducing the effect of the background which is usually made up of low velocity particles. The Cerenkov effect is the basis for a new type of gamma ray spectrometer which should prove useful for the determination of the energy of gamma rays in the range above 100 Mev.

The strong focusing principle is being used to procure intense focused beams of protons and mesons at considerable distances from the Cosmotron where greater flexibility with experimental apparatus is possible. At present three strong focusing magnets are in use (one is on loan from Columbia) to produce:

- a) a sharply defined beam of 3-Bev protons containing 10^6 particles within an area 1/4 in. by 1/2 in. which will be useful for cloud chamber experiments.
- b) a focused and analyzed beam of K^+ -mesons containing some 10^4 K-particles per cm^2 per pulse which, although contaminated with about one hundred times as many π -mesons, should be very useful for K-meson emulsion and counter experiments.
- c) a focused and analyzed beam of π^+ and π^- -mesons with energies up to 2 Bev and with intensities of 30 to 40 per cm^2 per pulse (or greater at lower energies).

The full intensity external proton beam will be brought out at one of the pump stations and at least partially focused with magnetic shims placed near the outside of the gap in the Cosmotron's magnet. This external beam should contain at least 10^{10} protons per pulse. It will provide an opportunity for many new types of experiments; in addition, however, it will create severe shielding and safety problems.

Collaborative research has increased over the past year. Groups from Yale, Harvard, Columbia and MIT, usually with a member of the Brookhaven staff assisting, are operating their own cloud chambers, and the BNL cloud chamber group continues to assist physicists from other institutions in obtaining photographs from BNL cloud chambers exposed to the various Cosmotron beams. These photographs are frequently analyzed at the home institutions of the visiting scientists. Following a proposal by the Columbia staff, and with additional initiative from Princeton, it was decided to produce a high intensity K^+ -meson beam with a pair of strong focusing magnets in an arrangement similar to one used by the Radiation Laboratory at Berkeley. The K^+ beam is now being used also by an emulsion group from the University of Rochester. Although cloud chambers and emulsions are technically better suited to the need of visiting physicists, some counter experiments are being carried on by visitors as well. A group from Princeton is using counters to determine the character of the various types of K-mesons and a group from MIT is prepared to search for mesons with a half-life of 10^{-3} seconds or greater. By far the largest group of visiting experimenters, in point of numbers, works with emulsions. This type of experiment is sometimes a collaborative one with a

BNL staff member. In view of the small amount of Cosmotron time needed for most emulsion exposures, it has been the policy to fulfill all reasonable requests for exposed emulsions.

The magnitude of the program in high energy can be judged from the number of physicists involved. From Brookhaven about 20 regular staff members and 5 graduate students spend a major part of their time on research with the Cosmotron. From outside institutions there are some 50 physicists and 44 graduate students who are doing experiments based on Cosmotron data.

Cloud Chambers

The BNL cloud chamber group has worked with two diffusion chambers, one 16 in. in diameter with a magnetic field of 10,000 gauss, the other 6 ft by 10 in. without a magnetic field. These chambers were filled with hydrogen, deuterium or helium and exposed to meson, proton, or neutron beams from the Cosmotron. About 100,000 photographs (in addition to 150,000 obtained previously) were obtained, many of which were analyzed by physicists at Cornell, Duke, Fordham, Harvard, Purdue, Wisconsin, and Yale universities.

In inelastic collisions with the gas atoms in the chamber, π -mesons are produced. However, at high enough energies, there are also some particularly interesting cases where heavy unstable particles occur. When positive mesons with energies less than 0.4 Bev collide with protons, one obtains almost entirely elastic scattering. Here the angular distributions of the scattered mesons are studied. At these energies, the scattering as seen in the center-of-mass system appears to be somewhat peaked in the forward direction.

At higher energies inelastic collisions predominate regardless of the specific interaction considered. The ratio of elastic to inelastic cross sections "converges" toward a value of 1/2. Most of the elastic scattering can be interpreted as diffraction scattering, and is thus merely a consequence of the inelastic collisions. The region where interactions take place has a radius of approximately 10^{-13} cm and is partially transparent. Specifically, in interactions of negative mesons (at 1.4 Bev) with protons, it is indicated that this region of interaction is not uniform but is very strongly interacting out to a radius of about 5×10^{-14} cm outside which the interaction becomes much weaker.

The mesons produced in inelastic collisions are studied with regard to the number of mesons produced simultaneously (multiplicity), the distribution of the electric charges, the angular and momentum distributions of all emitted particles, and specific correlations between groups of emitted particles, such as relative angles, relative energies, etc. The results can be compared with certain theoretical considerations. Fermi's statistical approach predicts multiplicities and also charge distributions. Another, so far only rather qualitative, approach modifies the purely statistical picture considerably by assuming that intermediate "excited states of nucleons" are produced with isotopic spin $T=3/2$, which decay almost immediately. The latter picture is consistent with the "resonant" elastic scattering observed in meson-nucleon collisions at lower energies.

Experiments with 0.9, 1.5, and 2.7 Bev protons on protons, and with neutrons on protons at energies up to 1.5 Bev and 2.2 Bev, all seem to indicate that the statistical model is not applicable at these energies, and features of the excited state model apply to many cases. Reactions resulting in the charge component state $T_z = \pm 3/2$, for $T=3/2$, are very much preferred, such as $n+p \rightarrow n+\pi^-+p+\pi^+$, where the combination (n,π^-) has $T_z = -3/2$ and (p,π^+) has $T_z = +3/2$. Relative multiplicities predicted by the statistical model disagree with the experiments by factors of up to 30. Correlations between pairs of particles in ordinary and momentum space are indicated as a further departure from the purely statistical model. In proton-proton collisions at 2.7 Bev a number of cases of triple-meson production has been observed. Statistically triple-meson production should be negligible at this energy.

While the data on nucleon-nucleon collisions seem to be consistent with the assumption that intermediate excited nucleon states are produced, meson-nucleon interactions are rather more consistent with the statistical picture, as far as multiplicities and charge distributions are concerned. This consistency may be due to the high energy available in these collisions, with only one nucleon to be excited here. However, strongly anisotropic angular distributions are observed; in the center-of-mass system the nucleons persist in travelling backward while the mesons are emitted rather in a forward direction. These studies have been performed with negative mesons on protons at 1.0, 1.4, and 1.8 Bev, and with negative mesons at 1.4 Bev on neutrons (in deuterium).

An experiment with positive mesons at 0.6 Bev on protons has been started.

When the energy is high enough, heavy unstable particles (h.u.p.) are seen to be produced in the gas in the chamber as well as in the chamber walls. Both hyperons (decaying into nucleon+meson) and K particles (heavy mesons decaying into mesons or lighter particles) are found. Mesons at 1 Bev and above produce h.u.p. copiously with cross sections of somewhat less than 1 millibarn. Nucleons with energies below 1.5 Bev did not produce any h.u.p., but at 2.7 Bev become also copious producers. At 1.5 Bev nucleons colliding with nucleons should easily produce $\Lambda^0 \rightarrow \text{nucleon} + \pi + 37 \text{ Mev}$. The observation (consistent also with experiments by other workers) that this reaction is unlikely supports the hypothesis of associated production proposed by Gell-Mann and by Pais.

These considerations attempt to reconcile the large production cross sections for h.u.p. with the relatively long lifetimes of h.u.p. Certain rules follow: single h.u.p. cannot be produced copiously but must be produced in association with other h.u.p., but two Λ^0 's cannot be produced together. A total of 14 cases of production of h.u.p. in the chamber gas have been observed in different reactions. Although only eight cases show the actual decay of both produced particles, all the others are kinematically consistent with the hypothesis of associated production of h.u.p. The reactions observed were $\pi^-+p \rightarrow \Lambda^0+\theta^0, \rightarrow \Sigma^-+K^+$ ($\Sigma^+ \rightarrow n+\pi^-$), $p+p \rightarrow \Sigma^++K^++n$. Some of the cases are more consistent with initial production of Σ^0 which decays very fast $\rightarrow \Lambda^0+\gamma$. In π^-p collisions, about twice as many neutral h.u.p. as charged h.u.p. are produced. Some angular correlations of interest are indicated. In the center-of-mass system the produced hyperon prefers to travel backward (in the original direction of the proton). The planes formed by the decay products of the hyperons tend to be parallel to the planes formed by incident particle and line of flight of hyperon before decay. This may indicate that hyperons have a high spin.

The group operating the Columbia University cloud chamber has been studying the production of heavy unstable particles (V particles) in carbon and lead. The cloud chamber, operated in a magnetic field of 10,000 gauss, is exposed to the 2-Bev negative π -meson beam of the Cosmotron. The chamber contains two 1/4-in. thick lead plates and three 1/2-in. thick carbon plates in which the particles of in-

terest are produced. Approximately 8000 photographs have been taken in some 300 hr of running. About 120 examples of the production of heavy particles have been observed. Of these, approximately one-fourth have been analyzed in detail and analysis of the remainder of the events is continuing.

The number of events occurring in carbon and lead are approximately equal and the absolute production cross sections are of the order of 1 percent of geometric for both nuclei. The observed ratio of Λ^0 to Θ^0 particles is greater for carbon than for lead and gives evidence for nuclear interactions of the V particles. Charged V particles are observed in about 10 percent of the cases. In support of the theories of associated production, approximately 10 percent of the events are simultaneous production of a hyperon and K-meson. Since the experimental arrangement permits the identification of the pion producing the particles, and the determination of the point of origin of the event, information may be obtained on angular correlations in the decay of the heavy particles, and the lifetimes may be measured. At present the data do not indicate any marked correlations and thus provide no evidence on the spins of the hyperons on K-mesons. Very preliminary lifetime measurements indicate values in general agreement with previous measurements.

Harvard has been operating a nitrogen-filled diffusion cloud chamber in the 1.4-Bev π^- -meson beam and has obtained the following preliminary results:

- 1) The cross section for inelastic events (nucleus disrupted) in nitrogen is $135 \text{ mb} \pm 35 \text{ mb}$. (Muon contamination is the largest uncertainty.)
- 2) From the stars there are 128 emergent particles believed to be mesons. Of these 37 are positive, 61 negative and 30 of doubtful sign. Thus on the average there are 1.57 emergent charged mesons per star to compare with 3.8 charged nuclear fragments. Helium nuclei and heavier fragments are often present.
- 3) More details on momentum and angular distributions and evidence on π^0 -mesons by momentum and energy balance will have to wait until the analysis and calculations are completed. (Some additional details are available in the Proceedings of the Fifth Rochester Conference on High Energy Nuclear Physics).

In order to observe the production of curious particles in lead and carbon by monoenergetic nucleons,

the Yale cloud chamber group has a diffusion chamber in a magnetic field of 7500 gauss and exposed to the so-called "blown-up" proton beam of the Cosmotron. This chamber has a visible sensitive region 1 ft square and 2 to 2-1/2 in. deep when operated with slightly more than 1 atmos (6 psig) of methane. A novel feature of this chamber is its re-entrant beam window in the "upstream" wall which makes possible the placement of a lead or carbon block within 1/8 in. of the visible sensitive region without opening the chamber. Maintaining sensitivity in the gas next to the beam window over its full height (1-1/8 in.) at all times is the major problem in operating this chamber for observation of curious particles from the lead or carbon blocks. A reasonably good beam of protons at the proper intensity was obtained during three of four operating days in September, 1954. The lead target was used during almost all of that exposure. Five neutral V events which appear to come from the lead have been found for about 20,000 beam tracks traversing the chamber. The beam density is being evaluated to obtain the number of traversals of the 1-in. thick lead target and the efficiency for observation of Λ 's and Θ 's with this arrangement.

Thus far during the summer of 1955, about 12,000 pictures have been obtained, 9000 with the carbon and 3000 with lead. The carbon pictures are in process of being scanned. So far, 3700 beam tracks through the carbon target have been completely scanned. No events coming from the carbon target were observed to be produced by these tracks.

In May 1954, the MIT cosmic ray group started a cooperative research program with the Brookhaven National Laboratory. The initial objective was the installation of a large multiplate cloud chamber for a study of the production of unstable particles by protons and π -mesons. In particular, it was planned to study the decay modes of various K-mesons, a problem to which the multiplate chamber is peculiarly adapted.

An initial period of several months was used in constructing a large concrete block house on the SE corner of the Cosmotron floor to provide adequate shielding of the chamber against stray radiation; various technical problems connected with operating the cloud chamber in a horizontal rather than a vertical plane also had to be solved.

Initial operation of the chamber took place during October and some preliminary experiments were

made with 3-Bev protons from the "blown-up" beam. Operation was interrupted by the repairs to the Cosmotron magnet and was resumed in May, 1955. About 500 photographs were obtained during preliminary runs in May and June. As a result of this initial experiment, it was decided to improve the illumination in the cloud chamber and to install a target in the Cosmotron so that 2.0-Bev π^- -mesons could be brought into the chamber.

These changes have been completed. The chamber is much improved and the π^- -beam is being tested. As a first experiment it is planned to make a comparison of the production of unstable particles by 2.0-Bev π^- -mesons and 3.0-Bev protons.

Counters

Figure 1 shows the recent data for total cross section for π^+, p and π^-, p interactions for meson energies up to 1.5 Bev. It is to be noted that an accurate determination of the shape of these curves in the region of 200 Mev is now available which supports the existence of a short lived isobaric state of the meson-proton system. A more accurate value of the cross section around 0.9 Bev has been obtained which confirms the existence of a second maximum at that energy.

A measurement of the total cross section of hydrogen for positive and negative pions from 150 to 750 Mev has been completed. In particular a precision determination ($\sim 3-5$ percent) of the π^+, p total cross section in the presumed resonance region (140-350 Mev) has been performed by means of liquid hydrogen transmission measurements. The results are shown in Figure 1. A theoretical analysis of the results in conjunction with other available data strongly supports the hypothesis of a resonance. The behavior of the phase shift of the resonant state was deduced, and it was found that the most probable position of the resonant point (90° phase shift) is at 175-180 Mev incident pion kinetic energy in the laboratory system. The data were found to fit the general behavior of the recent Chew-Low theory and the Brueckner phenomenological resonance theory, which are almost identical.

With the hydrogen target, the positive to negative pion ratios obtained were $\geq 20-40$ to 1 at 1.0. Bev and $\sim 4 \pm 2$ at 2.3 Bev. The observed spectra transformed to the center-of-mass system are shown in Figure 2.

A system of counters sensitive only to γ -rays has been used to detect the presence of heavy mesons or hyperons which, after being produced in a target,

Figure 1. Total cross sections of π^+ - and π^- -mesons on hydrogen; there are peaks for π^+ - and π^- -mesons of 180-Mev kinetic energy and for π^- -mesons of about 900 Mev. These peaks suggest special forms of interaction between these particles.

Figure 2. Relative number of π^+ - and π^- -mesons as a function of their kinetic energy in the center-of-mass system produced in beryllium by protons of 1.0 and 2.3 BeV.

move to a position where the γ -rays resulting from their decay can reach these counters. Since γ -rays coming directly from the targets are prevented from reaching the counters by a lead shield, counts detected are associated with hyperons and heavy mesons and can be used to measure the relative number of these particles which are produced. It has been found that the threshold for the production of heavy mesons and hyperons for protons in copper is close to 1.2 BeV or just about the value to be expected if associated production takes place.

Preliminary measurements of the angular distribution of elastic p,p scattering have been made with incident proton energies of 440, 590, 800 and 1000 Mev. The circulating beam of the Cosmotron struck a $1/4 \times 1/4 \times 0.514$ -in. CH_2 target placed inside a straight section. The two recoil protons passed through thin aluminum walls of the vacuum chamber and were detected in two scintillation counter telescopes. Elastic p,p events were selected by requiring coincidence of the two telescopes when set at

proper kinematic angles and with appropriate time delay.

The angular dependence at each energy was determined and the results show that with increasing energy the scattering becomes increasingly peaked in the forward direction. The integrated elastic cross sections are listed in Table 1 together with the total p,p cross sections as measured by Shapiro et al and the differences which represent meson production. The elastic p,p cross section falls only slightly in the region from 440 Mev to 1 BeV. The facts that the ratio $\sigma_{\text{total}}/\sigma_{\text{elastic}}$ is close to two and that the angular distributions at 800 and 1000 Mev are strongly peaked forward suggest that the elastic p,p scattering is primarily a shadow-scattering associated with the strong "absorption" of the incident proton wave via meson production.

Table 1

p-p integrated elastic, total, and inelastic cross sections, from 440 to 1000 Mev.

E(Mev)	Cross sections (in millibarns)		
	Elastic	Total	Inelastic
440	24 ± 2	27 ± 2	3 ± 3
590	25 ± 2	36 ± 3	11 ± 3.5
800	21 ± 2	47 ± 2	26 ± 3
1000	19 ± 3	48 ± 2	29 ± 3.5

Preliminary studies are continuing with a Cerenkov shower detector used as a high energy photon spectrometer. The photons are materialized in a lead radiator and are detected by a coincidence-anticoincidence telescope which gates a ten-channel discriminator in which the Cerenkov shower pulses are analyzed. The shower development takes place in a stack of lead glass plates of specific gravity 5.0 which are viewed end on by a DuMont 6394 photomultiplier tube. The glass occupies a cylindrical volume 10 cm in diameter and 18 cm long. The radiation length in the glass is 1.76 cm. The spectrometer has been calibrated with monoenergetic electrons of 160 and 390 Mev. Energy resolution is better than 30 percent at both energies. Photon spectra have been taken at 0° , 12° and 90° to a carbon target bombarded by protons of 1, 2 and 3 BeV. These measurements will be taken at two other angles with the present arrangement.

Nuclear Emulsions

A study of the characteristics of K^+ - and K^- -mesons has been made with the use of nuclear emulsions. Particles produced in a target inside the Cosmotron are analyzed and brought to rest in an emulsion where the decay products can be analyzed. The masses of the K^+ - and K^- -mesons were determined and within experimental error particles of both signs had the same mass as the τ -meson or 965 electron masses.

About 50 K^- -mesons were observed to be captured by nuclei of the emulsions. In about 1/2 of these stars a fast pion was emitted of such energy as to result only from production in the initial capture process. It was further observed that in about 1/5 of the captures, one of the emitted particles was either a charged hyperon or excited fragment heavier than a deuteron. At least some of the processes are explicable by the simple reaction

(where N is a neutron or proton, π^+ a pion and Σ^+ the positive hyperon of 2330 electron mass units).

Stars made by K^- particles in flight as well as at rest were observed. From these observations it was found that the cross section for interaction of K^- -mesons with nuclear matter was approximately the same as the geometric cross sections of the nuclei. This means that the K^- -mesons interact strongly with nuclei, as do π -mesons, rather than weakly, as do μ -mesons.

The energy spectrum of π -mesons emitted in high energy nucleon interactions has been studied at Harvard by the exposure of nuclear track plates to the radiations from an internal beryllium target bombarded by 2.2-Bev protons. Plates at laboratory angles of 12° , 36° , and 54° relative to the incident beam direction, corresponding to mesons near 30° , 90° , and 115° in the center-of-mass system, have been analyzed on the assumption of a simple nucleon-nucleon interaction in the target. Results to date confirm the form of the spectrum observed at a C.M. angle of 90° by Yuan and Lindenbaum, viz., a pronounced maximum near 100 Mev is found. In addition, comparison of relative cross section at different angles shows that the intensity at all energies is greater in the forward and backward directions than at 90° and that the intensity at the higher energies appears to increase more rapidly with departure from 90° than that at the lower energies.

There is also preliminary evidence which suggests the existence of two groups of mesons with energies near 100 and 200 Mev. The energy of these groups appears not to be a function of the angle of observation. The intensities, however, increase with departure from 90° in the C.M. system and the higher energy group appears to have a markedly greater angular dependence than does the lower energy group. Consideration of these results and other recent experimental evidence has suggested that the mesons are emitted from a metastable di-nucleon system which is assumed to be at rest in the C.M. system during the radiation process. The experiment has recently been extended by the exposure of plates at several different laboratory angles, from 12° to 90° , and with incident protons of 1.0, 2.2, and 2.9 Bev energy. The analysis of these plates is in progress.

NUCLEAR STRUCTURE

The study of complex nuclear spectra has been continued. New regularities have been established and new techniques developed. Among the decay schemes studied are those of Co^{57} , Cd^{113m} , I^{128} , Hf^{179m} , Os^{191m} , Hg^{199m} , Bi^{207} , and U^{232} .

A new kind of coincidence sorter has been developed, which is proving very useful in disentangling complex decay schemes. The principle of operation is as follows: Two NaI(Tl) crystals and photomultipliers are arranged in a normal coincidence spectrometer with the source between the crystals. The output voltages from the crystals are amplified, stretched and applied to the X and Y axes of an oscilloscope. At the same time, they are sent into a coincidence circuit, the output of which is used to trigger, for a few microseconds, the intensifier of the oscilloscope. Thus, when a coincidence occurs a dot appears on the oscilloscope face at the X,Y position corresponding to the pulse heights from the two crystals. The patterns produced in this manner are obtained by taking long time exposures with a Land Polaroid Camera (see Figure 3).

Within the framework of the collective nuclear model, the radiative transition probability for E2 radiation between successive levels in a rotational spectrum gives a measure of the intrinsic quadrupole moment of a nuclear state, and hence a measure of the charge distribution in the nucleus. The deviation of the charge distribution from spherical symmetry as deduced from the lifetime measurements is conveniently expressed in terms of a distortion parameter

Figure 3. Bi^{207} coincidences: 0.5-microcurie source (partially shielded); photographs taken at $f/11$; approximately three dots at the same position make a visible spot.

- A) 3-min exposure: 6000 coincidences (dots showing the 570–1063-keV photopeak-photopeak coincidence and photopeak-Compton coincidences).
 B) 20-min exposure in which the 570–1770-keV coincidence appears.
 C) 40-hr exposure in which the very weak 900–1440-keV coincidence appears.

β_r^2 . The deviation from the spherical symmetry of the matter distribution within the nucleus may be deduced from the excitation energies of the corresponding rotational states and is expressed in terms of a distortion parameter β_E^2 (see Figure 4). Distortion parameters evaluated from E2 radiative lifetimes are about 5–6 times smaller than those evaluated from the first excited state energies of even-even nuclei.

Figure 4. Distortion parameters β_E^2 and β_r^2 for even-even nuclei plotted against neutron number N . Note the different scale for β_E^2 and β_r^2 .

A study of the energy spacings of excited states in nuclei with even numbers of protons and neutrons was carried out. Between the spherical nuclei with filled shells which have very high first excited states (E_1) and the greatly distorted nuclei which show the so-called rotational states with very low E_1 , there are many nuclei with medium excitation energies ($300 < E_1 \leq 1200$) which had escaped interpretation. A survey of E_2/E_1 made for these nuclei brings out a surprising regularity, as shown in Figure 5. Here E_2/E_1 is plotted versus E_1 for $60 < A < 180$. At the left one sees group (a) consisting of rotational state nuclei with low E_1 and E_2/E_1 approaching the theoretical value $I_2(I_2+1)/I_1(I_1+1) = 3.3$ ($I_2=4$, $I_1=2$), while group (b) comprises the remainder of the nuclei. For $E_1 \leq 1200$ keV, E_2/E_1 is approximately 2.2, and the spin and parity of the second excited state are found to be predominantly 2^+ . An abrupt transition takes place between groups (a) and (b). A theoretical treatment, with the Bohr-Mottel-

Figure 5. Ratio of energies E_2/E_1 as function of E_1 . The character of the second excited state of the even-even nucleus is denoted by $\Delta(0^+)$, $\blacksquare(2^+)$, $\times(4^+)$, and $\bullet$ (not known).

son model of the nucleus in the region of weak to moderate coupling, gives account of the regular behavior of E_2/E_1 , as well as of the selection rules for the transitions between the excited states of these intermediate even-even nuclei. Additional levels predicted by this theory and selection rules concerning these levels can be tested experimentally. The empirical regularities are helpful for the discovery of levels hitherto unknown.

The equilibrium β^- spectrum from the thermal fission of U^{235} has been studied with the idea of determining the neutrino flux distribution emitted by the pile. Measurements were made with an external neutron beam, a thin U^{235} foil, and a plastic scintillation detector. The shape of the spectrum is in good agreement with that predicted by E. Wigner and K. Way.

The Van de Graaff accelerator has been used at energies as high as 4.1 Mev for a number of studies of the energy levels in light nuclei. The case of O^{16} is of special interest because of its connection with the alpha particle model of the nucleus. A new level in O^{16} has been found at 8.8 Mev both in the $F^{19}(p,\alpha)O^{16}$ reaction and in the beta decay of N^{16} . The properties of this state will indicate whether or not it is consistent with the predictions of the alpha-particle model. Low lying energy levels in F^{19} have been investigated since the structure of this nucleus

can be related to the shell model. A new level has been found at 1.46 Mev and this, together with previous information, indicates that F^{19} exhibits two sets of three close lying levels having the appearance of a repeated triplet with a spacing of 1 Mev.

A high pressure proportional counter for neutron detection has been completed. When filled with He^3 , it uses the $He^3(n,p)H^3$ reaction and the resolution is 4 percent for thermal neutrons. With an argon filling and the Van de Graaff as a neutron source, the reaction $A^{36}(n,\alpha)S^{33}$ is being investigated in order to determine the energy levels in S^{33} .

Construction of an iron-free, intermediate image, beta ray spectrometer has been nearly completed and at present the instrument is in use for research with radioactive sources. At full power, this instrument will focus 10-Mev electrons and thus can measure, by positron-electron pair detection, gamma rays as high as 20 Mev which occur in nuclear reactions with the Van de Graaff accelerator. At present, a fixed resolution of 1.0 percent is available, the corresponding transmission being 3.7 percent of a sphere. Line spreading due to source size is 0.3 percent per millimeter of diameter. Compared with the thin lens beta spectrometer previously in use, the new instrument has 300 times the transmission and 75 times the luminosity at 1 percent resolution. Two problems already completed with the spectrometer are

Figure 6. External conversion electron spectra from a 22 mg/cm² thorium converter from $H^1(n,\gamma)H^2$ and $Cd^{113}(n,\gamma)Cd^{114}$. The abscissa is proportional to electron momentum. The dashed part of the hydrogen spectrum is from the Compton electrons and the peak is the K-photoelectric line from the 2230-kev gamma ray. The cadmium spectrum indicates eleven photoelectric peaks above the background.

the internal conversion spectra of Bi^{207} and Ag^{106} . Construction of adjustable resolution and transmission baffles, a positron-electron pair detector and target holders are now in progress.

A thin lens beta ray spectrometer is being used at the reactor to study the gamma ray spectra from slow neutron capture. The gamma ray energies and intensities in the range 400 keV to 4 MeV are measured by means of the photoelectric effect in thorium and uranium converters. Figure 6 shows the spectra obtained from $\text{H}^1(n,\gamma)\text{H}^2$ and $\text{Cd}^{113}(n,\gamma)\text{Cd}^{114}$. The hydrogen spectrum (monochromatic line at 2230 keV) shows that the gamma ray background from the reactor is small. The K-photoelectric peak dominates the electron spectrum because of the K-x-ray K-photoelectron coincidence method used for detection. The L-photoelectric peaks are completely eliminated by this method and the Compton yield is suppressed by a large factor. The cadmium spectrum indicates 11 K-photoelectric peaks above the spectrometer background and any unresolved continuum that may be present. The yield obtained from hydrogen and sodium (which have thermal neutron cross sections of 0.3 and 0.5 barns, respectively) indicates that it is possible to study any element available in pound quantities that has a cross section in excess of 0.5 barns.

A series of elastic scattering experiments were performed with 40-MeV alpha particles from the 60-inch cyclotron to determine nuclear radii. For heavy elements (Ta, Au, Pb, Th), the measured results at small scattering angles agree with the theory of Blair and at larger angles with the theory of Ford and Wheeler; neither theory is adequate to explain the observations. Fitting the data to the Blair model gives a nuclear radius of $1.5 \times 10^{-13} A^{1/3}$ cm, whereas the Ford-Wheeler model gives $1.3 \times 10^{-13} A^{1/3}$ cm. For the alpha particle radius, these values are 2×10^{-13} cm and 2.5×10^{-13} cm, respectively.

For light elements (Al, Cu) on the other hand, the elastic scattering of alpha particles shows a pronounced diffraction effect (Figure 7). Assuming that the nucleus acts as an opaque disc for 40-MeV alpha particles, the pattern leads to a value of 5.7×10^{-13} cm for the sum of the radii of the aluminum nucleus and the alpha particles. Similar results were obtained for copper.

In addition to these experiments, observations were also made on inelastic collisions of alpha particles (Au, Ag, Cu) in which protons were emitted.

The angular distribution of the protons in these (α, p) reactions gives some information about the density of excited states of the compound nucleus; the results confirmed in general the theoretical expectations. Measurement of the distribution of proton energy at a given angle of scattering led to the same conclusion.

Figure 7. Diffraction effect in the elastic scattering of 40-MeV alpha particles from an aluminum nucleus.

The comparison of the tritium content of a meteorite with the tritium produced in iron under Cosmotron bombardment (2.2-Bev protons) gives the intensity of the cosmic ray flux that struck the meteorite in interplanetary space. For two meteorites (Pará de Minas and Norfolk) this flux was found to be 10 and 1.5 particles per square centimeter per second, respectively. From cosmic ray intensity in 1949 at the earth's poles, one expects this flux to be about 3 particles per square centimeter per second, but this value can be markedly different in different years.

The amount of He^3 in the meteorites was also measured by converting it to tritium under neutron bombardment in the reactor. Comparing the He^3 and tritium contents gives the "cosmic ray age" of the meteorite, that is, the time required to build up the He^3 from the tritium. For Pará de Minas, this age is about 2 billion years.

In a program sponsored jointly with Columbia University, the Columbia 180° beta spectrometer was moved to Brookhaven to measure the spectra of certain beta-active gases which can be produced in the reactor. The end point of the simple allowed He^6 spectrum was determined to be 3.50 ± 0.02 Mev. The end point of the lower energy group of the complex A^{41} decay is 1.20 ± 0.02 Mev; it is followed by the emission of a 1.26 ± 0.01 Mev γ -ray. The investigation of the electron-neutrino angular correlation of He^6 has been completed. The coincidence rate between the beta particles and recoil nuclei was observed as a function of the energies and angle between the particles. The results show that the correlation is given by $W(\Theta) = (1 + 1/3 \cos \Theta)$ and that the tensor invariant is dominant in the beta decay interaction for this transition. A careful measurement of the He^6 spectrum has been started to determine a limit on the possible mixing between the tensor invariant and the axial vector or pseudoscalar invariants in the beta decay interaction.

The beta spectrum of A^{35} was measured with the Alburger thin lens spectrometer. The gas was produced according to the reaction $\text{Cl}^{35}(\text{p}, \text{n})\text{A}^{35}$ by bombarding liquid CCl_4 with protons from the Brookhaven 60-inch cyclotron. The end point energy is 4.90 ± 0.05 Mev, and the half-life is 1.83 ± 0.02 sec. A search is being made for the existence of A^{34} produced by an $(\alpha, 2\text{n})$ reaction on S^{32} .

ATOMIC AND MOLECULAR PHYSICS

Nuclear Mass Measurements

At the new radiofrequency mass spectrometer, installation has been completed of the electronic equipment designed and constructed by the Instrumentation Division for generating radiofrequency voltages of suitable form for the measurement of accurate values of relative mass difference. The apparatus was designed to increase the speed of measurement and to obtain precise relative frequency differences. Together with the water-cooled magnet coils installed last year, the new radiofrequency equipment has permitted measurements over a considerably wider range of mass and, in addition, a much better understanding of the operation and limitations of this novel type of mass spectrometer has been obtained.

By combining carefully redone measurements of such well known doublets as $\text{CH}_4\text{-O}$ with doublets not previously measured (involving ions formed in the boron compounds B_3H_9 and B_2H_6), a new cycle

of doublets has been used to obtain new values of the mass defects of H^1 , B^{11} , C^{12} , and S^{32} . From these, by means of other doublet measurements, values of the defects of other light atoms (D^2 , He^4 , B^{10} , and N^{14}) have also been obtained. The value for C^{12} is in good agreement with that published in 1954 by Mattauch and Beiri and is about midway between the incompatible values found previously by Li, *et al.*, from nuclear disintegration data and by Nier, *et al.*, and by Ogata and Matsuda from mass spectrometric measurements.

Nuclear Moments

The nuclear moment program consists of a study of nuclear spins, magnetic moments and electron quadrupole moments for radioactive and rare nuclei. For these purposes, the techniques of the atomic beam and of paramagnetic resonance are being used. Apparatus for nuclear resonance measurements and microwave spectroscopy are also available for special problems when the need arises.

The atomic beam apparatus has been used for a precise measurement of the hyperfine structure interaction constant for the 3.1-hr isomer of $\text{Cs}^{134\text{m}}$. It yielded a value of $3,684.594 \pm 0.020$ Mc sec^{-1} . This value is of sufficient accuracy to determine the sign of the magnetic moment and of the hyperfine structure anomaly once the nuclear magnetic moment can be determined accurately. Work is now in progress toward this end. Preliminary work is being done on the measurement of the nuclear spin of At^{211} .

Nuclear hyperfine structure in the paramagnetic resonance of dilute solutions of organic radicals is of interest in that it may shed light on additional means of determining spins of radioactive nuclei. A study has been made of a series of three new radicals, triarylammonium perchlorates dissolved in tetrachloroethane. Hyperfine structure was observed in two of them. The third was unstable in solution. Attempts are being made at present to determine the spins of Ni^{61} , P^{32} , and V^{49} .

Some assistance has been given to the Nuclear Engineering Department in studying the production of free radicals in irradiated plastic monomer. These radicals are instrumental in effecting polymerization at room temperature.

NEUTRON PHYSICS

Fast Chopper

During the past year, parameters of some 200

neutron resonances from 2 to 700 ev have been determined for about 20 heavy nuclei ($A > 90$) from total cross section measurements. The first few resonances in each nuclide are analyzed to give values for the radiation width Γ_γ as well as the neutron width Γ_n . The radiation widths show little variation (~ 20 percent) from resonance to resonance in a particular nuclide because of the large number of possible gamma transitions to lower excited levels in the compound nucleus. In contrast to the near-constancy of the radiation widths in a particular nuclide, the neutron widths were found to have an extremely large variation in size. When a level decays by elastic scattering, there is only one mode of decay. The neutron width consists of an intrinsic nuclear width (a reduced width) and a barrier penetrability factor which is proportional to the square root of the neutron energy. The reduced neutron width of a resonance is defined as the observed neutron width of the resonance divided by the square root of the resonance energy in ev ($\Gamma_n^0 = \Gamma_n / \sqrt{E_0}$ (in ev)). The reduced neutron widths for a particular nuclide vary by factors of several hundred.

Figure 8 shows integral distributions for a few of the nuclides investigated. The number of widths exceeding a particular value is plotted against this value. The slopes of the straight lines are computed from the arithmetic averages of the reduced neutron widths. Within experimental accuracy, the reduced neutron widths follow an exponential distribution implying that the differential distribution would also be exponential. In order to combine the data for different nuclides, the reduced neutron widths are divided by the average value for the nuclide. Figure 9 shows a differential distribution of this ratio for 145 reduced neutron widths. Three semitheoretical curves are shown for comparison. At large widths the exponential gives the best fit, whereas at small widths the others provide better agreement.

Measurements on the total cross section of U^{235} have been analyzed to give neutron widths for 40 resonances up to 40 ev and total widths for 10 resonances up to 10 ev. Since the radiation widths of the resonances are constant and equal to 0.030 ev, the fission widths for the resonances can be obtained from the measured total widths. The fission widths show a much wider variation from resonance to resonance than the radiation widths but not as much fluctuation as neutron widths; the largest fission width is about 10 times the smallest. Since a given

Figure 8. The distribution in size of the reduced neutron widths for various nuclides. The figure shows the number of resonances with widths exceeding a particular value, plotted against this value. The slopes of the straight lines are computed from the arithmetic averages of the reduced neutron widths.

level may have several modes of decay by the fission process, it is not surprising that the spread in fission widths is not so large as the spread in reduced neutron widths. The fact that they have a broader spread than the radiation widths indicates that there are not as many modes for decay in fission as are possible for gamma transitions.

Total cross section measurements have been made on heavy nuclei in the kev neutron energy region.

Figure 9. Distribution (per 0.1 in Δx) of 145 reduced neutron widths relative to the average value for each nuclide. The curves are various suggested distribution laws described in the text.

The total cross section is composed of the potential scattering and the contribution from the resonances. Individual resonances are no longer observed for heavy nuclei at these higher energies; points taken 1 kev apart represent averages over many resonances. From measurements of the transmission of many sample thicknesses, the contribution of the resonances and the potential scattering can be separated. The contributions of the resonances give directly the Γ_n^0/D ratio. (The significance of this ratio, and the comparison of the experimental results computed from resonance parameters up to a few hundred ev are outlined in the previous Annual Report.) The values for this ratio obtained from these high energy measurements agree with values computed from the resonance parameters. The potential scattering cross sections obtained from these kev measurements agree with values obtained between resonances at lower energies after correcting for nearby resonances.

A new rotor for the chopper has been constructed with several modifications. The outermost plastic

arms have been modified in order to equalize the strains at the high speed so that the rotor can spin routinely at 12,000 rpm. The central section of the rotor has been modified so that the rotor "chops" gamma rays as well as neutrons. This was accomplished by replacing several of the plastic pieces at the center of the rotor with similar steel pieces. When the chopper is closed, there are 6 in. of steel in the beam which stops gammas from passing through the rotor. This reduction of the gamma rays will allow the use of scintillation counters having higher efficiencies.

Slow Chopper

Both x-rays and slow neutrons can be used to investigate the fundamental problem of the spectrum of lattice vibrations of a crystal. Since the energy of the slow neutrons is comparable to the energy of lattice vibrations, it is possible to measure directly the energy changes resulting from neutrons interacting with the lattice. If the energy of the incident neutrons is very small, the energy of the scattered neutrons is a measure of the energy gained from lattice vibrations in the solid.

Figure 10. Experimental equipment for measuring the energy distribution of inelastically scattered cold neutrons with the BNL slow chopper.

A beam of cold neutrons is produced by filtering the neutron beam from the reactor through a beryllium filter at liquid nitrogen temperature. These cold neutrons with energies of the order of 0.002 ev are scattered from the target. The energy distribution of the scattered neutrons is determined by using a slow chopper and a 4-meter flight path, as shown in Figure 10. For this experiment, a new low resolution rotor was designed for the slow chopper.

A large single crystal of aluminum and a polycrystalline beryllium sample have been used as scatterers. With aluminum, three discrete neutron energy groups have been observed centered about an energy of 0.025 ev. The three groups are related to one longitudinal and two transverse sound waves in the solid. When the single crystal is rotated, the energies and intensities of the three neutron groups vary. The variation of these three peaks with angle can be directly interpreted in terms of the spectrum of the lattice vibrations in aluminum.

Measurement of Capture-to-Fission Ratio

A new method using the Brookhaven slow and fast choppers has been developed that gives directly the variation of η (the number of neutrons produced per neutron absorbed) with energy in the near thermal region in a direct and unambiguous way. A beam of thermal neutrons, produced by the chopper, passes through a "thin" ($1/v$) counter, then falls on a thick foil of the material being investigated. The fission neutrons from the foil are detected by a scintillation counter. As essentially all the neutrons are absorbed by the thick foil, the thin counter gives the absorption rate, whereas the emission rate of fission neutrons is given by the scintillation counter. In this way, the ratio of the counting rates of scintillation to the thin counter is directly proportional to η . In order to make the results absolute, they are normalized to the accurate thermal value of α (the ratio of capture to fission) with no attempt at absolute standardization of the counters. The experiment determines the η variation with energy, but as η is equal to $\nu/(1+\alpha)$, where ν is the number of neutrons per fission, α can be obtained because ν is supposedly constant for small energy changes. Measurements have been made using both the slow and fast choppers on U^{235} , U^{233} , and Pu^{239} .

Crystal Spectrometers

At the reactor, a group has been conducting research in neutron physics with two crystal spectrom-

eters, one a high resolution instrument, and the other a spectrometer for measuring neutron scattering cross sections.

The high resolution spectrometer has successfully made use of a new type of collimation which has greatly improved the precision of the cross section measurements. Studies have been made of the variation of radiation widths of resonances as a function of atomic weight and also within a given isotope. Very precise values have been obtained for the Breit-Wigner parameters of many neutron resonances and a large mass of information has been collected on the behavior of the radiation widths. Work of this type requires advanced numerical analysis techniques to fit the observed curves to the theoretical formulas. This analysis has been carried out on the BNL digital computer (Remington-Rand 409.2R). Much of the computing has exceeded the practical capacity of this particular computer, and the work was completed only at the expense of much extra labor on the part of the scientific and computing staffs.

The spectrometer has been arranged so that the data are recorded directly on punched cards. All data are then automatically recorded 24 hours a day. This method has improved the quality of the data by eliminating the human errors which could not be avoided in such a large mass of data.

The spectrometer for scattering measurements has been adapted to make measurements by a new method. The resonance scattering for several isotopes has been studied and spin assignments made for the resonant state.

Another reactor program, of neutron and beta-ray spectroscopy, has been sponsored jointly by the Laboratory and Columbia University. In this program, the nonmagnetic neutron-electron interaction is being investigated by measuring the neutron transmission of liquid bismuth with the Columbia single crystal spectrometer. Transmission data, collected with the sample temperature held constant at 300° and 500°C, are being analyzed to determine depth of the equivalent square well potential for the interaction. In conjunction with these measurements, the total cross sections of several elements have also been measured. The useful energy range of the spectrometer has been extended into the subthermal range (to 0.001 ev). A focused mica crystal with a "d spacing" of 9.954 Å is used as the crystal monochromator, and higher order Bragg reflections are removed from the neutron beam with filters of

Be and BeO cooled to liquid nitrogen temperature. The neutron transmission near the Bragg diffraction cutoff for samples of Bi, Mg, C, and Pb have been measured to determine the usefulness of these materials as neutron filters. In cooperation with the Physical Chemistry Department of Columbia University, the effect of molecular binding on the proton cross section is being studied in this long wavelength region.

Cyclotron Results

The protons accelerated in the 18-inch cyclotron have been used to produce a neutron beam for measurements on neutron scattering. With a T-Zr target, neutrons of 1.7 Mev are obtained in pulses of a few millimicroseconds' duration, one pulse every 54 μ sec. With time-of-flight techniques the energy spread of these neutrons is found to correspond very well with the expected energy loss for the protons in the Zr layer.

Several different types of neutron collimators have been tested for improvement of a signal-to-background ratio and to observe any effect they may have on time dispersion of the neutron pulse. A 50-gal drum containing a saturated solution of lithium sulfate and provided with a 2-in. hole along the axis of the cylinder for the collimated neutrons, has so far given the best signal-to-background ratio.

With the focused beam from the 18-in. and a T-Zr target, the neutrons scattered elastically from carbon at 90° have been used for further collimator and detector studies. These elastically scattered neutrons are observed with a signal-to-background ratio of at least ten to one. With this ratio it is possible to observe neutron scattering cross sections at least as low as 0.1 barn.

The slow neutron time-of-flight equipment at the 60-inch cyclotron has been used with the n,γ resonance detector on a number of elements. Both self-indication and self-absorption data have been completed on silver, gold, indium, tantalum, and molybdenum and are in progress on tungsten. These data encompass a neutron energy range from the lowest resonance for each element through approximately 100 ev.

Work has been carried out to evaluate two important corrections, Doppler broadening and scattering in the detector foil. An analysis of the influence of the Doppler effect on self-absorption measurements shows that the measurements are primarily sensitive

to the peak Doppler cross section and relatively insensitive to the width of the resonance. A study has been completed of the number of neutrons captured after scattering in the resonance detector foil compared with the number captured in the first interaction. The results are complicated by the energy shift of the neutron on scattering and the resonance character of the cross sections before and after scattering, both modified by the Doppler effect. This correction is especially important when $4E_0/MT \leq 10$, where E_0 is the resonance energy, M is the ratio of the mass of the nucleus to the mass of the neutron and Γ is the width of the resonance.

SOLID STATE PHYSICS

Structure of Solids

The neutron diffraction program of the Physics Department has been concerned with ideal and imperfect arrangements of atomic nuclei and magnetic spin systems in solids, with emphasis on problems in which diffraction results can be related to macrophysical properties. During the period of this report, the magnetic studies have been done on special scattering effects at magnetic transition points and on domain wall thickness measurements by transmission measurements with a polarized neutron beam. Crystal structure work has been concentrated on ferroelectric and antiferroelectric structures. In addition, some time has been devoted to improvement of techniques and facilities, to machine computing methods for analyzing diffraction data, and to the phase problem for neutron structure analysis.

Further studies have been conducted on the spin-alignment structure in Fe_3O_4 as it changes with increasing temperature from ferrimagnetic to paramagnetic. This work has also been extended to some antiferromagnetic materials. It appears that one can draw a general conclusion that magnetic diffraction peaks consist of two components: an elastic part which drops sharply to zero at the transition to the paramagnetic phase, and a diffuse peak which rises to a sharp maximum at the transition point. The diffuse peak demonstrates the existence of a sub-structure of short range spin order which is maximum at the transition point but which persists at higher temperatures.

The analysis of the crystal structure of Rochelle salt is now in the final refinement stages. The crystal is monoclinic pseudo-orthorhombic in its ferroelectric

modification. It has not been possible for x-ray workers to detect the monoclinic symmetry, but this is clearly in evidence with neutron data. The structure is the most complex one yet examined with neutrons. There are 112 positional parameters in the noncentrosymmetric projection on (001). Present results (with a reliability index of about 13 percent) show a number of deviations from orthorhombic symmetry which can be related to the dielectric peculiarities of the crystal. All these are fairly small except for one of the hydrogens belonging to an OH group on the tartrate molecule. This OH group appears to have two possible orientations. It adopts one of these in half of the structure while its pseudo-symmetrically related mate adopts the other in the remaining half. This results in a net hydrogen displacement of almost one Angstrom unit, with principal component parallel to the ferroelectric *a*-axis.

The structure of ferroelectric BaTiO_3 cannot be solved uniquely by x-rays. Because Ba scatters x-rays so strongly in comparison to Ti and O, one cannot obtain sufficient sensitivity to the small displacements from the ideal cubic structure. An unambiguous solution is possible with neutrons, however, since the scattering factor magnitudes are much more nearly equal. Neutron data were collected from a small single crystal with unidirectional domain alignment maintained by an external electric field. A structure has been obtained which shows shifts (relative to Ba) along the ferroelectric *c*-direction of 0.06 Å for Ti, -0.09 Å for the O above Ti, and -0.006 Å for the O's on the side faces of the cell. While this structure shows excellent agreement with observed data (reliability index of less than 3 percent), it is being checked by measurement at high Bragg angles and by independent measurements on a second sample.

Neutron powder diffraction data have been collected to supplement cooperative x-ray analyses at Pennsylvania State University on several other perovskite ferroelectrics and antiferroelectrics: tetragonal PbTiO_3 , orthorhombic PbZrO_3 , orthorhombic KNbO_3 and rhombohedral $\text{Pb}(\text{Ti,Zr})\text{O}_3$. The PbTiO_3 structure has been completed and published. This crystal has a much larger tetragonal distortion than BaTiO_3 , and at first it was thought that a unique solution would be possible by x-rays alone. However, after a structure that gave very good agreement with observed data was arrived at, it was found that no significant change in agreement occurred if the displacement direction of an atom was reversed.

This resulted in four possible models. Fortunately, the large cell distortion permitted sufficient resolution in a neutron powder pattern to make an unambiguous choice of one structure.

This structure is consistent with results on BaTiO_3 if one views the two structures in terms of shifts of Ti, Pb, and Ba relative to the oxygen octahedral framework. In PbTiO_3 the oxygen octahedra are intact except for the overall tetragonal distortion of the lattice. It is found that Pb shifts by 0.47 Å and Ti by 0.30 Å in the same direction. In BaTiO_3 , there is a small distortion of the octahedra over the tetragonal distortion. Depending on which oxygen is chosen as fixed, Ba shifts 0.06 Å or 0.09 Å, and Ti shifts 0.12 Å or 0.15 Å. The considerable difference in behavior of Ba and Pb is presumably due not only to the large tetragonal distortion of the PbTiO_3 lattice but also to the higher polarizability of the Pb ion.

The General Electric x-ray SPG spectrogoniometer modified during the preceding report period for single crystal neutron studies has been placed in satisfactory operation. A 1.5-atmos pressure BF_3 proportional counter is now being used with the new instrument. The counter efficiency is comparable to that of standard large counters.

Radiation Effects

An absolute determination of the concentration of lattice defects introduced into graphite by reactor irradiation has been achieved by means of long wavelength neutron transmission experiments. Neutrons of sufficiently long wavelength (6–12 Å range) are scattered isotropically by isolated point defects and this scattering is measurable when crystalline effects (Bragg scattering) are absent. The cross section for this nuclear type of scattering is accurately known from other measurements and thus the number of scattering centers is measured in an absolute way. For an exposure of 1.1×10^{20} neutrons/cm² the fraction of displaced atoms in graphite was found to be 0.026. This value is in excellent agreement with that derived from Seitz's theory. A few postirradiation annealing experiments have also been carried out. For example, after an anneal for one hour at 500°C the fraction of defects has decreased by about 70 percent. After a similar anneal at 900°C, no defects were detectable by transmission measurements. An unirradiated sample was also heated at 900°C for one hour. No difference in the transmitted spectra was found

before and after annealing. Intensive experimental work is in progress to refine this method and to extend the measurements to low temperatures.

Extension of the above techniques to low temperatures is particularly important since it has been found that graphite irradiated at low temperature retains more damage than if irradiated at 30°C. This effect was found by x-ray studies of material irradiated at liquid nitrogen temperature. Preirradiation measurements were made on four samples of highly oriented natural graphite. The four samples were irradiated in the liquid nitrogen facility and one sample was removed at the end of every 10^{19} nvt. After removal of the first sample, a power failure caused a warm-up of the three remaining samples for a period of 12 hours. The three samples were not subjected to radiation during this interval and the maximum temperature did not exceed 90°C. The rate of c-axis growth before and after the warm-up was the same, and about 40 percent of the damage annealed out during this interval. The rate of c-axis growth at liquid nitrogen temperature was significantly larger than for a sample previously exposed in the Brookhaven reactor at 50°C. Detailed annealing studies are in progress.

Research activity on radiation effects in insulating materials has been concentrated on high melting inorganic oxides. The high melting inorganic oxides are considered to be analogous to alkali halides and consequently mainly optical techniques have been employed so far, i.e., the formation and nature of color centers induced by gamma and reactor irradiation have been studied. Quite extensive results are available for α - Al_2O_3 . When subjected to only gamma rays, this crystal develops absorption bands at 2300 and 4000 Å that reach maximum optical density at the rather small dose of 3×10^4 r. Additional gamma irradiation of 10^8 r does not modify these bands. Reactor irradiation, which subjects the crystals to fast and slow neutrons in addition to gamma rays, produced absorption bands at approximately 2040 and 2600 Å. The 2040 Å band is about 10 times as intense as the 2600 Å. These reactor-induced bands are unaffected by additional gamma ray irradiations. The growth of these bands as a function of irradiation, and their removal by thermal annealing, has been studied. Thus a coloration specifically due to reactor irradiation is produced. Heavy irradiations produce some weak bands in the visible that decay at room temperature over a period of several months.

Results similar in many ways have been obtained for Corning "superpure" fused silica. Gamma sensitivity is low but well defined absorption in the 2000—3000 Å region is produced by reactor irradiation with little absorption from 3000—10,000 Å. This is in contrast to the coloring of Brazilian crystalline quartz which shows considerable absorption in the 400—5000 Å region as well. It is well known that impurities play an important role in the coloration of crystalline quartz. Research on radiation effects in very pure materials is expected to yield important information about the properties of "basic" crystalline defects in contrast to impurity controlled coloration.

In Linde synthetic spinel, a rather complex absorption spectrum is produced by gamma irradiation. The most interesting feature is the production of a stable absorption in the 3000—4000 Å region. The growth of absorption is very roughly linear with gamma exposure in the 10^4 to 10^6 r region. In addition, reactor irradiation produced well defined absorption bands. This crystal may be of use in high gamma exposure dosimetry.

Considerable work has been done on sodium azide in cooperation with Picatinny Arsenal. This compound, which contains both covalent and ionic bands, is colored by γ -ray and reactor radiations. The reflection spectra are different for gamma and fast neutron irradiations, and are sensitive to subsequent heat treatment. The color centers are probably related to the decomposition of this crystal. In particular, a band appears at 3600 Å, probably due to color centers, and one at 6000 Å which might be due to colloidal sodium. Some success has been achieved in growing small single crystals in preparation for detailed optical studies in transmission. A recording Perkin-Elmer spectrophotometer, equipped with a reflecting optic microscope, was acquired and put into operation for this work. Improvements incorporated in this machine since it was delivered permit the determination of spectra from 1930 Å to 8μ on thin samples 1 mm on a side.

Gamma-ray induced solid state polymerizations are under study in cooperation with the Nuclear Engineering Department and the Polytechnic Institute of Brooklyn. From the solid state standpoint, the production of free radicals, their stability at low temperature, their paramagnetic resonance and the residual crystallinity of the end polymer are of particular interest.

It was pointed out last year that the resistivity of α -brass decreases upon irradiation in the reactor at 50°C. A resistivity decrease can also be produced by annealing at 160°C a sample previously quenched from 300°C. These phenomena have been studied in more detail with emphasis on the kinetic aspects. The thermal annealing process has been found to be approximately of first order with relaxation times equal to those obtained by elastic after-effect measurements. The kinetics of the recovery of the radiation-induced decrease in resistivity is also of first order and is characterized by the same relaxation times. All these effects have been successfully interpreted as radiation and temperature-induced changes in short range order. Part of the resistivity change produced by cold work can also be ascribed to altered short range order.

In connection with the general study of metals, striking spiral polygon tin and indium "whiskers" have been grown in cooperation with the Metallurgy Division. The angles of sharp bend observed in these whiskers can be correlated with crystalline twinning angles. The growth of the whiskers appears to be diffusion controlled since no growth is observed at liquid nitrogen temperatures.

In addition to staff work, irradiations have been done in the liquid nitrogen irradiation facility for Knolls Atomic Power Laboratory, North American Aviation, Argonne National Laboratory, Massachusetts Institute of Technology, Rutgers University, and Brown University.

Theoretical work on the physics of solids continued with emphasis on the kinetics of order-disorder transformations. A simple theory of the kinetics of order-disorder transformations, based on chemical rate theory, has been worked out. The theory is constructed entirely in terms of the long range order parameter and reduces to the Bragg and Williams theory of equilibrium. There are several unusual features in the theoretical rate curves. The origin of these characteristics is the order parameter dependence of the energy of ordering. It is shown that ordering must start by fluctuations which are expected to be particularly large for an AB_3 alloy. Thus, the shapes of the ordering curves remind one of nucleation and growth processes although they are derived entirely from simple rate theory. The theory is shown to be in agreement with the experimentally known qualitative behavior of the order-disorder systems.

A more elaborate theory is under development based on the concept of probability functions for the simultaneous occupancy of arbitrarily specified lattice sites by arbitrarily specified types of atoms. If it is also assumed that atom movements occur in certain simple ways, such as by pairwise interchange, motion of vacancies, etc., then within the confines of such a model, rigorous equations governing the time rate of change of each of the probability functions may be written. The foregoing chemical rate theory emerges as an approximation after certain assumptions as to the probability function and transition rates have been made, and the parameters of the chemical theory can be calculated from more basic properties of the lattice. The kinetics of short range order may also be examined on this basis, and an attempt may be made to predict the most important ordering mechanism in specific cases.

At the reactor, a spectrometer group from the General Electric Company has been conducting investigations on a number of problems in solid state physics. The results of this program are being reported in detail by GE in the appropriate journals. A list of the topics follows:

The antiferromagnetic structure of α -manganese and a magnetic structure study of β -manganese.

The magnetic structures of BiMn.

Single crystal neutron diffraction of nickel zinc ferrite.

The antiferromagnetic structure of LaFeO_3 .

The magnetic and crystal structure of $\text{La}(\text{Ba})\text{MnO}_3$.

Magnetic structures of Cr_2O_3 and of the solid solutions of Cr_2O_3 and Fe_2O_3 .

Magnetic and crystal structures of V_2O_5 .

Ferrimagnetic structure of Mn_3O_4 .

Single crystal diffraction of nickel oxide.

Crystal structure of mercuric oxide.

The ordering of atoms in the sigma phase alloys.

Neutron diffraction of vanadium deuteride.

ELECTRONICS

The work of the Instrumentation and Health Physics Department has proceeded along lines previously laid down. The Department consists of two divisions: Instrumentation (formerly Electronics) and Health Physics. While the activities of the latter division are described in this report under the section on Technical Operations and Services, those

of the Instrumentation Division, which fall more into the category of research and development, are covered below.

The design of electronic circuits is the Division's major interest, although some development work concerns radiation detectors and a wide range of other instruments, required throughout the Laboratory, which may not involve electronics. Consequently, the staff is composed approximately one-half of engineers and technicians, while the remainder includes three physicists, a mechanical engineer, several glass blowers, and some machinists, technical specialists and technicians.

In cooperation with the Health Physics Division, a constant representing energy spent in forming an ion pair was remeasured. As radiation passes through matter it dissipates its energy by producing ionization and heat. Biological effects of radiation are primarily due to the ionization produced, and many measurements of radiation intensity depend on a knowledge of the average energy lost by the radiation per pair of ions produced. It seemed that the generally accepted value of this constant for air was too low, so it was measured again this year at Brookhaven and at several other laboratories. The radiation used here was a beam of electrons from a Van de Graaff accelerator, and the technique was to use an ionization chamber whose dimensions could be changed to extrapolate to the value for air infinite gas absorber. Measurements were made on air and several other common gases. The new measurements at the several laboratories agree in determining a value for the constant for air which is about 5 percent higher than older measurements had indicated.

As usual, the techniques for detecting, counting and analyzing radiations received considerable attention. The Brookhaven design of pulse amplifier, which is used with all types of pulse detectors, was redesigned to give a larger output, greater linearity and better long term gain stability. Now that scintillation counters are widely used, the linearity and stability of all elements of a counting system must be carefully analyzed. A study at Brookhaven and at Oak Ridge showed that the gain of some photomultiplier tubes varied as the counting rate was changed. The behavior of a large number of old and new tubes of the commonly used types was carefully determined to try to understand what might be the cause of this effect and select those tubes which were suitable for use in critical applications.

Carbon-14 and tritium (extra heavy hydrogen) are very important radioisotopes for biological and medical applications. Both emit low energy electrons which are difficult to detect. In the past it has been necessary to convert test samples to certain gaseous compounds to be measured in a gas proportional counter. In some cases it may be much easier to obtain the samples in liquid form and to measure them in the recently developed liquid scintillation counter. This apparatus, however, is complicated and expensive. A simplified liquid scintillation counting apparatus has just been built which makes use of the best available components to achieve the required sensitivity rather than a multiplicity of detectors, amplifiers and pulse sorters.

Under certain conditions the pulse height of a scintillation counter is proportional to the energy of the incident radiation and the energy spectrum of a source may be analyzed by plotting the pulse height distribution from the detector. The energy distribution may be used to study the structure of the nuclei of different kinds of atoms, or, once the spectra are known, as a sensitive method of analyzing an unknown sample for isotopes. Several more of the Brookhaven cathode tube pulse height analyzers have been built. One new type of analyzer is designed for rapid analysis of radioactive decay spectra. Each radioisotope has its own unique pattern for decaying to a stable isotope. In a particular case there may be more than one transition path or sequence of events, and one, two or more radiations may be emitted in extremely rapid succession. The new analyzer displays all of the serial (essentially coincident) events and indicates their energy as dots on a cathode ray tube.

A few instruments were built for the Federal Civil Defense Administration to analyze the fallout radioactivity at the surface of the ground near one of the test explosions in Nevada in the spring of 1955. They consisted of a set of ionization chambers which had equal response to gamma radiation but were supplied with different absorbers to give different sensitivities to the beta radiation. The chambers were set on tripods at several distances from the surface of the ground. The meters and controls were at the end of long cables so that the operator could make the measurements while in a truck and be protected by its shielding.

The most ambitious project started this year was the design and construction of circuits for use with

the fast chopper. The chopper interrupts a collimated stream of neutrons emerging from the reactor to produce a series of short bursts. The energy of a given neutron is determined by the time it takes it to travel from the chopper to the detector 60 ft away. The circuits sort the neutrons into channels depending on their time of flight. A 100-channel analyzer was constructed 2 years ago and described in the 1953 Annual Report. The new instrument will have 1,024 channels. The width of each chan-

nel will be $\frac{1}{4}$, $\frac{1}{2}$, 1 or 2 μ sec long. Digital computer techniques are employed in the sorting and storage of counts. Timing is obtained from a stable oscillator which is started precisely as each neutron burst emerges from the chopper. This is fed to a scaling circuit which is used as a clock. Whenever a neutron pulse is detected, the position of the scaler or clock is read and stored temporarily while one count is added to the number stored in that element of the memory which corresponds to this setting of the clock or time channel. Up to 10,000 counts may be stored in each of the 1,024 time channels. The total of over 10 million bits of information is stored on 16 five-inch cathode ray tubes. There will be a continuous indication of all the data which have been accumulated on another cathode ray tube. At the end of a run, automatic circuits will cause the data stored in the memory to be printed on a paper tape or punched on business machine cards. In order to design these circuits the several types of computer memory devices were studied and tested. All parts of the instrument have been designed and tested. About one quarter of the circuits were built by June 30, 1955.

A new current integrator has been designed which has an electrometer input tube so that it may be used with small or large currents. This is used at accelerators to measure the total amount of charge which has hit a target in order to give an indication of the total amount of energy expended.

A liquid level recorder was built for use with a closed system which operates at high temperature. A water level monitor is under construction which will measure to better than .01 in. out of 4 ft.

A novel timing circuit was designed which will measure the time taken for one type of measurement and then control several successive operations so that they take the same time. This is achieved by the use of two electronic counter circuits which may be made to count forward or backward. A low

frequency pulse generator supplies clock pulses to the first counter during the first measurements. The clock pulses stop at the end of the first period. To time the next interval the clock pulses are subtracted from the first counter and added to the second until the first counter reads zero. In the meantime the clock pulses are fed to the second counter so that it now stores a number equal to the time interval. This count can be passed back and forth between the counters as often as may be desired.

A somewhat similar technique was employed to give a record of conversations at a reactor experiment. The object was to keep a record of the conversation as it went along to assist in determining what had happened in case of a mistake. Conversation which was more than $\frac{1}{2}$ hr old could be discarded. This operation is performed with two recorders arranged so that one starts to record before the other reaches the end of its spool. After the spool is full each recorder rewinds and awaits its next turn. Conversations are erased as a new recording is made so that there is always a record of the most recent hour.

A portable ionization chamber survey meter has been built which makes use of an electrometer tube and three transistors. The tube and transistors form a high gain current amplifier with inverse feedback to obtain linearity and fast response. The power supply is five flashlight cells and battery life should be several times as long as that for conventional tube circuits. The instrument is small in size; it is built in a $2 \times 5 \times 6$ in. portable test meter case. The characteristics of germanium transistors vary rapidly with temperature, which is a serious shortcoming for this type of use.

The glass shop, the tube shop, and the calibration laboratory continue to satisfy the needs of the Laboratory in their respective fields. Every year the number and variety of instruments to be repaired by the Division's skilled technicians increases.

The Division has been host for 6 months to an engineer, sent to this country by the Egyptian government, to learn about instrumentation for research. There were also six summer guests in 1954.

ACCELERATORS

By the very nature of its role as a centralized research laboratory, Brookhaven is ideally equipped

to design, construct and maintain large nuclear particle accelerators. At the present time, six accelerators are in active operation and are being used for research purposes, namely, the Cosmotron, 60-inch cyclotron, 18-inch cyclotron, and three electrostatic generators.

During the past year Cosmotron operations were curtailed by a short circuit in one of the main magnet coils. The extensive repairs consumed 6 months of research time. Several important improvements were made on various components of the machine during the repair period and the research efficiency of the accelerator was greatly enhanced. The machine can now reliably produce pulses of about 5×10^{10} protons at the full energy of 3 Bev. Upon resumption of research, the machine was put on three-shift operation which was necessary because of the large number of requests for Cosmotron time.

The cyclotrons and electrostatic generators were operated for research in the fields of physics, biology, chemistry and medicine. Several improvements have been made during the past year on all these accelerators. A pulsing technique has been developed for the 60-inch cyclotron which enables it to produce 1-ma bursts of 22-Mev deuterons at a rate of 1600 pulses per second; the energy of the Physics Department Van de Graaff has been boosted to a maximum value of 3.8 Mev with ion currents of as high as 50 μ amp being available with this machine.

Design and development of the 25-Bev accelerator has continued. In this program, the most outstanding event of the past year was the successful construction and operation of the electron analogue (Figure 1) which demonstrated clearly the practicability of the strong focusing principle. Good progress has been made on the design of the various

Figure 1. Electron analogue with vacuum tank covers removed. Guide and correcting lenses can be seen mounted on the supporting girders.

components of the 30-Bev Alternating Gradient Synchrotron and the AGS building complex. Detailed design of the service building of this complex has been completed, and construction is scheduled to start within the very near future.

ALTERNATING GRADIENT SYNCHROTRON

The major effort of the Accelerator Development Department during the past year has been concentrated on the design of the multi-billion volt, strong focusing proton accelerator. Furthermore, since completion of construction of this Alternating Gradient Synchrotron (AGS) is scheduled for about 1960, most of the Department's work over the next few years will undoubtedly also deal mainly with this machine.

During the year, design and development of the various AGS components made good progress and will be described below under the appropriate headings. At this time design is roughly 50 percent completed and it is expected that it will be in its final stage at the end of the next fiscal year.

Theoretical work was again greatly aided by computations performed on the AEC's New York University Univac installation and on the BNL Remington Rand Electronic Digital Computer. Orbit dynamical studies are continuing.

Toward the end of the fiscal year it became possible to review the design of the accelerator in the light of the last 18 months of theoretical and experimental design and development work. A revised set of parameters was developed (see Table 1) and it can be seen that the additional information obtained during the development period has not caused any alterations of the basic preliminary parameters, which were reported last year.

From the magnet study work it has become evident that it will not be possible to produce usable gradient plateaus above guide field values of 13,000 gauss. Also, data from the electron analogue have given strong indication that design of the AGS has to include many facilities to correct for equilibrium orbit displacement. With these facts in mind, it has been possible to design the lattice structure of the AGS, i.e., arrangement of magnets, correcting magnets, and straight sections. The structure of one of the twelve periods of the lattice is shown in Figure 2.

The information and experience gained during the design effort had made it evident that it would

be highly impractical to build a 25-Bev synchrotron first, and later, in a second step, increase this accelerator's top energy to 35 Bev. Consequently, a new proposal was made to the AEC for the construction of a 33-Bev accelerator which is to be built in essentially one step. This proposal has been approved.

During the year Accelerator Development Department personnel increased by 25 percent and now totals 89, of which 31 are on the scientific and engineering staff. This personnel expansion is according to plan and it is expected that further expansion will take place during the next 2 years. The Department is now housed in seven barracks buildings, with the analogue located in the Cosmotron Test Shack.

Electron Analogue

The construction and assembly of the Electron Analogue (Figure 3), which had been started the previous year, was completed. Several major prob-

Table 1

Parameters for BNL alternating gradient synchrotron

Orbit circumference	2648 ft
Radius of proton orbit	421 ft
Radius of curvature	280 ft
Repetition period	3—4 sec
Rise time	1 sec
Field index, n	350
Peak magnetic field	13 kg
Injection energy	50 Mev
Maximum energy	33.3 Bev
Weight of steel	~3000 tons
Weight of copper	~350 tons
Number of betatron wavelengths per orbit circumference	8.75
Number of super-periods	12
Number of periods	60
Number and effective lengths of magnet	<div> <div>144 magnets 7.83 ft long</div> <div>96 magnets 6.58 ft long</div> </div>
Number and effective lengths of straight sections	<div> <div>144 sections 2 ft long</div> <div>72 sections 5 ft long</div> <div>24 sections 10 ft long</div> </div>
Number of accelerating cavities	24
Number of power amplifier stations	12
Frequency range	1.4—4.4 Mc
Total number of quadrupole correcting magnets	24
Total number of sextupole correcting magnets	24
Total number of magnets arranged for corrective position changes	24

Figure 2. Super-period of AGS lattice structure.

lems had to be overcome. One of these concerned the proper alignment of the guide lens assemblies. After the lens components had been fabricated to the best available manufacturing tolerance, they were assembled and all the eighty completed lens assemblies were gauged. This information was then analyzed and a stacking order was computed which averaged out the effects due to misalignments and reduced them by a factor of one hundred over the effects which would be experienced by the electrons in an unstacked machine. The analytical technique

developed for the stacking order will later on be used to determine the order of the AGS magnet sectors.

Another problem was presented by the original magnitude of the magnetic field found at the equilibrium orbit after machine assembly. Fields up to 300 milligauss were observed. Since only fields of about 50 milligauss could be tolerated by the beam, an extensive degaussing program was instituted. After various attempts, this degaussing program was successful and fields remeasured at 1600 positions

RESONANCE DIAGRAM vs. QUADRUPOLE VOLTAGES

DATA TAKEN FROM ELECTRON ANALOGUE JULY 28, 1955
(WITH OPTIMUM SETTINGS OF KICKERS & SEXTUPOLES)

Figure 4. Diamond experimentally obtained with the electron analogue.

along the equilibrium orbit revealed that the rms field value after degaussing was only about 20 milligauss. The vacuum pumps were then turned on and no difficulties were encountered in getting the required pressure of about 5×10^{-7} mm of Hg. On March 28, 1955 injection was attempted and within hours an electron beam was observed to circulate, without acceleration, for about 2–3 milliseconds (equivalent to 14,000–21,000 revolutions).

Following this first successful operation of a strong focusing device, considerable time was spent to standardize conditions for optimum machine operation. The Van de Graaff beam was matched to the analogue acceptance conditions, inflection was stabilized, injection optics were simplified, the observation pickup electrode system was extended, and a system of kicker electrodes was installed. These modifications, changes, and additions produced a machine which now operates very reliably.

The first problem to be studied with the analogue concerned resonances. By means of a system of quadrupoles the betatron wavelength was changed and the operating region of the necktie diagram was scanned. Figure 4 shows an experimentally determined resonant diamond which demonstrates the existence of integral, half-integral, one-third integral, and sum resonances. The observed inter-resonance spacings are in excellent agreement with the theoretical predictions. Attempts have been made to cross these resonances dynamically. At this time it appears that it is not possible to cross integral and sum resonances. Some loss of beam intensity is observed when half and one-third integral resonances are crossed.

As soon as the experiments with the coasting electron beam have been completed, acceleration will be started and passage through the phase transition region will be attempted.

Magnet and Magnet Power Supply

The magnet program continued along the logical lines of development. A new measuring and testing laboratory was set up in a barracks-type structure having a concrete floor slab, so that measurements could be made to accuracies of a fraction of one percent. Here measurements on the second dc model were continued. New pole face contours were designed on the basis of experimental data and relaxation method computations. These new poles were then constructed and incorporated in Model No. 2.

The results came up to expectations in that this model produced usable gradient plateaus up to fields of about 12,500 gauss, which was about 1000 gauss higher than in any previous models.

Simultaneously with this measurement program, the first dynamic magnet model was designed and fabricated (see Figure 5). This model consists of two 3-ft. long, 1-in. laminated sectors having a cross section which is about full scale (30×36 in.). Two sets of coils and power supplies were designed for this model. A 144-turn coil and ignitron power supply was designed and built to cycle the magnet up to peak field values for studies of dynamic n values and fringing fields. A 32-turn coil, which corresponds in number of turns to the contemplated final AGS coil, and a 2-farad, 50-volt condenser bank supply have been designed and are now under construction. They will be used to cycle the magnets up to fields of only 1000 gauss for investigations of eddy currents in the core, coil, and vacuum chamber wall. A fourth magnet model has been designed and is now being built. This model is similar to the dynamic model described above, except that it will consist of 0.35-in. laminations.

A complete set of dynamic magnetic measuring equipment was designed, and has been built. Included in this array of instrumentation are a time and current marker system, a dynamic n meter and facilities to measure dynamic flux, field, magnet coil voltage and current values.

A very thorough study of the magnetic characteristics of various types of steel was started. Samples are being supplied by various steel manufacturers and are being tested by the magnet group. Preliminary arrangements also have been made to check the variations of samples coming from various stages and locations of a production run of sheet and plate steel.

It has been possible, from existing magnet data, to set up the general specifications of the magnet power supply. This supply will probably be similar to the one now being used by the Cosmotron in that it will consist of an induction motor, a set of flywheels, and a 12-phase alternator which will put out approximately 4100 volts at a power level of about 25,000 kw. Rectification will be handled by an ignitron bank. Preliminary discussions about the detail design and construction of this power supply have been started with various manufacturers of power equipment. However, the exact specifications

Figure 5. Magnet Model No. 3. The cross section of these model magnets is approximately equal to the cross section of the final AGS magnets.

of this supply cannot be set until the final design of the magnet has been determined.

Linear Accelerator

The major problem confronting the linac group is the determination of the type of linear accelerator structure which is to be used in the 50-Mev injector for the proton synchrotron. The criteria which will determine this selection are a) power consumption and b) mechanical simplicity and stability. Four linac structures are under consideration, three of which were developed at BNL and utilize traveling waves, and one which has been successfully used at Berkeley and is of the standing wave type. As the characteristics of the Alvarez type of machine at Berkeley are well known, they are being used as a standard for comparison. Many models and mock-ups have been built of the BNL designs, which have been named "interdigital," "organ-pipe," and "coupled cavity" structures. These test structures are being used to investigate the propagation characteristics of the traveling waves. These studies are now coming to an end and it is expected that the decision on the ultimate linac structure will be made in the very near future.

A model ion source has been built to supply protons for an interdigital linac model which will actually accelerate these ions. The protons produced in the source are preaccelerated to an energy of 90 kev and a pulsed (100 μ sec long pulses) beam of 1.5 ma has been obtained. The accelerating linac model, named the "preliminac," has been designed and is now being assembled. It is 4 ft long and consists of 46 drift tubes which will accelerate the 90-kev preaccelerated protons to 110 kev. The preliminac's rf system consists of a power-oscillator which operates at a scaled-down frequency of 90 Mc. A "magic

Figure 6. Iron powder pattern showing magnetic field produced by a ferroxdure quadrupole magnet.

T" power recirculation system, which is being considered for the 50-Mev linac, has been built for application with the preliminac.

Development of the linac's rf power system has started. A review of power sources made it evident that a 5-Mw, 200-Mc klystron would produce by far the simplest power supply system. As no such tubes are commercially available, discussions with the tube manufacturers are now in progress to investigate the possibilities of developing a 200-Mc klystron. A development of this type is, however, uncertain and consequently a supply using EIMAC 3W10,000A power triodes has been designed and is now under consideration. A model triode power oscillator amplifier, which utilizes the EIMAC tube, has been constructed and is now being tested.

Permanent magnet quadrupole rings are still being considered as strong focusing devices for the linac beam (see Figure 6). Cunico, alnico, indox, and

ferroxdure rings have been magnetized with a one-turn coil which has been energized by current pulses of as high as 100,000 amp. Gradients up to 1000 gauss/cm have been obtained.

Structures

The foundation of the AGS magnet is without doubt the most critical component of the AGS structure complex. Extreme stability of the order of 0.010—0.020 in. is required in order to insure successful operation of the synchrotron. The type of foundation required depends strongly upon the character of sub-surface soil. Consequently, it was necessary to start a thorough program of soil mechanical exploration.

First, a site for the machine was chosen on the basis of:

- minimum variation of ground elevation over the area which is to be covered by the machine
- proximity to central BNL facilities
- proximity to present utility lines
- radiation safety for the rest of the Laboratory.

Plans now call for erection of the accelerator on a site located about 1200 ft NW of the reactor com-

plex and about 1200 ft NE of the Cosmotron complex. Immediately after the location of the AGS site, test borings, soil loading tests, soil analyses, and year-round soil temperature recordings were started. These tests were finished during the year and the Stone and Webster Engineering Corporation, which is the architect-engineering firm for the structures, in conjunction with members of the ADD mechanical engineering staff recommended that the magnet be located on a steel girder which is to be supported on 40-ft long piles. The magnet group has now started experiments to check whether such a steel girder would have adverse effects on the accelerator's magnetic field.

The general layout of the AGS complex was determined; it is shown in Figure 7. At this time the AGS service building has been completely designed. This structure will house the staff and departmental offices, electronics and machine shops, physics, chemistry and electronics laboratories, a large assembly area, the AGS control room, and the AGS power room. Construction is expected to start in September 1955, and occupancy is planned for late in 1956.

An expansion of the BNL steam facilities, including an extension of the Laboratory's boiler house, was made necessary by the advent of the AGS. Construction of this extra facility is well under way and the boiler is expected to be in operation this coming winter.

COSMOTRON

Two years of operation have revealed and corrected most of the weak points in the design of the Cosmotron and produced an experienced operating group. As a result the performance of the machine is remarkably good. An experiment once scheduled now has about 80 percent chance of taking place. The intensity has been increased to about 5×10^{10} protons per pulse at the full energy of 3 Bev.

Proton synchrotrons because of their size and nature can be extremely versatile and the full utilization of the machines requires a complete understanding of their operating characteristics. For this reason about 10 percent of the Cosmotron's running time is assigned to the study and improvement of the Cosmotron itself.

Experimenters continue to request more Cosmotron time than is available. This situation has been met but not solved by three-shift operation, by sched-

Figure 7. Schematic layout of AGS structures.

uling experiments to run concurrently, and encouraging types of experiments which utilize a relatively small amount of running time. This problem is still a most difficult one.

During the afternoon of November 5, 1954 while proton and meson beams were supplying three cloud chambers, a short circuit developed in Quadrant No. 2 of the Cosmotron. This failure was accompanied by an unusual noise and a moderate amount of smoke. The operator stopped magnet pulsing and with the aid of others, extinguished a small fire at one end of the quadrant. The cause of the short was a small water leak in one of the copper cooling tubes which is brazed into the end of the copper bars. Very little external damage was visible but it was clear the copper conductor bars would have to be removed from the second quadrant. This task has been done but since the repair required dismantling almost the entire quadrant it was nearly 6 months before normal operation for research purposes was re-established. The cost of this repair was mainly the loss of 6 months' operation at a time when a large and important experimental program was under way. Although this loss was a serious one, it was partly mitigated by improvements which it was possible to make during the period of enforced shutdown.

- 1) The vacuum chamber which was removed has been modified to provide an exit port for a deflected internal proton beam to emerge at this point. The intensity of the external beam should then be a large proportion of the internal one.
- 2) The high and low level rf systems have been modified in the light of past experience for a threefold increase in intensity and greatly improved stability of operation.
- 3) An experimental distribution system has been installed to avoid the confusion of individually laid cables which existed before the shutdown. It has markedly increased the ease of setting up counter experiments at different points about the Cosmotron.
- 4) Two of the fore pumps inside the magnet ring have been relocated to provide space for the K-meson beam setup and the deflecting magnet for the external proton beam.
- 5) A dynamic beam attenuator has been added to the low level rf system which reduces the circulating protons to any determined value and maintains this intensity from pulse to

pulse to a few percent. The result is a very constant beam intensity of considerable benefit to all experiments which do not require maximum intensity.

- 6) Additional shielding was procured and incorporated in a new arrangement which will permit the use of external proton and meson beams.

The large strong focusing magnet pair is now in use. This is a pair of large four-pole electromagnets weighing in all about 15 tons. Its purpose is to focus high energy beams originating in the Cosmotron to a point outside the shield. It has been used to obtain a high intensity, high energy pion beam outside the shield. In addition to this facility, there are now available three large electromagnets with flat pole pairs 18×36 in. These magnets are frequently all in use in connection with the several experiments being run simultaneously.

After a careful study of various sources of supply of liquid hydrogen, an order has been placed with the US Bureau of Standards at Boulder, Colorado for a 50-liter/hour liquifier. A separate building to house this unit is being planned.

The operating staff has increased by 6 during the past year and now stands at 73.

RESEARCH ELECTROSTATIC GENERATOR

Since the completion of the rebuilding of this generator and the incorporation of the beryllium-lead geometry at the anode end of the acceleration tube, the machine has operated very satisfactorily at energies up to 4.1 Mev. The generator has been used with proton and deuteron beams for a number of charged particle nuclear excitation researches as well as for some neutron research. The energy stability, without the use of the electrostatic analyzer, is about ± 5 kev which has been adequate for these researches.

18-INCH CYCLOTRON

By time-of-flight techniques, the energy of the protons accelerated in the 18-inch cyclotron has been measured and the energy spread of the phase grouped particles determined. These measurements indicate that the protons arriving at a target have an energy spread of less than 1 percent about the mean value of 2.5 Mev. The proton beam has been partially focused on a target 15 ft distant from the exit port

of the cyclotron chamber. Target currents up to 150 μ amp have been obtained on a 3/4-in. square area. A technique has been developed whereby thin Zr films of less than 1 mg/cm² can be successfully deposited on copper to make it possible to have available well cooled TZr targets for the proton beam.

60-INCH CYCLOTRON

Within the first quarter of this year, a satisfactory focused beam was obtained at a distance of 20 ft from the target chamber of the cyclotron. A beam of 5 μ amp through a 1/2-in. hole can be consistently maintained at this distance with either 10-Mev protons, 20-Mev deuterons, or 40-Mev alpha particles. As much as 2 μ amp through a 1/8-in. hole has been obtained on a target at the end of the 20-ft beam pipe. Change-over from operation with one of these beams to any other can be accomplished in a matter of minutes.

The technique of pulsing the cyclotron arc has been improved. The operating beam now consists of 1-ma bursts of 22-Mev deuterons on an external target at a repetition rate of 1600 pulses per second. The pulses are of 0.5- μ sec duration.

The machine has operated with a very high degree of reliability and has been used for charged particle researches by members of the Physics, Chemistry and Biology Departments as well as by some visitors from outside the Laboratory. Some of the machine time is used for neutron cross section measurements by the time-of-flight technique and some time is used for the production of radioactive isotopes.

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; molecular structure and solid state.

NUCLEAR CHEMISTRY

Nuclear Reactions

Studies of nuclear reactions induced by protons in the Bev energy range continued throughout that part of the past year during which Cosmotron beams

were available. The emphasis in this work has gradually shifted from surveys of the over-all yield patterns of product nuclides obtained with representative target elements (such as Al, Cu, Pb) to more specific studies of particular processes. Among the latter are investigations of excitation functions and studies of the ranges and angular distributions of some radioactive products.

A preliminary survey of excitation functions for about 30 products of the proton bombardments of Pb and Bi has been completed. At 3.0 Bev the yield data together with some recoil studies indicate that the spallation or boiling-off process leads to high yields of products 20 to 80 mass numbers below the target mass. Very large energy transfers from the bombarding proton to the target nucleus are thus indicated. This is consistent with a mechanism of energy deposition developed earlier in this work which is based on the creation, scattering and re-absorption of mesons within the same nucleus. Data on the cross sections for the production and interaction of mesons indicate that this mechanism is qualitatively sufficient to account for the indicated energy transfers.

The fission peak of neutron-excess products of about half the target mass which was seen in 0.34-Bev work on Bi has virtually disappeared at 3.0 Bev. Cross sections for these nuclides decline with increasing energies, as shown in the typical excitation functions of Figure 1. Apparently this type of fission requires relatively little excitation energy and it thus becomes relatively less probable as the spectrum of the energy deposition in the target nucleus

Figure 1. Excitation functions of neutron-excess products from the proton bombardment of lead.

moves to higher values with increasing bombarding energy. By contrast, however, the yields of neutron-deficient medium mass products, and, more especially, of products in the region $15 < A < 40$, increase sharply at the higher energies (Figures 2 and 3). Although these reactions seem to be associated with large energy transfers, the mechanism by which the excitation energy is dissipated to form these products is not understood. It is hoped that measure-

Figure 2. Excitation functions of neutron-deficient products from the proton bombardment of lead.

Figure 3. Excitation functions of light nuclei produced by proton bombardment of lead.

ments now being made on the range and angular distribution of these products will shed some light on the mechanism of this type of nuclear reaction.

The emission of very light nuclei from bombarded targets has received increased attention. In particular, a study has been made of the production of tritium; this is of interest not only from the standpoint of nuclear reaction mechanisms, but also in connection with attempts to account for tritium found in nature. Cross sections starting at about 14 mb for C and increasing monotonically to about 0.5 b for Pb were found for the tritium production from targets bombarded with 2-Bev protons. An investigation of the emission of He^6 and Li^8 fragments is also in progress. A photographic plate technique is being used to detect the Li^8 by means of its characteristic hammer tracks. Preliminary results for Al bombarded with 2.2-Bev protons indicate that approximately 50 percent of the Li^8 fragments have energies above 15 Mev and that approximately 8 percent are more energetic than 40 Mev. The overall ratio of Li^8 emission at 45° to the beam axis to that at 135° is about 2.

The study of the range and angular distribution of reaction products is expected to aid in the clarification of reaction mechanisms. In addition to the study of Li^8 already mentioned, the angular distributions of Na^{24} from the $\text{Al}(p,3p)\text{Na}^{24}$ reaction at 0.38 and at 2.2 Bev have been measured. A preliminary evaluation of the results suggests that, as expected, they are consistent with a mechanism of knock-on followed by evaporation. This experiment has been of special value as a preliminary to the more difficult study of the range and angular distribution of Na^{24} from Pb that is now in progress.

The earlier survey of the reactions of Cu with 2.2-Bev protons has been followed up by the determination of the excitation functions for a few particular products shown in Figure 4. The general tendency for yields to rise to their maximum value at higher energies for products farther removed from the target is again consistent with the high and increasing energy transfers predicted by the meson production and reabsorption model.

A program to study some relatively simple reactions occurring in the Bev energy range is continuing. It appears that reactions such as the (p,pn) process in F and C and some slightly more complex reactions in Al have cross sections which are relatively independent of the bombarding energy. On

Figure 4. Excitation functions of products from the proton bombardment of copper.

the other hand, preliminary data show that for similar reactions in heavier target elements the excitation functions tend to decline with increasing energy. A plausible explanation of these observations is that mesons created in the nucleus at higher bombardment energies have a smaller chance of being reabsorbed in the nucleus if it is small. This means that the likelihood of depositing only a small amount of excitation energy would decrease less rapidly with increasing energy in the smaller nuclei than in the larger nuclei. Since the occurrence of simple reactions is presumably dependent on the presence of only a small amount of excitation energy, the corresponding excitation functions would then be expected to be more constant in the case of smaller nuclei.

It is of interest to learn whether at high proton energies, such simple reactions as (p,pn) take place by a knock-on mechanism with the emission of two fast nucleons, or whether the second nucleon is "evaporated" after the deposition of excitation energy in the initial collision. To provide information on this point, the (p,pn) and (p,2p) reactions on Ce^{142} were studied with protons of energies 0.38 and 1.0 BeV. For a pure knock-on mechanism the ratio

of formation cross sections $\sigma_{\text{Ce}^{141}}/\sigma_{\text{La}^{141}}$ should be approximately equal to the neutron-to-proton ratio in the target nucleus, Ce^{142} , which is 1.45. If the reaction involves the evaporation of a second particle from an excited Ce^{142} nucleus, a larger value is to be expected for the ratio of cross sections, owing to the greater ease of evaporation of neutrons. The data obtained are presented in Table 1. To determine the relative probabilities of neutron and proton evaporation from a Ce^{142} compound nucleus, the excitation curves for the reactions $\text{Ba}^{138}(\alpha,n)\text{Ce}^{141}$ and $\text{Ba}^{130}(\alpha,p)\text{La}^{141}$ were measured with 10- to 40-Mev alpha particles. Between 25 Mev and 40 Mev the ratio $\sigma_{\text{Ce}^{141}}/\sigma_{\text{La}^{141}}$ varies between 3 and 4. It is thus concluded that, at least at 0.38 BeV, the mechanism for (p,pn) and (p,2n) reactions is predominantly knock-on.

Another study of competitive nuclear reactions also arose from the desire to understand the general features of high-energy-induced nucleon evaporation. In particular, it had been hypothesized that the large ratio of the formation cross sections for Mn^{52} to those for Fe^{52} observed in several high energy nuclear reactions might be interpreted in terms of the evaporation of nucleons from excited nuclei. This hypothesis has been examined by investigation of the relative probabilities of the loss of a proton and a neutron as compared with the loss of two neutrons from excited Fe^{54} nuclei. Chromium-50 in normal chromium was bombarded with alpha particles of various energies up to 40 Mev. The excitation functions for the reactions $\text{Cr}^{50}(\alpha,2n)\text{Fe}^{52}$, $\text{Cr}^{50}(\alpha,pn)\text{Mn}^{52}$, and $\text{Cr}^{50}(\alpha,pn)\text{Mn}^{52m}$ are shown in Figure 5. The relative formation cross sections for these three species are seen to stay approximately constant from threshold to 40 Mev and are remarkably close to those found in bombardments of various target elements (Fe, Co, Cu, Zn, As) with protons of energies between 300 Mev and 2 BeV. The surprisingly large ratio of (α,pn) to ($\alpha,2n$) cross sections

Table 1
Cross sections for the formation of Ce^{141} and La^{141} from proton bombardment of Ce^{142}

Proton energy (Bev)	$\sigma_{\text{Ce}^{141}}$ (mb)	$\sigma_{\text{La}^{141}}$ (mb)	$\frac{\sigma_{\text{Ce}^{141}}}{\sigma_{\text{La}^{141}}}$
0.38	87.3	57.7	1.53
1.00	31.6	17.4	1.80

Figure 5. Excitation functions for α -induced reactions on Cr^{50} .

is interpreted as indicating an energy level density in the odd-odd nucleus Mn^{52} which is substantially larger than that in the even-even Fe^{52} for a given excitation above the ground state. The conclusion is that this level density effect governs the relative probability of neutron and proton evaporation and is considerably more important than the coulomb barrier, which hinders proton emission.

The cross section of Ra^{223} (actinium X, half-life 11.7 days) for radiative capture of pile neutrons was determined to be 125 ± 15 . For this study, a rapid and efficient separation for lead from radium was developed and the alpha activity arising from the lead isotopes of mass 211 and 212 was followed. From the ratio of these activities, the ratio Ra^{223} to Ra^{224} could be estimated and thus the cross section for neutron capture in Ra^{223} .

Decay Schemes

The past year has seen the completion of studies of the decay schemes of several more radionuclides. These include Rb^{83} , Rb^{84} , Ge^{75} , and Se^{75} . Information has been obtained on the ratios of K-capture to positron for first forbidden transitions, on the relative probability of L- to K-electron capture and on certain limitations of the single-particle shell model.

Most of the measurements were made with a gray wedge coincidence scintillation spectrometer.

The decay scheme of Rb^{84} is shown in Figure 6. The ratios of K-capture to positron emission for the transition to the 0.89-Mev level ($\Delta I=0$, yes) and to the Kr^{84} ground state ($\Delta I=2$, yes) are 5.15 ± 0.38 and 2.06 ± 0.36 , respectively. These values are in qualitative agreement with theory. Theoretical calculations are in progress which will permit quantitative comparisons. The L-/K- capture ratio in the decay to the 0.89-Mev level was found to be 0.12 ± 0.05 , if a value of 0.65 is used for the fluorescence yield of krypton.

Because of the difficulty of preparing Rb^{84} sources completely free of Rb^{83} contamination, the disintegration scheme of Rb^{83} was also studied. The decay of Rb^{83} has been determined to proceed by electron capture to an excited state of Kr^{83} which is 0.566

Figure 6. The decay scheme of Rb^{84} .

Figure 7. Energy level scheme of As^{75} . Level and transition energies are given in kev.

Mev above the ground state. The excited state is depopulated exclusively by emission of a 0.525-Mev gamma ray (M1) to the 0.041-Mev state, Kr^{83m} . Little or no electron capture directly to the 0.041-Mev level or to lower levels occurs. The spin-parity designation of the 0.566-Mev state is $p_{3/2}$, and that of the Rb^{83} ground state is $f_{3/2}$.

The most elaborate investigation undertaken was that of the decay schemes of Se^{75} and Ge^{75} (Figure 7). In this case a magnetic lens spectrometer and a permanent magnet spectrograph were employed in addition to a scintillation spectrometer. From measurements of internal conversion coefficients and gamma-gamma angular correlations, information was obtained on the multipole character of most of the gamma transitions. The evidence indicates that most of the levels of As^{75} have spin 1/2 or 3/2 and that they are not single-particle shell model states.

New Radionuclides

Some of the radiochemical experiments of the past year resulted in the discovery of three nuclides: Zn^{61} , Tl^{195} , and Tc^{98} . The first of these was pre-

pared by bombarding nickel with 18-Mev alpha particles. Zinc was separated and purified and then milked periodically for Cu activities. The known 200-min Cu^{61} was observed to grow from a new Zn isotope which decays with a half-life of 1.5 ± 0.1 min by emission of 4.5 ± 0.5 -Mev positrons. No gamma rays were observed except the 511-kev annihilation radiation.

The work on light isotopes of Tl, including Tl^{195} , was undertaken because these nuclides are important for spallation studies of heavy elements at Cosmotron energies. The Tl^{195} was produced by deuteron bombardment of mercury enriched in the isotope of mass 196. Identification was made by successive milkings of the known 9.5-hr Hg^{195} from the chemically separated Tl fraction. The half-life was determined as 1.2 ± 0.1 hr. In similar experiments the assignment and half-life (2.8 ± 0.2 hr) of Tl^{197} were confirmed. Measurements of the radiations from the thallium fractions revealed several new gamma rays associated with the decay of Tl^{198m} . These show that the ratio of orbital electron capture to isomeric transition in Tl^{198m} is about 1.5.

The experimental work on Tc^{98} is being carried out in two ways. Both are related to the question of the occurrence of technetium in nature, and both investigations are still incomplete. One approach is to search for a long-lived Tc^{98} in concentrates of certain minerals (columbite, chromite, thortveitite, and yttrotantalite). Twelve of these concentrates were highly purified, irradiated in the Brookhaven pile, and finally examined for the 140-kev gamma rays of 6.0-hr Tc^{99m} . The Tc^{99m} may be formed by the (n, γ) process on any possible Tc^{98} . Of the twelve concentrates, seven gave positive results, two negative results, and three uncertain results. Further work is in progress at the University of Chicago to establish unequivocally whether the positive results indicate the occurrence of a long-lived Tc^{98} in nature, or whether they are due to interfering impurities.

The alternative approach to this problem is to produce Tc^{98} by a nuclear reaction and then determine the properties of this nuclide. Indeed, a new isotope of technetium was found in a sample of ruthenium which was subjected to a long, intense neutron irradiation in the Materials Testing Reactor at Arco, Idaho. The principal radiations of this isotope are 300-kev beta rays followed by 0.74-Mev and 0.65-Mev gamma rays in cascade. The mass is not yet definitely established but evidence, from beta

decay systematics and from certain regularities observed in even-even nuclei, strongly suggests that mass 98 is the correct assignment. The half-life was estimated by comparing the amount of the new activity with that of Tc^{99} (2.1×10^5 yr) which was observed in the same sample. A value of $\sim 10^4$ yr was computed by assuming that both Tc isotopes were produced by (n,p) reactions on the corresponding ruthenium isotopes. If any reasonable alternative assumptions are made, the half-life must still be lower than 10^5 yr. This is far below 2×10^8 yr, the minimum value required for the survival of a nuclide in nature since the formation of the elements. Further work is continuing at Brookhaven on the mass assignment, half-life, and neutron cross section.

Chlorine-36 in Nature

The 308,000-yr half-life chlorine isotope, chlorine-36, has been detected in nature. On the basis of estimations of the amount of Cl^{36} activity induced by cosmic ray neutrons and neutrons from small amounts of uranium and thorium in the materials studied, it is concluded that the activity arises from cosmic ray neutrons. The chlorine was counted as ammonium chloride in the usual low level screen wall counter. The chloride was isolated from four natural sources: a phonolite rock from Cripple Creek, Colorado; a syenite rock from Red Hill, New Hampshire; Great Salt Lake water; and Atlantic Ocean water. Each sample was purified to constant specific activity by evolving HCl from the chloride

and dissolving the HCl in ammonia prepared from tank ammonia. The results appear in Table 2. The phonolite contains a measurable amount of activity while the other samples contain less activity than the minimum detectable with the counter used. The Cripple Creek phonolite is a durable rock located at high altitude in an area free from glacial erosion. The specific disintegration rate measured leads to the conclusion that this rock has been on the surface $24,000 \pm 4000$ yr. The syenite rock from New Hampshire is a relatively easily eroded rock from a low altitude and an area glaciated in Wisconsin time. The activity is less than detectable, which suggests that this rock had been on the surface for less than 10,000 yr.

The specific disintegration rate of chlorine derived from the Atlantic Ocean was as low as that of any sample studied. On the basis of the cosmic ray neutron production rate, one estimates that the Cl^{36} content of sea water should be far below the amount detectable. The observations on chlorine from Great Salt Lake also show the Cl^{36} content to be below detectability. The salt in Great Salt Lake is derived from two sources, fresh water rivers and littoral springs that leach saline material from the sediments. The relative amounts of chloride brought into the Lake by these two sources are difficult to determine quantitatively. If the chloride is brought into the Lake by river water derived from the weathering of surface rocks, it might contain Cl^{36} . Surface rocks at 5000 to 10,000 ft elevation would contain 1 to 2

Table 2
Counting data obtained on samples of chlorine derived from various natural sources

Origin of chlorine	Weight NH_4Cl on liner (g)	Counting rate above Atlantic Ocean reference standard* (cts/min)	Specific activity (dis/min/g Cl)
Atlantic Ocean	15.0	$-0.06 \pm .03$	$-0.02 \pm .01$
Phonolite, Bull Cliff, Cripple Creek, Colorado	19.8	$0.37 \pm .05$	$0.12 \pm .02$
Nepheline-sodalite syenite, Red Hill, New Hampshire, surface sample	34.6	$0.01 \pm .04$	$0.00 \pm .01$
Nepheline-sodalite syenite, Red Hill, New Hampshire, sample from 8 ft below the surface	36.1	$-0.06 \pm .03$	$-0.01 \pm .01$

*Reference liner contained 16.4g of ammonium chloride.

counts $\text{min}^{-1} \text{g}^{-1}$ of chlorine at saturation. The measurement shows that the level of activity is below saturation by a factor of 100. An explanation of this result may be simply that erosion is greatest in the vicinity of a stream bed and at these locations the Cl^{36} activity level would be far below the saturation value.

Extranuclear Effects in Argon - 37 Decay

Theoretical calculations have been made of the effect of an Auger process on the other electrons in an atom. The change in the effective nuclear charge seen by the other electrons as a result of the Auger process may act as a sudden perturbation on these electrons and induce transitions to higher states. These transitions may all lead to additional ionization of the atom either directly or by Auger processes, previously not possible, after excitation to the higher bound states. The electron capture decay of A^{37} gives rise to chlorine ions having a spectrum of positive charge, which has recently been measured by Snell and Pleasanton. They observed measurable abundances of Cl^{+6} and Cl^{+7} , while conventional Auger theory permits only a maximum charge of plus five on the chlorine atom. This observation may be explained on the basis of the above theoretical considerations if the probability of exciting 3s and 3p electrons is 0.20. The above calculations lead to a value of 0.12 for this probability, which, in view of the approximate wave function employed, must be regarded as satisfactory agreement. It is possible, as pointed out by Snell and Pleasanton, that Auger processes entirely within the M shell, which are not conventionally considered, may contribute toward the production of the high charges.

The pulse height spectrum in a proportional counter produced by the electron capture decay of A^{37} has been analyzed, as was reported previously. The spectrum consists mainly of one peak, centered at 2.83 keV, the K binding energy of chlorine. The processes giving rise to peaks in the region between 5.4 and 9.7 keV have been interpreted as K-electron excitation and ejection as a result of the sudden perturbation due to the K-capture. The theoretical value for this process has been calculated by Primakoff and Porter to be 2.8×10^{-4} . Theoretical calculations have now been made on L-electron excitation processes accompanying K-capture and K-electron excitation processes accompanying L-capture. These processes raise the probability per decay for acts giv-

ing rise to pulses in the energy region of interest to 3.4×10^{-4} compared to the experimental value of 3.9×10^{-4} . These additional processes also tend to bring into better agreement the theoretical and experimental distribution in energy of the pulses.

Neutrino Detection

An experiment is in progress to detect the neutrino by an inverse beta process. The accepted theory of beta decay predicts the occurrence (with very small cross section) of a process which is essentially the inverse of beta decay, that is, a process in which a neutrino enters a nucleus and an electron (or positron) is emitted. The cross section for such a process can be accurately calculated for particular cases. Recently investigators at the Los Alamos Laboratory have reported observation of the inverse of the beta decay of the neutron with approximately the calculated cross section (Reines and Cowan, 1953). A question which has not been resolved and which the present experiment should answer is whether the neutrino (ν) emitted in positron and electron capture decay and the antineutrino ($\bar{\nu}$) emitted in negative beta decay are identical. Only if they are should it be possible to induce the inverse of electron capture decay with antineutrinos originating from beta decay.

The reaction studied in the present experiment is the inverse of the electron capture decay of A^{37} which may be represented as $\text{Cl}^{37}(\bar{\nu}, e^-)\text{A}^{37}$. The experiment involves irradiating a large volume of carbon tetrachloride (1000 gallons) with the intense antineutrino flux from a nuclear reactor. The radioactive A^{37} , along with carrier argon, is removed from the carbon tetrachloride by sweeping the liquid with helium gas. The argon is removed from the helium gas stream, chemically purified and placed in a low background counter to observe the A^{37} radioactivity (34-day K-capture). The experiments to date set an upper limit to the cross section of $1 \times 10^{-43} \text{ cm}^2$ per atom for the reaction $\text{Cl}^{37}(\bar{\nu}, e^-)\text{A}^{37}$ for fission product antineutrinos. The theoretically expected cross section for the reaction is $4 \times 10^{-45} \text{ cm}^2$ per atom (if $\nu \equiv \bar{\nu}$). In order to improve the present experiment to the point where it is possible to measure the theoretically expected cross section, it will be necessary to shield the containers from cosmic radiation and use a higher flux of antineutrinos than is available at Brookhaven. These conditions of cosmic ray shielding and flux are available at the Savannah

River Plant. Arrangements are being made with the AEC and DuPont Company to carry out an irradiation at this location.

CHEMISTRY AND APPLICATIONS OF CHEMISTRY

Thermodynamics of Mixed Isotope Systems

One of the most useful empirical relationships in isotope chemistry is the rule of the geometric mean. This states that the vapor pressure of the mixed isotopic molecule $XY_{n-z}Y'_z$ can be expressed in terms of the vapor pressures of the isotopically pure species XY_n and XY'_n by the equation:

$$P^n(XY_{n-z}Y'_z) = P^{n-z}(XY_n)P^z(XY'_n).$$

Similarly the equilibrium constant for the isotopic exchange reaction

is given by the classical value, determined only by symmetry numbers. A rigorous proof of this hitherto empirical law has been derived for the case of molecules subject to small quantum corrections. Expressions for partition functions and other thermodynamic properties of such molecules have been derived. It is found that the differences in thermodynamic properties of isotopic species subject to small quantum corrections depend on the masses of the isotopic atoms and are independent of all other masses. By the use of suitable corrections, the method can be extended to give approximate thermodynamic functions for systems with larger quantum corrections.

The isotopic fractionation of hydrogen during the freezing of ice or the melting of water is of some geochemical interest. Several discordant experimental results are reported in the literature, both for natural ice samples and for laboratory experiments. By the use of standard thermodynamic considerations pertaining to ideal solutions, the rule of the geometric mean, and available thermochemical data for H_2O and D_2O , the hydrogen fractionation between ice and water has been calculated. It is found that at $0^\circ C$ the ice is enriched in deuterium by 1.92 percent compared to the water with which it is in equilibrium. The enrichment in ice from sea water is calculated to be 1.95 percent. While natural processes may not occur under equilibrium conditions,

the equilibrium enrichment value should be useful in interpreting observed fractionations.

Kinetic Studies

The reactions between hydrogen and halogens have always been of great interest in the field of chemical kinetics. A theoretical study of the H_2Cl transition complex has been made by the consideration of experimental hydrogen isotope effects. The parameters of the transition state have been in part calculated *a priori* and in part evaluated from data on the relative rates of reaction of chlorine atoms with H_2 and HT molecules. The temperature-independent term in the ratio of rate constants is relatively insensitive to the transition state geometry and is calculated *a priori*. Of the three transition state frequencies, two are estimated and one is obtained from experimental data at a single temperature. The calculated ratio of isotopic rate constants as a function of temperature is in fairly good agreement with the observed ratio under the assumption of either a linear or a triangular transition state configuration

Figure 8. Relative rates of reaction of the isotopic hydrogen molecules with chlorine atoms as a function of temperature. Solid lines calculated for an isosceles triangular H_2Cl complex, $\omega_1 = 1002 \text{ cm}^{-1}$.

Figure 9. Relative rates of reaction of the isotopic hydrogen molecules with chlorine atoms as a function of temperature. Solid lines calculated for a linear H_2Cl complex, $\omega_2 = 1460 \text{ cm}^{-1}$.

(Figures 8 and 9). By the same procedure, calculations have also been made for the rates of reaction of chlorine atoms with HD and D_2 compared with H_2 . The results suggest that new experiments with these species would serve as a valuable check on the theory.

The C^{13} isotope effect in the rate of decarboxylation of sodium trinitrobenzoate in water and 90 percent ethanol has been measured at different temperatures. This reaction is interesting in that the rate increases a thousand-fold from water to ethanol as

a solvent. The results of this work are given in Table 3 (where k and k' are rate constants for the C^{12} and C^{13} species). At 50° , the isotope effect in ethanol is significantly lower than that in water. The participation of a proton in the transition state has been ruled out in both solvents by a comparison of the rate in normal and deuterated solvents. A possible explanation of the solvent effect is that a resonance form which involves charge separation and gives some double bond character to the C-COOH bond is stabilized in the solvent of higher dielectric constant.

Experiments have been continued on the tritium isotope effect in the isomerization of cyclopropane to propylene. The object of these experiments was to confirm the Lindemann theory of collisional activation in unimolecular reactions by measuring the pressure dependence of an isotope effect. The Lindemann mechanism may be written

in which M is any second gas molecule and the asterisk refers to an activated species. This mechanism predicts that the isotope effect should decrease with decreasing pressure if the rate constants a and b are the same for the two isotopic species. The experimental points of Figure 10 are in qualitative agreement with this prediction. The curves shown in the figure are calculated from the Lindemann mechanism by using alternative choices of the ratio of rate constants b/c and are fitted to the experimental isotope effect at high pressure. In further confirmation of the theory, the addition of inert gas

Table 3

Rate constants for the decarboxylation of sodium trinitrobenzoate

Rate constants	T($^\circ\text{C}$)		
	30.0	50.0	79.8
$k, \text{sec}^{-1} \times 10^7 (\text{H}_2\text{O})$		5.6	
$k, \text{sec}^{-1} \times 10^7$ (90% EtOH—10% H_2O)		2700	
$k/k' (\text{H}_2\text{O})$	—	1.0379 ± 0.0007	1.0340 ± 0.0006
$k/k' (90\% \text{ EtOH})$	1.0370 ± 0.0010	1.0338 ± 0.0004	—

Figure 10. Tritium isotope effect in the isomerization of cyclopropane to propylene. ($\epsilon = 1 - k_{\text{labeled}}/k_{\text{normal}}$).

to cyclopropane at low pressure has been found to raise the isotope effect to its high pressure value. Work is currently in progress to determine the carbon-13 isotope effect.

The rate of decomposition of ethane into methyl radicals has been studied by the toluene carrier technique, and the use of C^{14} -labeled ethane. The latter is necessary in order to discriminate between the methane produced by the pyrolyses of ethane and toluene. The rate of C-C bond dissociation is measured by the rate of production of radioactive methane, and the C-C bond dissociation energy is obtained from a determination of the activation energy. The results obtained at present indicate a reasonable value of 85-89 kcal/mol for the activation energy; this leads to a frequency factor of $7 \times 10^{14} - 5 \times 10^{15} \text{ sec}^{-1}$. It is expected that this work will be continued elsewhere with the aim of increasing the accuracy of the method.

Electron Exchange Reactions

Studies of the kinetics of electron exchange reactions have been continued, principally with the ferrous-ferric system. The reaction,

was followed with radioactive iron tracer. The particular points studied in detail have been the kinetic effects of some anions capable of forming complexes with ferric iron (bromide, thiocyanate, and oxalate) in aqueous solution, and also the rate of the reaction in ethanol-water perchlorate media. Observa-

tions have also been made on the effects of sulfate, nitrate, and cyanide ions, and of other nonaqueous solvent components.

Bromide and thiocyanate, like the other monovalent complexing anions which have been studied, chloride and fluoride, were found to increase the rate of the ferrous-ferric electron transfer. The results indicate not only that the specific rate constants for the reactions of FeBr^{++} and FeSCN^{++} are approximately equal to those of FeCl^{++} and FeF^{++} , but also that the energies and energies of activation are closely comparable. This fact, along with other observations, leads to the idea that some common feature is to be sought in the rate-determining step of a number of electron exchange reactions. It is suggested that the common feature is the solvent, water, and that the rate-determining step involves interaction of the waters in the first coordination sphere of the reactants. In this picture, the function of the catalyzing ion is thought to be that of a bridging group between the two reactants.

The solvent studies are in line with this suggestion. While the ferrous-ferric exchange rate is decreased by the addition of ethanol, as expected when the dielectric constant of the medium is lowered, there is indication at very low water concentrations in ethanol that water participates directly in the reaction. The rate is a linear function of the water concentration, and, within experimental error, extrapolates to zero at zero concentration of water. How general this effect is in inorganic oxidation-reduction systems remains to be seen.

The reactions involving the mono-oxalato- and monosulfato- complexes of ferric iron, like that involving FeCH^{++} , are exceptionally rapid. A possible explanation is that the polyvalent anions and hydroxide may participate directly in a hydrogen transfer mechanism.

Mass Spectrometer Studies

The mass spectrometer has been used to investigate electron impact dissociation reactions of certain metal cyclopentadienyl compounds. The neutral bis-cyclopentadienyl compounds of V, Cr, Fe, Ni, Co, etc., are stable molecules with cyclopentadiene rings symmetrically placed above and below the central metal atom in the "molecular sandwich" type of structure. Chemical evidence indicates significant structural differences between the latter and the di-cyclopentadiene derivatives of Mg and Mn. The

"sandwich" structures produce large yields of molecule ions with relatively little decomposition on electron impact, whereas the dicyclopentadienyl Mn and Mg derivatives readily dissociate into metal atom ions. These differences are correlated with weaker metal-to-ring bonding in the latter. Additional support for this correlation was obtained from appearance potential studies of the major ion fragments in the mass spectra of the two types of compounds.

Similar studies have been made on the halogen fluorides. In this system the extreme reactivity of the compounds required the development of special gas handling techniques in the mass spectrometer sample system. The sample manifold which was built serves also to permit investigation of chemical reactions of the halogen fluorides. For example, bromine oxyfluoride observed in the spectra of both BrF_3 and BrF_5 was synthesized by direct reaction of BrF_3 and O_2 in the sample manifold. Studies indicated no reaction of CO , N_2 , CO_2 or CH_4 with BrF_3 at room temperature in the mass spectrometer sample manifold. Appearance potential determinations give values of 11.8 ± 0.2 and 12.7 ± 0.3 eV, respectively, for the ionization potentials of BrF and ClF . This establishes approximately equal bond dissociation energies for the diatomic molecule ions and the diatomic molecules in contrast to the marked lowering of diatomic molecule ion bond dissociation energy in the pure halogens. Ionization and dissociation mechanisms for BrF_3 , BrF_5 , ClF_3 and IF_5 are being examined in the light of appearance potentials and supplementary thermochemical data.

Mass spectra and appearance potentials for the aliphatic alcohols from methanol up to and including the isomeric butanols have been determined for the purpose of comparing Eyring's statistical theory with empirical correlations of spectra. The theory relates relative ion yields to the threshold energies for the respective processes, the entropies of activation for the activated complexes undergoing decomposition, the excess energy imparted to the molecule above the ionization energy, and the number of internal degrees of freedom in the molecule. The experimental results for the alcohol series show that all major processes, i.e., large ion yields, are well correlated with low energy appearance potentials. Those processes having low thresholds and low ion yields are readily accounted for on the basis of Eyring's theory as giving rise to secondary dissociation or having unfavorable entropies of activation

associated with energetically favorable rearrangements in the dissociation process.

The distribution of partially deuterated pentaboranes resulting from the reaction between B_2D_6 and B_5H_9 and between B_2H_6 and B_5D_9 has been examined mass spectroscopically. It was found that the deuterium enters the pentaborane by two main processes: (1) exchange between BD_3 and B_5H_9 , and (2) polymerization of BD_3 to B_5D_9 . In the exchange reaction five of the B_5H_9 hydrogens may participate. If the remaining four hydrogens react they exchange at a very much slower rate. The mass spectra indicate that the deuteriums enter the molecule one at a time during exchange. Tracer studies with B^{10} showed no exchange of boron under the conditions of the experiments.

Organic Reaction Mechanisms

A number of organic reactions have been studied in which unique determinations of the mechanisms have been made possible by the application of tracers. Several plausible mechanisms can be written for the rearrangement of α -cinenic acid I to geronic acid II.

Preparation of methyl- C^{14} α -cinenic acid where the methyl group alpha to the carboxyl group is labeled and subsequent rearrangement of the α -cinenic acid have shown that the isomerization involves carboxyl transfer rather than methyl migration.

A study of the mechanism of some first order electrophilic substitutional decarboxylations ($\text{S}_{\text{E}}1$) has been carried out. The rate of decarboxylation of sodium 2,4,6-trinitrobenzoate was studied in water and in deuterium oxide. The rates were shown to be identical. These facts taken together with data obtained by other workers support an interpretation in which the negative charge initially associated with the number one carbon is distributed over the whole molecule in the transition state.

Numerous mechanisms have been proposed for the rearrangement of tropolone (and derivatives) to benzoic acid (and derivatives). The rearrangement of 2,4,7-tribromotropone I and 2,7-dibromotropone IV, both labeled in the carbonyl group with C^{14} , has

given 2,4- (and 2,5-) dibromobenzoic acid (II and III) and 2-bromobenzoic acid V, respectively, with all the radioactivity in the carboxyl group. It is concluded that the carbon atom from the carboxyl group is derived from the carbonyl group in rearrangements of tropolone (and derivatives) to benzoic acid (and derivatives). In the ring enlargements of ketones by diazomethane it has been shown incidentally that the carbonyl group retains its integrity during rearrangement.

It has recently been demonstrated that Reissert compounds will rearrange to carbinols under the influence of a number of strong bases. The question has arisen as to whether the acyl substituent migrates inter- or intra-molecularly. Plausible mechanisms for the migrations have been postulated. Rearrangement of a mixture of 1-benzoyl-6-methoxy-1,2-dihydroquinolondinitrile I and 1-benzoyl-(carbonyl- C_{14})-1,2-dihydroquinolondinitrile II with methyl magnesium bromide as the base gave unlabeled methyl phenyl-2-(6-methoxyquinolyl)-carbinol III and active methyl phenyl-2-quinolyl carbinol IV.

This fact, in conjunction with kinetic data on the system, demonstrated that the reaction must proceed via an intramolecular mechanism.

Tracer Studies in Co-precipitation

The nature of the co-precipitation of radium with barium sulfate has been studied with Ra^{223} as a tracer; the technique of precipitation from homogeneous solution was used. The distribution of radium between the aqueous and solid phases was found to follow the law of Doerner and Hoskins. The value of λ , the distribution coefficient in the Doerner-Hoskins equation, was found to be constant within experimental error over the range in which the fraction of the barium precipitated was 0.03 to 0.96. Its value under the experimental conditions is 1.21 at $90^\circ C$, 1.32 at $70^\circ C$, and 1.43 at $50^\circ C$.

In order to make an analytical determination of the barium in the co-precipitation experiments it was necessary to develop a method for 0.1—5 mg quantities. A procedure was devised in which the barium was titrated with EDTA at a pH of 10.3 with Eriochrome Black T as indicator and a spectrophotometric end point. It was found possible by this method to determine barium with an average error of 0.02 mg barium.

CHEMICAL EFFECTS OF RADIATION

Aqueous Solutions

When water is decomposed by radiation, four products are formed: the molecular products, H_2 and H_2O_2 , and the free radicals, H and OH. The molecular products are sometimes obscured by reactions of the free radicals simultaneously produced or by reaction with the radicals themselves, but in many solutions their yields can be inferred from mechanism studies.

During the past year a Co^{60} gamma ray source has been used for the irradiations in the studies of the H_2 and H_2O_2 yields. The H_2 and H_2O_2 yields were found to be functions of the nature and concentration of added solutes. The H_2 yields from $CuSO_4$ and KNO_3 solutions and H_2O_2 yields from neutral and acid KBr solutions were decreased as the solute concentration was increased. At Oak Ridge, H_2O_2 was found to lower the H_2 yield, while Br^- and Cl^- in acid solution lowered the H_2O_2 yields. All solutions at low solute concentrations give the same limiting H_2 yield of 0.45 molecules produced per 100 ev and H_2O_2 yield of 0.70 molecules per 100 ev.

Figure 11. Effect of solutes on the molecular yields of H_2 and H_2O_2 in the radiolysis of water. $G(R_2)/G(R_2)_0$ is proportional to the yield and $[X]$ is proportional to the solute concentration.

In Figure 11, the ratio of the yield at a given solute concentration to the limiting yield at low solute concentration is plotted as a function of the solute concentration. The plots have been made to coincide by multiplying the concentrations by a factor characteristic of the solute. This behavior suggests that the H_2 and H_2O_2 are formed in kinetically similar processes and that the mechanisms by which solutes affect them are similar. It has been suggested that they are formed in densely ionized spurs associated with the secondary electrons. The water is dissociated into H and OH radicals in these spurs and the molecular products are formed by the combination of like radicals as they diffuse out of the spur. Added solutes would lower the molecular yields by competing for these radicals. This mechanism is consistent with the facts presented above but is somewhat difficult to handle mathematically because of the nonuniform distribution of the radicals. With certain assumptions, however, an approximate kinetic treatment of this effect has been made and is given as the solid line in Figure 11. In view of the approximations, the agreement is considered good. The H_2O_2 yield in KNO_3 solution is exceptional in that its behavior does not follow that of Figure 11. Work is in progress to determine the reason for the discrepancy.

The radiation chemistry of H_2 , O_2 , and H_2O_2 dissolved in water is particularly interesting since it deals with reactions which are the reverse of those occurring in the radiation decomposition of water. These systems have been studied at Oak Ridge and recently at Brookhaven. When H_2 and O_2 are present in large amounts, the H_2O_2 production varies

linearly with dose, and yields 3.1 molecules per 100 ev. This is consistent with the reactions

If the O_2 is present in small amounts the rate of production of H_2O_2 decreases with increasing dose. This suggests a competition between H_2O_2 and O_2 for H atoms:

Qualitatively this explanation agrees with the data, but quantitatively it does not. Quantitative agreement can be obtained, however, by assuming that two reducing species are present. One species is produced directly in the decomposition of water and reacts according to the above mechanism. The other species is produced in reaction (1) and reacts only with O_2 .

A detailed study of the oxidation of deaerated $FeSO_4$ solutions, similar to the previous study of aerated solutions, has been carried out. In 0.8N H_2SO_4 , the ferrous oxidation is not linear with dose; the rate of oxidation decreases slightly as ferric ion accumulates in the system. This effect becomes more pronounced at higher pH and depends on the ferrous to ferric ratio, not on total iron concentration. At large doses the system comes to a steady state with both ferrous and ferric iron present. In the irradiation of $Fe_2(SO_4)_3$ solutions, however, ferric ion is not reduced. On the addition of H_2 , reduction takes place and the system proceeds to a steady state. The appearance of steady states in the radiolysis of $FeSO_4$ solutions is understandable, since H_2 is a product of the reaction and reacts with OH radicals to produce H atoms. The data are quantitatively consistent with a mechanism suggested by Weiss in which H atoms in acid solution oxidize $FeSO_4$,

in competition with the reduction of ferric ion according to the reaction

The concept of H atoms acting as oxidizing agents is rather unusual and has not been needed in chemi-

cal reactions other than those of radiation chemistry and photochemistry. The evidence is strong enough to suggest that a search be made for this effect in other systems.

The effects of nonuniform radical distributions are obviously of prime importance in radiation chemistry, and cyclotron beams offer a powerful method for studying them. The Brookhaven 60-inch cyclotron produces 20-Mev deuterons and 40-Mev helium ions which may be stepped down to lower energies by the insertion of absorbers in the beam. The accuracy of the determination of the total energy input to the sample has been improved by taking into account the net displacement of charge in the window of the radiation cell caused by the forward component of the motion of secondary electrons produced in the window by the ion beam. The application of a suitable correction has resulted in agreement to within 2 percent between the charge-input method and the calorimetric measurement.

Cyclotron beams have been used to study the oxidation of aerated FeSO_4 solutions in $0.8N \text{ H}_2\text{SO}_4$. The FeSO_4 yield in molecules oxidized per 100 ev is given in Figure 12 as a function of the rate of energy loss of the ionizing particle. In the FeSO_4 reaction, each H atom that escapes combination with other radicals reacts with O_2 to form HO_2 which in turn is capable of oxidizing three ferrous ions. If the H atom reacts with other radicals no oxidation is to be expected. As the rate of energy loss of a particle increases, the radicals are produced closer

together and more combinations take place, and the FeSO_4 yield decreases as observed. Small effects which are functions of the FeSO_4 and O_2 concentrations have been noted in this work that have not been found in gamma ray and fast electron irradiations of the same solutions. These effects will receive considerably more study.

Deaerated FeSO_4 solutions have also been studied with the cyclotron. With gamma rays and fast electrons, the ratio of yields of aerated to deaerated FeSO_4 is 1.89, which agrees with the Weiss mechanisms for the reactions when they are modified to take into account the production of molecular H_2 in the aerated system. As the ionization density is increased this ratio decreases gradually; it is 1.60 for 30-Mev helium ions. The mechanisms for the reactions in the aerated and deaerated solutions differ only in the fate of the H atoms, as all OH radicals and H_2O_2 molecules oxidize iron. Hence, as the combination of H atoms with other radicals increases, because of the greater ionization density of the slower particles, the two yields should approach each other. The ratio does not drop as fast as was originally expected. This may involve the effects of O_2 and FeSO_4 concentrations on the yields as mentioned above.

Dosimetry

Gross discrepancies in the absolute yield of the gamma ray or fast electron FeSO_4 oxidation which have been discussed in previous reports have been cleared up and the evidence indicating the reproducibility of the dosimeter has become very impressive. In general, determinations of the rate of oxidation made by several people using the same radiation source will agree within 1–2 percent. However, none of the determinations of the absolute yield had a reliability of less than 3 percent. A new, more precise determination was made in order that the dosimeter might be used with confidence as a secondary energy standard.

A Van de Graaff electron accelerator delivering 2-Mev electrons was used for the determination. The electron energy scale was calibrated against the photodisintegration thresholds of deuterium and beryllium. Current measurements were made with a current integrator designed and constructed by the BNL Instrumentation Division. The rate of oxida-

Figure 12. Dependence of the yield of FeSO_4 oxidation (ions oxidized per 100 ev) on particle energy.

tion of the dosimeter was reproducible to 0.3 percent. After appropriate backscattering and window absorption correction had been made the yield was determined to be 15.45 ± 0.11 ferrous ions oxidized per 100 ev absorbed in the solution. The quoted error is the probable error and is believed to represent the over-all reliability of the measurement. The yield is independent of the dose rate between 10^3 rep/sec and 10^7 rep/sec. It is the same for 1- and 2-Mev electrons and hence presumably for high energy gamma rays. The dosimeter and the yield given here have been used by the Health Physics Division in a series of determinations of the energy required to produce an ion pair in various gases.

It has been found that the gamma ray flux in a cylindrical Co^{60} source has an appreciable component of soft scattered radiation. Approximately 2 percent of the total energy is in quanta below 400 kv. Since elements with high atomic numbers will absorb this soft radiation selectively, this can be an important factor in dosimetry.

Organic Systems

In the last Annual Report it was noted that when cyclohexane is irradiated with gamma rays or with high energy electrons, H_2 is produced with a yield of 5.35 molecules per 100 ev. This yield has now been measured with deuterons and helium ions from the cyclotron and is found to decrease slightly, being 4.9 for 10-Mev helium ions. This small difference, though probably real, stands in marked contrast to the effect of particle energy in aqueous systems. More work on hydrocarbons with the cyclotron is planned.

Gas Phase Reactions

It had been reported in the literature that the equilibrium constant for the system H_2 , HT and T_2 differed from the thermodynamically calculated value by a considerable amount. It was concluded that a radiation-induced steady state was being measured which differed from the thermodynamic equilibrium. In order to check this, an H_2 , HD , D_2 equilibrium was produced by alpha radiation and by catalytic equilibration. The equilibrium constants measured in these systems agreed within experimental error and were equal to the thermodynamically calculated value, which suggests that the explanation for the observed results in the tritium system is incorrect.

A search has been made for the participation of ionic reactions in the radiation-induced exchange of H_2 and D_2 by comparing the effects of inert gases on this system with the thermal and mercury photosensitized exchanges. It was found that a 10 percent addition of neon, krypton, or xenon to H_2 - D_2 mixtures did not appreciably affect the rate of the thermal and photochemical exchanges. In the radiation-induced exchange, krypton and xenon inhibit the reaction. Helium, neon, and argon in low concentration have a slight accelerating effect but in larger concentrations inhibit the reaction. Since the reactions of H and D atoms occur in both the photochemical and thermal systems and are not affected by rare gas additions, it is concluded that ions must play an important role in the radiation-induced exchange. Rare gases could affect the rate through reactions of the type

which have been observed in mass spectrometry and have a high collision yield.

CHEMICAL EFFECTS OF NUCLEAR TRANSFORMATIONS

Irradiation Techniques for Isotopic Labeling

Several aspects of the chemical effects of nuclear transformations are being investigated at the present time. Experiments which might elucidate the over-all mechanism of "hot atom" processes are of primary interest. But an outgrowth of this approach, which involves the interesting discovery that certain organic compounds can be labeled with either C^{14} or tritium directly by neutron irradiation of suitable target systems, has received much attention and will be emphasized here.

Two nuclear reactions have been employed to label organic compounds, $\text{N}^{14}(\text{n,p})\text{C}^{14}$ and $\text{Li}^6(\text{n},\alpha)\text{T}$. In the case of C^{14} labeling, a suitable nitrogen-containing organic compound is irradiated at room temperature in a high thermal neutron flux. It is found after purification that 3–5 percent of the C^{14} nuclei produced reside in the target molecules. In addition, by use of carrier techniques a smaller fraction of C^{14} nuclei is found in the carbon analogue of the target molecule. For example, the irradiation of nicotinic acid yields nicotinic acid- C^{14} and, via carrier, benzoic acid- C^{14} .

among other, as yet unidentified, compounds. Two facts of interest emerge from studies on this and other systems, such as isonicotinic acid, acridine, a benzene clathrate complex, and several alkyl aryl amides. The first is that the target material is labeled in a roughly uniform manner with a low but usable specific activity. The second is that the carbon analogue molecules are specifically labeled by a process which, in a formal way, can be represented as a displacement of an N^{14} nucleus in a given molecule by an energetic C^{14} nucleus. Thus the irradiation of nicotinic acid yields meta-labeled benzoic acid (see above) while isonicotinic acid yields para-labeled benzoic acid.

That this is so was first suspected when the relative total amounts of C^{14} in the target compound versus the carbon analogue paralleled the carbon-to-nitrogen atom ratio in the target compound. In the case of irradiated acridine the ratio of acridine- C^{14} to anthracene- C^{14} was 18/1 and the C/N ratio in acridine was 13/1. Also, for irradiated nicotinic acid the found radioactivity ratio was 7.5/1 and the C/N ratio 6/1. The specific nature of the labeling has been fully established by direct chemical degradation studies.

The production of radioactive organic compounds with recoil tritons has been found to be equally promising. The tritons produced by the $Li^6(n,\alpha)T$ reaction are extremely energetic and have an appreciable range in matter. This has led to the technique of making mechanical mixtures of lithium salts (Li_2CO_3 or Li_2SO_4) with the desired organic compound and irradiating the mixture. Some of the recoil tritons then move from their point of origin in the inorganic particle into the organic particle and replace protons in the latter substance. Somewhat higher percentages of produced tritons are found chemically bound in the organic compound than is the case with the C^{14} labeling technique described above. This heterogeneous recoil labeling is both

simple and flexible and provides reasonably high specific activities in the organic compounds. The technique has been used to label sugars, aromatic acids, and steroids.

Beta Decay in Diatomic Molecules

Considerable work has been done on the theoretical problem of the effect on a molecule of the beta decay of one of its atoms. The quantum mechanical problem has been formulated for the case of a diatomic molecule. The perturbations are the sudden change in nuclear charge of one of the nuclei and the momentum imparted to the nucleus in the decay act. The change-in-charge perturbation leads, as in the atomic case, to electronic excitation of the system. The momentum recoil leads to rotational-vibrational excitation of the molecule. The problem was first treated for the highly idealized case of harmonic potential with no interaction between rotation and vibration. It was then discussed under the more realistic assumption of a Morse potential and vibration-rotation interaction. The calculations show the importance of rotational excitation in dissociation, and emphasize the interaction between rotation and vibration for large rotational excitations. While exact calculations are hampered by the nonavailability of good wave functions for highly excited vibrational-rotational states, it is still possible to make a reasonable estimate of the extent of dissociation arising from a beta decay act. One thus estimates that there is a probability of the order of 0.60 that an intact H_3CNH_2 molecule will result from the beta decay of a C^{14} in H_3C-CH_3 ; this estimate is in accord with the most recent experimental result, 0.47.

MOLECULAR STRUCTURE AND SOLID STATE

Spectroscopy of Rare Earth Compounds

The earlier studies of the polarized absorption spectra of single crystals of rare earth salts and of the absorption spectra of solutions of these salts have been continued and amplified through similar observation of their fluorescence spectra. A study was made of the complete polarized sharp line fluorescence and absorption spectrum of single crystals of europic ethyl sulfate nonahydrate. While previously only five line groups in the spectra of europic salts had been completely analyzed with respect to their quantum nature, these observations have now made

possible the analysis of twenty-one such groups. The work has also led to a somewhat more quantitative understanding of eleven additional line groups.

Generally, in the spectra of rare earth compounds, changes of the symmetry of the distribution of electric charges about the rare earth ion are reflected in marked changes in the positions and number of lines. In some of these studies, however, changes of symmetry of the microfield about rare earth ions, which have been too slight to produce noticeable line shifts, have been revealed through changes in the relative line intensities. Solutions of europic chloride in water and some alcohols show to a first approximation lines in the same wavelength positions, which indicates the same basic orientation of solvating molecules about the europic ion in the different solutions. Marked relative intensity changes in lines, which occur in going from an alcohol to an aqueous solution, may be correlated with the increased symmetry of the solvating molecules themselves. Both absorption and fluorescence measurements of europic chloride solutions indicate a C_{2v} microfield about the rare earth ion dissolved in lower alcohols which goes to a slightly more symmetric, D_{2h} , field in water.

Figure 13. Transitions to 1D_2 state in praseodymium fluoride: A, after cooling to 77°K; B, at 4°K; C, after warming from 4°K to 77°K.

A similar subtle change in symmetry was observed in films of praseodymium fluoride. Upon cooling from the temperature of liquid nitrogen to that of liquid helium, some lines increased so markedly in intensity as to indicate a lowering of symmetry of charge about the praseodymium ion (Figure 13). The fundamental line positions were not altered, however; this indicates that the alteration of symmetry probably resulted from only a distortion of the basic structure rather than an over-all change in it.

Magnetism and Crystal Structure

A study of the magnetic properties of three allotropic forms of manganese sulfide has shown that the different crystalline forms are antiferromagnetic below the temperature of dry ice and that the observed values of the antiferromagnetic exchange energy depend almost entirely on the number of interacting magnetic ions and the nature of the chemically bonding anions. Support for this view has come from an investigation of two crystalline modifications of MnO .

Table 4

Interatomic distances in some transition group disulfides

Disulfide	Unit cell A	Parameter	S-S distance A	M-S distance A
FeS_2	5.404	0.384	2.17	2.26
CoS_2	5.523	0.389	2.12	2.32
NiS_2	5.677	0.395	2.06	2.40

The interatomic distances of compounds with the pyrite structure have been used by Pauling to obtain a set of octahedral radii for the transition elements and to confirm the tetrahedral radius of sulfur. Recently Néel proposed new electronic structures, and assigned magnetic moments to the disulfide groups rather than the metal atoms. The series of compounds FeS_2 , CoS_2 , and NiS_2 would be expected, according to Néel, to have increasing S-S interatomic distances, in disagreement with the predictions of Pauling. A reinvestigation of the structures of these compounds by x-rays has been carried out. The results are given in Table 4. The decreasing S-S distances found are probably due to decreasing negative charge on the sulfurs in the sequence FeS_2 , CoS_2 , NiS_2 . The S-S distance in NiS_2 is very close to the sum of the Pauling tetrahedral covalent radii. These findings do not support Néel's suggestion that in this compound the disulfide group has the $^3\Sigma$ structure of the oxygen molecule.

Neutron Diffraction

The diffuse scattering of neutrons by zinc ferrite has been measured at several temperatures and the differential magnetic cross section of the magnetic ions (Fe^{+++}) has been obtained as a function of angle (Figure 14). The extrapolated value for zero

Figure 14. Magnetic scattering cross section per Fe^{3+} ion in ZnFe_2O_4 . To the left of the axis of ordinates the arrow indicates the theoretical value 21.2b. The short vertical bar opposite the arrow indicates the uncertainty arising from determinate errors as discussed in the text.

scattering angle was found to be in good agreement with the theoretical value for an ion having $S=5/2$. Some evidence of short range ordering at liquid nitrogen temperatures was observed. The ordering was interpreted as ferromagnetic coupling between iron ions. The measurements were corrected for multiple scattering by means of calculations based on the work of Chandrasekhar and of Vineyard. The theory was compared with measurements of the scattering from Be, Pb, Bi, and Th under conditions where multiple scattering predominated. Very good agreement was obtained. Tables of values of the expected multiple scattering by flat samples were computed.

Work is continuing on other ferrites and chromites in connection with a general program of characterization of ferromagnetic spinels. Neutron diffraction is also being used in current investigations of the properties of certain antiferromagnetic alloys and inorganic compounds.

ENGINEERING

This section of the report is devoted to the research, development, and some of the service activities of the Reactor and Nuclear Engineering Departments. Engineering and development for accelerators are described in the accelerator section.

The Reactor Department operates the reactor, and, on a service basis, produces and distributes radioisotopes and performs neutron irradiations. Research in shielding and in some aspects of neutron physics are within the realm of this Department's responsibilities. Also, much of the work at the reactor by groups of scientists from other organizations is under the cognizance of the Reactor Department.

The research work of the Nuclear Engineering Department centers on the design of new reactor systems. The service functions of the Department consist of providing gamma irradiations and hot chemistry facilities for highly radioactive chemical separation work. Because of the increased interest by AEC and industrial organizations in the liquid metal fuel reactor as a potential power source, the development work on this project will be accelerated in the Department during the coming year. During the latter half of this report period, a comprehensive evaluation study of the feasibility and practicality of a liquid metal fuel power reactor was conducted by a group of scientists and engineers, under the administration of The Babcock and Wilcox Company. The final report of this group concludes that a full-scale LMFR system is feasible in the near future as a source of electrical power.

LIQUID METAL FUEL REACTOR SYSTEMS

The last Annual Report described in some detail the design and development work being conducted by the Nuclear Engineering Department on the liquid metal fuel reactor (LMFR). This work has recently been stimulated considerably by the growing interest of the Atomic Energy Commission in this system as a promising source of future electric power from fission. A number of industrial companies having also expressed their desire to study the feasibility of the LMFR, the Commission's Reactor Development Division recommended to Brookhaven that a formal survey by an industrial task group be initiated. Accordingly, after negotiations by the Commission and Brookhaven, a contract was awarded on

November 29, 1954 to The Babcock and Wilcox Company.

This contract specified that the primary objectives of the study were a complete survey, analysis, and evaluation of the research and development done to date by Brookhaven, and as complete an evaluation as possible of the research and development still to be done for a successful LMFR to be built. It was also required that a preliminary design for a practical LMFR system be prepared, and a preliminary evaluation of the feasibility and economic potentialities of the system be submitted.

Personnel for the Study Group was quickly recruited from Babcock and Wilcox and augmented by technical people from six other qualified organizations; in January, 1955 the group began operations. The areas covered by the study included metallurgy, reactor physics, mechanical design, chemistry, and chemical engineering. An interim report was issued to the Laboratory on March 31, 1955; as of June 30 this was superseded by the final technical feasibility report, BAW, #2 (classified Confidential).

The findings of this comprehensive study indicate that the LMFR can become technically feasible in the near future and that it is also attractive from an economic viewpoint. The engineering designs presented are based on single and multiple 550-megawatt reactors served by common auxiliaries, particularly by complete on-the-site chemical processing facilities for the core and blanket systems. Detailed estimates were made for electric power stations ranging from 226- to 904-megawatt electrical capability. The estimated unit costs range from 8.5 to 6.5 mills per kilowatt-hour, respectively. The final report of the Study Group further pointed out that the LMFR had the additional attractive feature of flexibility. Thus, it could function as a breeder or as a non-breeder and, in either case, over a wide range of power levels. It is expected that the proposed further mechanical design and chemical processing studies should offer improvements with far greater potential than the present proposal.

The potentialities of the LMFR concept have also been studied by another group, working independently of the Babcock and Wilcox team. This group, known formally as Brookhaven's Guest Engineers Study Team, was composed of ten power engineers, mostly from utility companies in the New England area. Every Wednesday, during the greater part of 1954, they received training in nuclear engineering

and physics from Brookhaven specialists. Upon completion of the study period the team, assisted by members of Brookhaven's Nuclear Engineering Department, undertook the concept design of a 200-megawatt nuclear power station, in which thermal energy was supplied by an LMFR system. A report, prepared by members of the team for presentation at the Nuclear Engineering Congress to be staged at Cleveland by the Joint Engineer Societies in December, 1955, was also very favorable to the LMFR proposal. This report found the total estimated capital cost for the entire 200-megawatt power station would be \$43,750,000, with an estimated energy cost of approximately 7.5 mills per kilowatt-hour.

A number of papers on various technical features of the LMFR were prepared by Brookhaven staff members for presentation at the International Conference on the Peaceful Uses of Atomic Energy in Geneva (see Appendix A of this report). These papers, which included much information previously classified, were submitted to the AEC for advance clearance and were in all cases declassified without deletions. Thus, many areas of the LMFR have now been opened up to the general public, and, in particular, to industry both in the United States and abroad.

Concurrent with the feasibility studies by outside groups as described above, the Nuclear Engineering Department is working on the solution of the more complex engineering problems, for the realization of a successful LMFR system. The removal of fission products from the fuel, to obtain a high economy in neutrons, and the inhibition of corrosion in the reactor container material have been two of the outstanding problems. Within recent months, satisfactory solutions for them have been worked out, and the LMFR concept has thus been advanced considerably. The details on the most important research projects on the LMFR are described below.

Fuel Processing

One of the unique aspects of the LMFR is the possibility of continuous removal of fission products for 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. For this reactor, the fission products can be arbitrarily divided into three groups:

- 1) those which are appreciably volatile at the operating temperatures of the reactor,

- 2) those which are nonvolatile and either form chlorides more stable than UCl_3 or, as anions, form salts, and
- 3) those which are nonvolatile and form chlorides less stable than UCl_3 . As reactor poisons, the first two groups are by far the worst, the first because of Xe^{135} with its 2.7×10^6 barn cross section and the second because of the rare earths, particularly Sm^{149} with its 50,000-barn cross section.

In the LMFR, it is proposed to remove the first group by a continuous volatilization process, either one of gas stripping or one of low pressure desorption. During FY '55, further experimental evidence was obtained to indicate that the removal of this group of fission products, both as to rate and degree, should present no great engineering difficulties.

In regard to removal of the second group of fission products from the LMFR fuel, work completed before July 1954 had established in broad outline the feasibility of using a fused salt mixture for the extraction of rare earths and those fission products in Groups IA, IIA, and IIIA of the Periodic Table. The hypothesis that selective chlorination was the mechanism involved had been proposed; and work had been begun on scaling-up the experiments from a test-tube to an engineering level. From July 1954 on the task was to confirm the theory by a series of experiments done under more widely varying conditions, to design a process which would be practical on an engineering scale, and to develop such a process through a series of scale-ups, increasing both in size and in level of radioactivity.

The fundamental research has consisted primarily of determining the equilibrium distributions of tracer-level fission product nuclides between fused salt and liquid metal phases under various conditions. Much of the year's effort has gone into determining the conditions that are required to give truly reproducible and exact results in such experiments. Very small amounts of extraneous matter such as oxides can have a serious effect on the distribution of an element which is present at a concentration of a few parts per million. Oxide contamination may originate in either of the reactants, salt or metal, in the blanketing gas, or on the container walls. Consequently all materials require special pretreatment.

The research program on distribution coefficients is still far from complete, although quite a body of

data has been obtained. This is in general consistent with the selective chlorination hypothesis, although the reactions are probably more complex than was originally supposed. This work has also been valuable from a practical point of view, since it provides the engineers with more definite separation factors to use in designing process equipment. These factors, while not so high as indicated by the earliest, less exact experiments, are still very good. This means that it should be possible to remove the rare earth fission products (and probably many others) from the fuel, without removing uranium, in extraction apparatus which provides the equivalent of only a very few equilibrium stages.

Part of the basic research program has been the measurement of thermodynamic functions of liquid metal systems. High temperature galvanic cells have been set up, of which the following may serve as an example:

This cell, when operated at a temperature where both the electrodes and the electrolyte are fused, gives an emf which measures the free energy of formation of the liquid cerium-bismuth alloy which constitutes the right-hand electrode. Knowledge of this quantity is required for the calculation of the distribution of cerium between bismuth and a salt in the equilibration experiments. Having it, one can compare calculated and observed distributions and check out hypotheses as to the mechanism involved.

In most of the earlier extraction experiments, the KCl-LiCl eutectic was used. It served both as flux and oxidant, K and Li metal being formed as the rare earths were oxidized. These go into the fuel and, in a reactor system, would affect the neutron economy adversely; this is particularly true of the Li. The ternary eutectic of NaCl-KCl-MgCl_2 ($\text{mp} = 396^\circ\text{C}$) seems at present very promising and it is now used in most of the equilibration experiments. This mixture also can serve as both flux and oxidant, with the MgCl_2 doing the oxidizing. Control of oxidation potential is possible, through variation of the MgCl_2 content of the salt or the Mg content of the metal, or both. In this type of chemical oxidation system, known as the buffer system, the uranium is protected against oxidation by the presence of the Mg in the metal. However, in order to obtain satisfactory distribution coefficients with this system, the Mg concentration in the fuel needs to be below that

presently desired for inhibition of corrosion and mass transfer.

A second method, known as the "stoichiometric" method, presents an attractive alternate. In this, just enough of a strong oxidant like BiCl_3 is added to the carrier salt, e.g. the KCl-NaCl-MgCl_2 eutectic, to remove those fission products which form more stable chlorides than UCl_3 ; however, not enough is added to affect the uranium. This system has the disadvantage of requiring a very delicate control on the concentration of the oxidant in the processing salt stream. Both the buffer and stoichiometric systems are being further investigated at the present time.

Chemical engineering flowsheets for both these methods have been drawn up. From an engineering standpoint they are very similar. Flow rates and equipment are very small because operation is continuous, the chemistry is nonaqueous and reaction between salt and metal is rapid. Pipe lines and ex-

traction columns need be no longer than $\frac{1}{4}$ in. and 4 in. in diameter, respectively. Items of major cost in such plants would presumably be heat exchangers, instrumentation, remote operation devices, and shielding.

One of the main accomplishments of the year was the start-up of Loop B (Figure 1). This in-pile loop circulates a U-Bi solution through the Brookhaven reactor and will be used to test the feasibility of removing the first two groups of fission products by the methods described above. At the end of the year, radioactive operation was started, and the fission products began building up in the metal solution. Thus far, the loop has operated exceedingly well. Work continued during the year on the design, construction, and operation of additional loops to get full processing data and to test loop components on an engineering scale.

The third group of fission products, owing to their relatively low poisoning effect, have received

Figure 1. Loop B.

little attention thus far. Methods have been proposed for their removal, however. It is expected that their tolerably high concentration in the fuel will mean average residence times in the fuel of several months, compared to a few minutes for the first group and a few days for the second group.

Corrosion and Mass Transfer of Steels

Static corrosion tests of a variety of steels have shown that nickel is an undesirable steel constituent and the corrosive attack by bismuth on iron or steels was decreased by the addition of zirconium to the bismuth. Chromium steels containing minor quantities of molybdenum have proved the most promising.

Thermal convection loops have been built to study the mass transfer type of corrosion. Mass transfer results from the iron dissolved in the hot leg of the loop depositing in the cold leg and eventually plugging the loop. With zirconium additions to bismuth, loops operated for periods greatly in excess of their expected life without zirconium. There are indications that titanium additions act in a similar manner.

The exact nature of the mechanism by which small zirconium additions inhibit the transfer of iron in bismuth solutions is being studied by radioactive iron tracer techniques. The solubility of iron in bismuth has been determined in the presence and absence of other possible constituents in bismuth. Zirconium and magnesium do not affect the solubility of iron while the presence of chromium lowers it slightly. Experiments with radioactive zirconium have established that zirconium does adsorb on iron surfaces and the amount is a function of time and temperature. Kinetic studies to determine the rate of solution and precipitation of iron and chromium from bismuth with and without additives have shown that zirconium affects both processes. It decreases the rate of solution and causes the bismuth to retain a high degree of supersaturation after precipitation. In some experiments, ZrN has been detected on steel surfaces. Nitrogen is available as constituent of steel. This layer could reduce the rate of solution of iron in bismuth and thereby inhibit mass transfer. A layer of ZrN can explain the mechanism by which zirconium inhibits mass transfer.

During the last year a pumped high velocity loop was built and operated. Bismuth containing uranium, magnesium, and zirconium was circulated at velocities up to 8 fps in a reduced section in the cold portion of the loop. After 1000 hr with a thermal

gradient of 125°C (525-400°C) no corrosion was detected in a standard sample in the hot portion of the loop and very little deposition in the high velocity section.

Blanket Development

Dispersions of Th_3Bi_5 in bismuth and lead-bismuth alloys are being developed for the breeder blanket of an LMFR. The production of fine grained equiaxed dispersion of thorium-bismuthide in bismuth has been accomplished by reacting finely divided thorium (in the form of chips or powder) with the molten alloys of bismuth and lead-bismuth at various temperatures below 600°C. The resulting particle size is between 40 and 70 μ . This procedure had to be developed to avoid the platelet form of Th_3Bi_5 which results after complete solution of the thorium.

Dispersions of equiaxed particles have been subjected to various thermal treatments and the changes in particle size were observed. The particle growth encountered when the dispersion was treated isothermally at temperatures up to 600°C for periods up to 3 months was below 0.1 μ on the diameter per hour. The equiaxed particle dispersions have also been thermally cycled between 350 and 600°C for 500 hours at a frequency of 5 cycles per minute without serious growth. Another important observation was that no platelets were formed by heating equiaxed particle dispersions to temperatures at which an appreciable fraction (up to 80 percent) of the solids had been dissolved and cooled with agitation.

The conclusions which may be drawn from this work are:

- 1) in equiaxed dispersions, the particle shape remains equiaxed as long as not more than 80—90 percent of the solids are dissolved and the dispersion is constantly agitated;
- 2) particle growth under reactor conditions (below 600°C for periods of a month) is not a likely problem;
- 3) readjustment of the particle size may be desirable and several methods for this operation are promising.

Processes for the removal of radiation products (Pa and U) from thorium-bismuthide in bismuth dispersions are being studied. The most promising method is based on the insolubility of thorium in liquid bismuth at low temperatures. The radiation product, being a minor constituent, dis-

tributes itself between the solid and liquid phase. Experimentally, a 5 percent thorium-bismuth alloy containing 100 ppm uranium was completely dissolved at high temperatures and filtered at 350°C. By analysis of the filtrate and residue, the relative thorium and uranium concentrations in the solid and liquid phases were determined. The ratio of the concentration of uranium in the solid phase to that in the liquid phase was 6 while a similar ratio for thorium was 6000; thus a separation coefficient of 1000 was found. It is assumed that protactinium could be separated in a similar manner.

A process employing the above principle would have the following steps:

- dilution to facilitate a later liquid phase separation,
- thermal treatment to allow the radiation products to reach equilibrium;
- readjustment of the thorium concentration to 10 percent thorium by removal of excess liquid phase;
- removal of radiation products and dissolved thorium from the separated liquid phase by oxidation, and return of purified bismuth to the dilution step; and
- addition of thorium to make up losses.

Various methods for attaining equilibrium in the thermal treatment step of the process are under investigation.

Uranium-Graphite Reaction Studies

The reaction between the uranium-bismuth solution fuel and graphite (moderator) has been investigated. The amount of UC formed at 550°C was estimated from the extrapolation of high temperature experiments to be nil. This was verified by experiments at 550°C in which UC could not be detected. It has been shown that, at high temperatures of 850-1200°C, both carbon and graphite react with uranium. The deposit is usually uneven and crumbly. Zirconium added to the uranium-bismuth solution produced ZrC-ZrN coatings which are adherent and prevent the formation of UC. Therefore, the zirconium present in the uranium-bismuth solution as a mass transfer inhibitor and fission product serves also as inhibitor for the uranium-graphite reaction.

PHASE RULE STUDIES

The uranium-bismuth phase diagram shown in Figure 2 was deduced from work at Brookhaven and

Figure 2. Uranium-bismuth phase diagram.

elsewhere. The crystal structures of the intermetallic compounds in this system were determined by neutron diffraction experiments. Both the solubility of uranium in bismuth and lead (up to 1000°C) have been established by a graphite filtering technique.

Work on the thorium-bismuth and thorium-lead-bismuth phase diagram is in progress. The solubility of thorium in bismuth has already been determined.

REACTOR PHYSICS

The work of the Reactor Physics Division is divided into two broad areas, theoretical and experimental, which are the responsibilities of two groups so named. Their main projects are given below.

Studies on the neutron-multiplying properties of uranium-water lattices have continued, by means of exponential and other experiments. In this work rod size, U^{235} concentration, and volume ratios of water to uranium have all been varied, in order to obtain measurements on the various parameters that govern neutron economy. Some of these parameters are: critical buckling, migration area, fast fission effect, thermal utilization, resonance escape probability, and neutron temperature. The results of the studies have produced a good understanding of the properties of slightly enriched uranium-water lattice systems.

Theoretical investigations, together with exponential experiments, have also continued in design calculations for various types of LMFR systems. Such factors as core and blanket analysis, critical size, concentration and breeding are being studied. The kinetic behavior, as related to temperature coefficient, is receiving theoretical consideration.

A critical assembly facility has been completed; this will be used to study the properties of the proposed new Medical Research Reactor. Of special interest in this work are the critical mass, temperature coefficient, and shutter. It will also be employed in the investigation of various lattices with water and fuel elements of the Materials Testing Reactor type, with particular consideration of reflector effects and temperature coefficients.

FUEL ELEMENT FABRICATION

The fuel element of the Brookhaven reactor consists of 33 4-in. long natural uranium rods, 1-1/10 in. in diameter, encased in a 6-finned aluminum tube (Figure 3). The uranium rods are prepared by extruding billets which are heated into the gamma range, i.e., above 772°C. The long rods are straightened and then machined to diameter on a 6-spindle lathe. To remove oil, water, and relieve machining stresses, the finished rods are then heat-treated in argon.

The finned aluminum tubing which is unusual in that the fins are 0.6 in. in height and only 0.018 — 0.020 in. thick at the tip and 0.025 in. at the base,

is fabricated by Alcoa by extrusion. To straighten and stiffen the tubing, the extruded section is cold-drawn to 15 percent reduction in area.

Since the design requirements called for operation of the fuel elements at a temperature of 350°C at the interface between the uranium and aluminum, it was necessary to develop methods for applying a coating either to the uranium or aluminum to prevent the alloying reaction between these two metals. This was accomplished by anodizing the aluminum tubing inside and out.

The actual canning requires 13 individual operations. These are:

- 1) chemical stripping of the anodized film at one end of the finned tube.
- 2) trimming of the end of the tube.
- 3) inert arc (argon) welding of a cap to this end of the tube.
- 4) dehydrating the anodized film on the interior of the finned tube by a vacuum anneal at 350°C.
- 5) helium mass spectrometer leak-testing to determine leak-tightness of finned tube and welded cap.

Figure 3. The BNL fuel cartridge.

- 6) loading of uranium slugs into finned tube.
- 7) trimming of loaded tube to size.
- 8) induction brazing of special He cap to finned tube.
- 9) second He mass spectrometer leak-testing.
- 10) hydrostatic collapsing of finned tube onto the uranium slugs.
- 11) flame-brazing of device for anchoring cartridge in channel.
- 12) flame-brazing 1/8-in. helium tube to helium cap.
- 13) the final acceptance test—a composite pressure and He mass spectrometer leak-test.

HEAT TRANSFER STUDIES

A project was initiated last year, as a PhD thesis, to study heat transfer and fluid dynamics in a spray column. In this investigation, mercury at about 205°F was sprayed in 1- and 2-in. (ID) columns into rising streams of water. Droplet sizes and fluid dynamics were studied by means of high speed photography. Steady-state heat transfer coefficients based both on column volume and interfacial area were obtained. The area coefficients were lower than predicted from published correlations for fixed spheres.

The results from these studies, now completed, permit an increased understanding of the nature of flow and the mechanism of heat transfer in spray columns, and also provide a basis for evaluating spray columns as a possible means for obtaining high-density heat fluxes. Such heat exchangers have a possible application in nuclear power reactors employing metals as reactor fuels and fused salts as coolants.

Another PhD thesis was devoted to obtaining heat transfer data for the cross flow of mercury through a staggered tube bank. A revised experimental facility was nearly ready for the resumption of runs by the end of this report period. The variables to be studied in this work are: linear velocity, tube location, variation of local coefficient with angle, "wetting" versus "non-wetting," tube spacing, and Prandtl number.

SHIELDING

The reactor shielding program has continued to provide information on the transmission of neutrons and gamma rays through various media and configura-

tions. The investigation of neutron transmission through cylindrical air ducts has yielded several useful observations. Rather severe limitations have been set on the applicability of the phenomenological theory of neutron transmission through bent ducts developed by Clifford and Simon, and a better understanding of which processes are important has been obtained. In this connection, the efficacy of "traps" at a bend in a duct has been demonstrated. Also, the validity of a line-of-sight approach in estimating the neutron transmission of some ducts has now been established.

The concept of the effective fast neutron removal cross section has found extensive application in the field of shielding. The techniques currently employed to obtain an experimental value for the removal cross section of a particular material require quite large samples. A new cross section, which has been called the "collimated removal cross section," has been defined and a technique has been developed to obtain experimental values for the cross section which requires relatively small samples. The definition of the collimated removal cross section is based on a plane monodirectional fission source rather than the isotropic source employed with the conventional removal cross section. The values which have been obtained for the collimated cross section are systematically higher than the corresponding conventional removal cross sections.

An investigation has also been undertaken of the use of spherical coordinates in the formulation of the gamma ray gun source problem, by means of the moments method. The moments so obtained are simply related to the moments for other basic source geometries.

ULTIMATE WASTE DISPOSAL

During the past year, efforts on radioactive waste disposal problems were directed chiefly toward completion and operation of the pilot plant (see Figure 4), and development of waste pretreatment steps which would improve the subsequent adsorption of the fission products on montmorillonite clay.

Construction of the pilot plant has been completed, and several preliminary tracer runs have been made. As a remote controlled operation the plant has performed very successfully, and results so far are in good agreement with those obtained in the laboratory. Preparations are being made for opera-

Figure 4. Pilot plant for clay process.

Figure 5. Calciner pilot plant.

tion of the plant at higher activity levels in the future.

Both laboratory and pilot plant data have shown that ruthenium is not adsorbed to any extent on the clay, and, therefore, it is planned to handle its removal and fixation by means of some additional process. Since the clay column effluent is almost neutral and should have a low solids content, the use of evaporation as a ruthenium removal step appears attractive at present. After evaporation of the effluent, the small volume of salts remaining would then be fixed in a stable solid. The extent to which the ruthenium-bearing residue may be incorporated and fixed in fused glass or ceramic bodies is now under investigation.

Since the mechanism of incorporating the fission products into the clay is one of ion exchange, there is much to be gained by reducing the concentration of extraneous nonradioactive cations to a practical minimum. The development of pretreatment steps for effecting this removal in wastes containing nitric acid or aluminum nitrate as their main ingredient is now in progress. Use of distillation and semipermeable membranes for acid removal appears to be very promising and an electrodeionization unit is presently being developed for use in the pilot plant. Initially, use of an electrodeionization cell was considered for treatment of wastes containing aluminum nitrate, but problems encountered in this type of application led to a more direct method of removal, that of direct conversion to stable aluminum oxide by means of thermal decomposition. The oxide thus formed is leached with water or acid to remove the soluble fission products, which may then be adsorbed on clay. Results of tests so far indicate that if the leaching procedure is carried to its logical conclusion, the fission products which are not leached away can be considered permanently fixed in place, and the aluminum oxide may then be disposed of without further treatment.

Another type of waste under study has as its chief constituents zirconium and aluminum fluorides. As in the case of the aluminum nitrate wastes, conversion to the stable oxides of zirconium and aluminum provides a method of separating the fission products from the extraneous substances, and yields an end product which, being highly stable, may be safely disposed of. Although the fluorides do not decompose to the oxides by heating, they may be converted by hydrolysis with steam at elevated tempera-

tures. Good conversion to the oxide has been obtained in the laboratory, and leaching tests similar to the ones performed on the aluminum oxide are now under way.

One phase of this work has been concerned with the development of process equipment for use in pretreatment steps which involve conversion to an oxide, and several designs have been proposed. One such unit, which might be described as a combination ball mill and rotary kiln, shows considerable promise for use in converting aluminum nitrate to the oxide. A small experimental unit has been constructed and is now being tested.

Little work has been done so far on the development of equipment designed specifically to process the fluoride solutions, but it is believed that designs which prove suitable for use with the aluminum nitrate wastes may be modified for use with the fluoride wastes.

WASTE PROCESSING

The Waste Processing Development Project has been investigating the feasibility of treating aqueous wastes from fuel processing plants to produce either a molten salt mass or a dry powdered material.

Storing either fused salt or dry powdered wastes has several advantages over storing dilute aqueous wastes. The first is the reduction of the corrosion hazard. The fused salts would remain molten for a short time and then solidify, and greatly reduce the corrosion rate. In contrast, the present practice of aqueous storage requires either expensive alloy steel tankage or chemical treatment of the aqueous wastes to allow storage in cheaper tanks. The second advantage is a reduction in the mobility of the wastes. Aqueous wastes could easily enter the environment in the event of a tank failure while fused salts would remain intact as one solid mass. The third advantage is the reduction in waste volume. Depending upon the waste, volume reductions of from 50 to 70 percent have been attained in pilot plant runs. Also, the dry powdered waste may be leached with water to remove certain long-lived fission products either for separation and recovery, or to reduce the critical storage time required for the bulk waste.

A horizontal auger-agitated calciner was developed to reduce aqueous waste streams to molten salt or dry powder. Figure 5 is an over-all view of the calciner pilot plant. This machine is of stainless

steel construction with three-zone electric heating. The first zone is held between 250 and 300°F to evaporate the free water from the waste. The second zone is held between 300 and 500°F to remove final traces of water and decompose the majority of the waste solids. The third zone is held between 600 and 750°F to melt the mass prior to leaving the calciner. The molten salt is free flowing and does not require the agitator for removal. The production of a dry powder is carried out in the same manner at a slightly lower terminal temperature and with a different feed pretreatment.

Various feed pretreatments have been used on the raw acid waste solutions. To obtain a free flowing melt a carrier or flux must be present in the final melt. This flux, NaNO_3 , must be added to the raw feed, although caustic addition to neutralize or partially neutralize the feed will supply some of the required NaNO_3 . To produce a dry powder the raw acid feed is used with no addition of flux. The calciner temperature is kept below the melting point of the salt mass in order to keep the powder from agglomerating.

Further development work is planned on the investigation of induction heating as a heat source and nonagitated hot tube calciners with no moving parts.

FISSION PRODUCTS UTILIZATION PROJECT

Radiation Application Research

Solid state polymerization has been observed in a number of monomers which had been exposed to gamma radiation. The list includes acrylamide, methacrylamide, methylene-bis-acrylamide, *N*-vinyl carbazole, acrylic acid, methacrylic acid, potassium acrylate, and barium acrylate. The acrylamide system was investigated in detail over the intensity range of 3,000 to 900,000 rep per hour and in the temperature range -18°C to 60°C . It was found that the rate of polymerization varies with the first power of the intensity and has an activation energy of 4.6 Kcal per mole. The molecular weight was independent of both temperature and gamma ray intensity. Irradiation of monomer at -18°C or lower produces no polymerization but trapped free radicals are formed. The concentration of these radicals after irradiations of 25 and 50 million rep was estimated from paramagnetic resonance measurements to be approximately 10^{-3} molar.

The gamma ray investigation of *N*-vinyl pyrrolidone polymerization has been completed. The polymerization rate depends on monomer concentration to the first power and intensity to the one-half power. An activation of approximately 2 Kcal per mole was calculated from rates at four temperatures. These results are compatible with a mechanism involving initiation via H or OH radicals from the water solvent and a bimolecular termination of two radicals. Conditions have been determined which are optimum for producing polyvinylpyrrolidone of blood plasma expander quality. At the present time polymer is being evaluated for toxicity effects and retention time characteristics by the National Research Council.

Graft co-polymerization has been successfully achieved by gamma irradiation of mixed films of polymethylmethacrylate and polystyrene. The optimum mixture contained 20 percent polystyrene and 80 percent polymethylmethacrylate. The irradiation dose required was less than 30 million rep. An alternate method under investigation involves irradiation of a radiation-sensitive polymer in the presence of a monomer.

An attempt was made to use the fission recoils from dissolved uranyl nitrate (1 gram) to convert methanol (25 ml) to ethylene glycol. After 4 hours' irradiation in the Brookhaven pile the gas pressure developed in the quartz irradiation capsule was 200 psi, but only 20–30 mg of glycol and formaldehyde were found. Based on the calculated energy absorbed, the gas evolution was considerably higher than expected and the yield of liquid products was surprisingly low.

Studies are in progress on the improvement of aging characteristics of wood by impregnation of the wood with vinyl monomers and irradiation. Initial experiments with methyl methacrylate showed little promise so effort is now concentrated on use of water soluble monomers which are capable of penetrating the cellulose cell structure.

The printing characteristics of polyethylene film have been greatly improved by irradiation in an oxygen-containing atmosphere for 15 million rep at temperatures of approximately 50°C .

The curing rates of commercial and experimental polyester resins have been investigated with radiation as the curing catalyst in place of the conventional method which employs chemical catalysts and heat. Curing rates obtainable with the maximum radiation field, 850,000 rep per hour, are slower than indus-

trially obtainable rates but the exotherms for the radiation method are appreciably lower.

Polymerization of monolayers and multilayers of butadiene adsorbed on the surface of carbon black has been successfully accomplished with dosages of 25 million rep. Material will be evaluated for its rubber compounding qualities.

The projects described above have been assisted by the cooperation and contributions of technical personnel from various outside organizations. Among these should be mentioned the following: Polytechnic Institute of Brooklyn, Columbia Carbon Company, General Aniline and Film Corporation, Hercules Powder Company, and Pittsburgh Plate Glass Company.

Radiation Application Engineering

The following is a resumé of the utilization of the gamma irradiation facility, and the fabrication, irradiation and sale of cobalt sources for fiscal '55.

Table 1 indicates the sources sold, the sources used to replace those sources whose curie content was incorrectly estimated before improved techniques for evaluating curie levels were arrived at, and the income from the sale of sources and containers.

Ten standard and 20 flat cobalt sources were put into the reactor; 2 nested, 6 standard, 4 flat cobalt sources, and one 3-section tantalum nested source were discharged. Eight standard cobalt sources and 150 flat cobalt sources are ready for pile irradiation. Ten standard and 32 flat sources are in the reactor. Letters of intent or purchase orders for sources have been received from the institutions listed in Table 2.

Table 2

By Whom Ordered	Type of Source
Sloan-Kettering Institute	1 standard
Johnson and Johnson	1 standard
Stevens Institute	Special source
AEC	6 standard
Quantum, Inc.	1 small tubular cobalt
Glenn L. Martin Company	Outer section of nested source
AEC	1 small tubular cobalt source
Army Food and	
Container Institute	5 flat cobalt sources
Columbia University	4 flat cobalt sources

During the past year four lead shields were sold and four additional shields were built.

The following companies availed themselves of the use of the gamma irradiation facility during fiscal '55:

Plax Corporation
B. F. Goodrich
Minnesota Mining
Celanese Corporation
Standard Oil Company of N. J.
Polytechnic Institute of Brooklyn
Diamond Alkali
General Foods Corporation
Ruskin Research Institute
Chemstrand Corporation
Camp Detrick
E. I. DuPont
Sprague Electric
International Wax
Hercules Powder
Evans Signal Laboratory

Table 1

Source No. or Type	To Whom Sold	Curie Content	Source Charge	Container Number	Container Charge
Co #10	Dow Chemical Corporation	330	\$2,015.	13	\$1,875.
23	Dow Chemical Corporation	1100	5,840.	7	1,600.
11	MIT (Replacing Co #9)	915			
21 N-1	Stanford Research (Making up curie deficit)	2000			
22	Rock Island Arsenal	504	2,860.	1	1,380.
25	Esso Engineering & Developing Company	3153	16,115.		
28 N-5	Glenn L. Martin Company	295	1,665.		
32	U. of Chicago (Replacing Co #11)	1143			
33	California Research (Replacing Co #10)	916			
36	General Electric Company	885	4,765.		
37	Diamond Alkali	767	4,175.	6	1,675.
4 Flat Co	B. F. Goodrich Company	1378	7,650.		
			Total		\$6,530.
					\$45,085.

Indian Head Arsenal
 Purolator Corporation
 Walter Kidde Company
 Graton and Knight
 Armstrong Cork
 National Filter
 Glenn L. Martin Company
 Tracerlab
 American Polymer
 S. A. Goldblith (MIT)
 Republic Steel
 Bell Telephone
 Flintkote
 Westvaco Corporation
 India AEC
 Atlantic Refinery

The total income received from off-site users was \$46,697 as compared with \$29,734 for fiscal '54. On-site users of the gamma irradiation facility were billed for \$82,815.

The source days for on-site users totaled 1,975; by off-site users, 978 days.

The accompanying graph (Figure 6) compares the source days used and the income for the fiscal periods from '52 to the present.

SPECIAL RADIOISOTOPES DEVELOPMENT

Iodine-133

Two processes were studied this past year for the production of fission product iodine-133 (21-hr

half-life). The first uses direct controlled dry ignition of an irradiated uranium foil; the iodine is released as the metallic uranium disintegrates into the oxide powder and is swept out of the reaction vessel with the excess oxidizing gas. The second process is a wet distillation method and comprises irradiating U_3O_8 , dissolving this in 50 percent H_2SO_4 , and distilling over part of the resulting solution with the dropwise addition of hydrogen peroxide. Although both methods are satisfactory, the latter is being used at the present time since it gives a higher yield and is somewhat more reproducible.

Yttrium-90

The problem of making macro beads, hard, uniform clay spheres of 0.035 in. diameter, containing stable yttrium was completed. Such spheres can now be made available for medical research and other purposes. The diameter may be varied within limits. These spheres when irradiated in the Brookhaven reactor will have about 0.5 mc of yttrium-90 per milligram of finished particle.

A small amount of work has been performed in an attempt to develop a *simple* milking system whereby this very important β -emitting yttrium isotope (65-hr half-life) could be separated from its long-lived β -emitting strontium parent. Although still incomplete, results indicate that an ion exchange process may prove quite satisfactory.

Figure 6. Income and use of gamma irradiation service.

Fluorine-18

During the past year, the yields of 112-min fluorine-18 were improved and the process scaled up to permit production of 10 mc batches of this isotope, in a physiologically compatible solution. This development work is now complete. The proposed price has been approved and the availability of this isotope in batches of 1 mc to 8 mc has been announced.

Cesium-137

Some work was done with a new inorganic cation exchange resin to adsorb activity from large volumes of water containing 9×10^{-8} curies of old fission products per milliliter. The purpose of this experiment was two-fold: (1) to pre-clean waste liquid prior to concentrating and to further clean concentrated wastes, and (2) to concentrate cesium-137 activity into a source which could then be used for (gamma) irradiation purposes. In the work performed so far, essentially all the cesium activity from 50 liters of waste was concentrated into a few milliliters of solution; this activity was shown to be pure cesium-137.

Magnesium-28

The reaction, $\text{Mg}^{26}(\text{t,p})\text{Mg}^{28}$, has been confirmed by using (1) a fused mixture of lithium nitrate and magnesium nitrate, (2) a mechanical mixture of lithium carbonate and magnesium carbonate, and (3) a fused alloy of elemental lithium and magnesium, and irradiating these systems in the reactor. The tritons for this secondary reaction are provided by the $\text{Li}^6(\text{n},\alpha)\text{H}^3$ reaction. Interest on the part of others in magnesium-28 is apparently considerable, and the effort here has been to determine optimum conditions for giving the highest specific activity of this isotope. Although this work is not quite complete, results indicate that the fused alloy will probably give the highest specific activity, with such values approaching the useful range. This work will continue.

Iodine-132

The already simple "generator" for supplying iodine-132 was still further simplified, several of

these "super-simple" generators have now been built and placed in routine use with completely satisfactory results.

Molybdenum-99

Work was recently begun on the development of a method of producing millicurie quantities of molybdenum-99, at the request of a potential customer.

Beta Coating for Balloons

During the year some work was done on the problem of applying relatively large amounts of pure beta emitter to the surface of a thin rubber balloon. A balloon thus coated completely or in part could then be introduced into any of the various body cavities and when inflated would put the active material in direct contact with tumors growing on the inner surface of such cavities. A technique was worked out which was satisfactory for coating small patches of such a balloon with relatively small amounts of beta-emitting material. This work, however, was temporarily suspended partly because of the press of more important work and partly because it became obvious that the relatively large amounts of activity that would be desirable to use would present a serious handling problem.

Tagged Micro Beads

The Ginell-Simon method of making micron size clay beads was modified somewhat and an apparatus set up for the small scale production of such beads. These beads contain approximately 50 percent by weight montmorillonite clay; the remainder is an oxide of either yttrium, cesium, or some other suitable element. When these beads are irradiated in the reactor the characteristic radiations of the tagged element (in this case yttrium-90 or cesium-134) are produced. Possible sizes range from 1 to about 30μ in diameter; classification before irradiation separates the beads into groups, in each of which the size variation from bead to bead can be kept to within a few percent. Although primarily used thus far for medical research where a small concentrated source of radiation is desired in chemically inert form, these beads have also been used for other purposes such as determining the sedimentation rate in sewage.

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 extremely 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 used extensively and is still 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 now an important part of the research and educational activities of the Department. This summer (1955) there are 24 scientists and 31 students working in the Department. Thus the scientific activities of the Department are more than doubled during the summer.

RADIATION-INDUCED MUTATIONS IN PLANTS

One of the important problems under study is the question of whether there is a threshold for the production of mutations by radiation. Most studies in the past have indicated that there is no threshold, and that any radiation received by the germinal tissue has a finite probability of producing a mutation. Recent work with plants has tended to throw some doubt on this concept. Several different loci in corn have been tested in large enough numbers to produce quite sure results, and there appears to be a dose of radiation that can be given which produces no more mutations than the controls (spontaneous rate). However, for somatic mutations in carna-

tions, several mutations in barley, and mutations in the mold *Neurospora*, there seems to be a straight line relation between mutation rate and dose which indicates no threshold. These latter data are in agreement with data from other laboratories on mutations in *Drosophila*. Thus, the present indication is that there is a threshold for some mutations and not for others, but the question is as yet still largely unresolved.

A closely related problem is the one of the changes in radiation mutation sensitivity during pollen development. The results reported last year, that mutation rate in corn for a given radiation dose is highest when the tassels are irradiated shortly before pollen shedding and lowest when they are irradiated just prior to meiosis, have been confirmed and extended. The differences in sensitivity are certainly higher than a factor of ten for all genes so far tested, and may be as high as a factor of 100. The physiological state of the plant at the time of irradiation may be very important in determining the radiation mutation sensitivity. Such factors as time of day, humidity, and temperature are being investigated; the present indication is that all these factors do play a part, and the exact relationships are being worked out.

It was reported last year that an experiment had been performed to test the feasibility of producing new varieties of plants with specific, predetermined characteristics by means of radiation-induced mutations. A rust-resistant variety of oats was produced from a variety which was very susceptible to this disease. This work has now been confirmed and extended. *Helminthosporium* blight resistance was induced in certain strains of oats with a frequency as high as 3 percent of the plant progenies tested.

As an interesting by-product of this work, a number of different mutants have appeared in the irradiated grains. One oat mutant has considerably shorter, stronger straw with wider leaves and a more dense spike than normal. This may have considerable practical importance. One very interesting wheat mutant has very short awns which is typical of a cross between awn and awnless forms. This

Figure 1. Oat seedlings infected with *Helminthosporium* blight. The plants on the right hand side of the flat are a naturally resistant strain of oats and did not succumb to the disease. The plants in the rest of the flat were from seed of a very susceptible variety which had been irradiated with thermal neutrons. It can be seen that mutations were produced in three of the seeds which rendered them resistant to the blight. These plants were grown to maturity and their progeny represent a new variety of oats.

appears to demonstrate for the first time that a dominant mutation of a morphological nature can be induced with radiation.

From other genetic studies it has been found that for the Victoria variety of oats, resistance to the blight *Helminthosporium* is a closely linked genetic character to crown rust susceptibility. It was thus not surprising to find that in a variety which was originally susceptible to blight and resistant to rust, that radiation-induced mutants which had been screened for resistance to blight also had susceptibility to rust. However, there is an indication in some of the mutants that the nature of the rust susceptibility is considerably changed. This is the most promising method for breaking such very close linkages, but it will certainly be much more difficult than producing simple mutations.

As a result of a study of various radiation-induced mutants of corn, a mutable system was found as part of the genetic structure of some plants. Mutation is controlled by a dominant factor, which when present in the system will induce dominant to recessive mutations for the loci on every chromosome

tested. Analysis of the types of mutations for loci on the various chromosomes reveals the nature of the mutable system. It appears that every chromosome may have a number of sites where the mutation activator may induce chromosome breakage with resulting dominant to recessive mosaic mutations. These sites are more prevalent near chromosome ends.

It was reported last year that carnations which have been grown in the gamma field produce somatic mutations as indicated by changes in flower color or size. It has now been found that carnations which are grown in the gamma field at very high dosages, so high that they produce almost no growth while in the field, will exhibit a great many mutations when moved to the greenhouse and grown out there. A number of plants have three different kinds of flowers blooming simultaneously.

In producing somatic mutations of this kind there has always been considerable question as to whether such mutations are produced more efficiently by long-continued radiation at a low level, or by intense radiation for a short period of time. Several

Figure 2. Mutation in carnation flower. The normal flower is on the left and the mutant, a very much smaller flower but otherwise identical, is on the right.

Figure 3. Hydroponic growth of corn plants. The solutions are very carefully controlled, and each has a different chemical composition. It has been found that the spontaneous mutation rate is greatly affected by the composition of nutrient, and that calcium and potassium are the most important ions in determining the mutation rate.

Figure 4. Blueberry plant growing in the gamma field. It has been there for two years and has not grown nor formed more than a very few leaves, but it continues to bear fruit.

Figure 5. X-ray induced mutation in barley. The plant on the right is the control and the plant on the left is the mutant. It has shorter, stiffer straw and a more dense head.

experiments are in progress to test this question. Experiments with roses and apples are going on and an experiment with carnations has given very preliminary indications that the short intense exposure may be the most efficient for this type of plant.

Another important question is whether it is more efficient to produce such somatic mutations by incorporation of a radioactive material into the growing plant than by chronic, external gamma irradiation. Mutations have been produced by growing carnations in a nutrient solution containing P^{32} .

Last year it was reported that, as a result of attempts to find factors responsible for radiation-induced mutations, it had been noted that the nutrient medium of the plant is very important for determining the mutation rate. On low calcium concentrations in the nutrient medium both the radiation-induced mutations and the spontaneous mutations are increased by as much as a factor of 20. The calcium deficiency effect is reduced in the presence of low potassium. This reduction could be explained by a potassium-calcium antagonism where, in the presence of low potassium, calcium is more easily transported from roots to inflorescence.

The cooperative program designed to produce useful mutations in agriculturally important plants and trees continues to expand. During the year an arrangement was completed whereby Canadian universities and experiment stations were included in the program. There are now more than 100 institutions in the program. Brookhaven continues to perform the irradiation, act in an advisory capacity, and collect and analyze the data. The individual institutions initiate the program, grow the material and screen it for the desired mutations.

It is becoming increasingly apparent that dosage control from a biological point of view is extremely important. The moisture content of seeds greatly affects the sensitivity, so the seeds are being stored in a controlled atmosphere for a period before irradiation, in order to achieve better dosage control. From a biological point of view, dosage control can be achieved much better with neutrons than with x-rays, and neutrons appear to be much better than x-rays for mutation production. However, most experiments are still being run with both neutrons and x-rays since it is felt that this should be proved on a practical scale.

The biology thermal column at the reactor, which is used for the neutron irradiations, has been in con-

tinuous use. Even so, work has fallen somewhat behind and it has been decided to make another neutron irradiation facility at the reactor to take care of the anticipated increased demand.

The phase of the program which involves the growing of trees and other woody material in the gamma field is expanding very little. It is felt that this is the phase of the program which has been tested least, and it probably should not be expanded until the present experiments so indicate. A number of the trees and bushes which were planted in the spring of 1952 were moved from the field to their original institutions where they will be grown and observed for the desired mutations. Most of these had been exposed at very high dosage rates and had grown almost not at all. The hope is that nearly every latent growing point contains one or more mutations which will grow out to produce a whole branch mutation.

Although positive results are very few as yet, the program continues to appear very promising. Research at the University of Minnesota has produced a rust-resistant variety of wheat and also a barley variety with considerably stiffer straw. The Boyce Thompson Institute has produced a strain of tobacco with different photoperiod response and a considerably higher yield. The North Dakota Agricultural Experiment Station has obtained a variety of flax resistant to a prevalent rust disease. There are a number of other interesting mutations, but the great majority of the material has not been tested adequately yet. However, there seems little doubt that many interesting new varieties of plants will come from this work.

An exhibit demonstrating this work was prepared for the meeting of the National Academy of Sciences in Washington, April 26, 1955 and the same exhibit is being prepared for the "Atoms for Peace" meeting in Geneva in August 1955.

GENETICS

The work in *Drosophila* genetics for the past year has been primarily concerned with the changes in sensitivity to x-irradiation of cells during oögenesis. Female *Drosophila* are subjected to rather large doses of radiation and mated at different times thereafter. No significant difference in fecundity was detected between control and irradiated female flies which indicates that there is little or no selection for mutant-free cells. Two types of mutations

Figure 6. An x-ray induced bilateral gyandromorph of *Drosophila*. The radiation induced a mutation very early in embryonic development which changed this animal from a normal female to an animal which is male on the left side and female on the right.

Figure 7. Chart showing stages of egg development in *Drosophila*. Table indicates the x-ray sensitivity of the cells in the different stages of development, and shows that mature eggs are extremely sensitive to radiation from a genetic point of view.

were studied, dominant lethal mutations and x-chromosome elimination; and for both types the mutation rates changed in the same way. The rate is fairly constant in the first eggs laid, then falls abruptly to a lower constant rate and subsequently declines to the control level. These data have been correlated with the cell types which were actually subjected to the radiation. The data indicate that x-irradiation induces many more chromosome breaks in mature than in immature ovarian cells. The observed rates for sex-linked recessive lethals and x-chromosome losses in mature cells are reduced to a proportionally greater degree than in immature cells because where higher primary breakage occurs more potential mutants are lost by being drawn into chromosome configurations which function as dominant lethal mutations.

These results indicate that either oögonia do not respond to x-rays or dominant lethal bearing oögonia cannot proceed as far as meiotic prophase. Thus, if one eliminates the first 230 eggs produced and scores all subsequent ones, the offspring would be free of dominant lethal mutants even though their mother received 2,000 r of x-rays.

It is obvious that such results are of considerable practical importance for a consideration of the pos-

sible genetic effects of radiations in man. If a sufficient time elapses between the exposure to radiation (a few menstrual periods) and fertilization, the incidence of dominant lethal mutations will be very low. This does not, of course, imply anything with reference to point mutations.

Methods have been worked out for screening large numbers of *Neurospora macroconidia* for specific biochemical mutants. X-irradiation will induce such mutations in quite high frequencies, and for one glutamic acid locus mutation rates as high as 18 per 10,000 conidia have been observed. It appears that there is a straight line relation between mutations and x-ray dose.

In the course of these studies it was observed that *Neurospora* germination is stimulated by small doses of x-irradiation. At a dose of 3000 r there is almost 100 percent germination, while there is about 75 percent germination in the control populations. This could probably best be interpreted as a damage to the system which normally inhibits germination.

RADIOBIOLOGY

It has been found that plants exposed to chronic radiation either in the gamma field or the gamma greenhouse all show various growth abnormalities. One of the most striking of these is a radiation-induced tumor in tobacco plants; other plants are stimulated to flower earlier, some have changed photoperiod requirements, etc. There is a very wide divergence of radiosensitivity among different plants and one of the problems under study for some time has been the question of the factors responsible for these differences. A great deal of data has been collected and several theories tested, but so far no satisfactory theory has been evolved.

The finding that irradiation will greatly prolong the storage life of potatoes has been confirmed not only at this Laboratory but at others. The same phenomenon has been shown to be true for other root vegetables, notably onions. It now seems safe to say that for vegetables whose storage life is limited by sprouting, the storage life can be greatly increased by radiation. There is considerable commercial and military interest in this problem and the Laboratory sponsored, on May 25, 1955, a conference on the subject attended by 125 representatives. The Laboratory has turned the project over to the State experiment stations and is now concerned with it only in an advisory capacity.

Figure 8. Close-up view of the growing end of a shoot on an apple tree grown in the gamma field. This is typical of such trees, and shows that there is almost no stem elongation but there is considerable lateral growth, with many leaves coming from the resultant knob.

Figure 9. Plants growing in the gamma greenhouse. The cobalt source is in the pipe extending into the ground at the back of the picture. A V-shaped wall of lead bricks protects the plants in the adjoining greenhouse from the radiation. This facility makes a very valuable adjunct to the gamma field.

Figure 10. Representative bulbs of yellow sweet spanish onions stored 153 days at 55° F. Left, control; center, irradiated with 1000 r; and right, irradiated with 2000 r prior to storage.

Figure 11. Bar graph showing different response of seeds to soaking for x-rays, thermal neutrons and fast neutrons. This illustrates the qualitative differences between these three types of radiation.

As a direct outcome of the work on potato irradiation, work has been carried out in conjunction with the US Department of Agriculture Nematode Research Laboratory to investigate the possibility of using radiation for nematode control. It is found that relatively small doses of radiation, while they do not affect the normal life of the nematode, cause an effective sterility of the organism. This offers the distinct possibility of controlling the spread of nematode infection by irradiation of all potatoes coming from an infected area.

This result also opens up the possibility of controlling many other nematode infections by the use of radiation. For example, it is difficult to control nematode infections in strawberry plants, and by the use of radiation it should be possible to sterilize all plants and thus control the disease. This aspect of the application of radiation to the control of plant disease is also under study in conjunction with the Nematode Laboratory.

It was reported last year that there are certain qualitative differences between irradiation with x-rays, thermal neutrons and fast neutrons. Dormant seeds respond differently to the different radiations, depending upon such factors as water content, temperature, previous treatment and atmospheric gases. Some of these differences can be at least qualitatively accounted for by the dilution of sensitive material. Thermal neutrons affect the nitrogen and boron primarily and an increase in water content dilutes these elements so it is not surprising to find the radiosensitivity decreasing with increasing water content. On the other hand, fast neutrons produce these effects primarily by proton recoils, so it is not surprising to find the radiosensitivity increasing with increasing water concentration.

However, it has been found that soaking seeds at 0°C does not change their sensitivity very much to any of the radiations as compared with the changes which are made at higher temperatures. Largely for this reason, it is felt now that most of the striking effects one sees are due to the physiological changes taking place as a result of these treatments.

So far no treatments have been found which markedly affect the nonuniformity of the response of seeds to x-rays. As long as this situation prevails, it appears that neutron irradiation will be the most effective by a considerable factor for the production of mutations.

The parasitic wasp *Habrobracon* can be grown either as the haploid or the diploid. One prevalent theory of radiation damage postulates that the damage is directly proportional to the genome number. This has been tested here and found not to be true. The relative sensitivity of haploids and diploids were markedly different for different stages of development; during certain stages haploids are more sensitive and during others, diploids are more sensitive.

It is found that various gases have a very marked effect on the radiosensitivity of *Habrobracon*. Oxygen has by far the most striking effect; and the sensitivity is decreased by as much as a factor of 3 by excluding oxygen during the irradiation. An atmosphere of pure oxygen causes an arrest of development, but a careful analysis has indicated that this is an unrelated phenomenon to the increased radiosensitivity in high oxygen atmospheres. In this connection, it is interesting that *Habrobracon* are more radiosensitive in atmospheres of hydrogen than in nitrogen or carbon dioxide.

It has been known for some time that DNA synthesis in cells is seriously affected by relatively small doses of radiation and a study has been under way to investigate this phenomenon. Methods have been worked out for measuring the P^{32} uptake in relation to DNA content in *Tradescantia* microspores during different stages of microsporogenesis.

The work has led to the following conclusions: 1) P^{32} incorporation occurs prior to DNA synthesis, 2) this incorporation is apparently all in the phosphoprotein fraction, 3) P^{32} is also incorporated during and following DNA synthesis; some is incorporated into DNA and some into phosphoprotein, 4) actual DNA synthesis occurs very rapidly and occupies only a brief portion of the cycle, 5) although there is no strict correlation, a general correspondence exists between cytological appearance and stage of DNA synthesis.

BIOPHYSICS

For several years there has been an increasing conviction on the part of radiobiologists that the linear energy transfer (LET) of a particular radiation is of primary importance in determining the biological effectiveness of the radiation. Alpha particles, deuterons and protons from the Brookhaven 60-inch cyclotron have been used to test this hypothesis. The test was the inactivation of dry T-1 bacteriophage.

It has been found, contrary to expectations, that over quite a wide range of LET values from different energies of radiation, the inactivation is a linear function of LET. It would be expected that a saturation value of ionization density would be reached eventually, but even with rather slow alpha particles

Figure 12. Drawing of thermal column showing way in which material is inserted and removed from the column.

it appears that saturation has not been reached. Experiments are in progress using beams of stripped carbon atoms, to determine if and when saturation is reached.

When energy of the three radiations was adjusted to have the same LET, the cross section for this material was found to be $5.2 \times 10^{-12} \text{cm}^2$ for all three radiations. This further confirms the idea that density of ionization is the important factor in radiosensitivity.

The thermal column continues to be used constantly, and much of the work in this report is based on work done in this facility. Quantitative value of the work depends upon an accurate physical calibration of the facility, which has been done in cooperation with the Health Physics Division.

At the thermal column, the chief problem is the measurement of gamma rays in the presence of a large neutron flux. Absorbers of pure lithium metal have been made and an absorption curve indicates that there is a gamma ray flux in the facility of about 115 r/hr. A special gas flow graphite ionization chamber has also been constructed; it has been found to function very well and, where applicable, appears to be the best instrument yet devised for the accurate measurement of gamma rays in the presence of neutrons. Results with this method confirm the lithium extrapolation method very closely. These results show that, depending on the material treated, 80 to 90 percent of the biological effects produced by exposure in the thermal column are due to neutrons and the remainder to gamma rays.

The fast neutron facility, which utilizes a U^{235} "converter plate" placed in the thermal column, is not calibrated as accurately as the thermal column. Sulfur and plutonium foil calibrations have placed the fast neutron flux at about $2.5 \times 10^8 \text{ n/cm}^2/\text{sec}$. The gamma ray flux is much less well known, but is probably about 7 r/min. The thermal neutron flux is negligible from a biological point of view. This means that the biological effect is 80 to 90 percent a fast neutron effect.

The demand on the thermal column has become so great that it was necessary to look for an additional neutron facility. There is a tunnel under the reactor which can be used for such exposures. By appropriate shielding the gamma ray flux can be reduced to quite low values, and whereas the neutrons are neither completely thermal nor completely fast, they are quite satisfactory for many purposes.

RADIATION EFFECTS IN MAMMALS

It was found here several years ago that the removal of the thyroid gland plus a large dose of radiation will produce a tumor of the pituitary gland. It was found that this tumor is transplantable and is a tumor specifically of the cells of the pituitary responsible for the production of thyrotropic hormones. It has also been found that the removal of the thyroid plus irradiation of the body without irradiation of the head produces a tumor as does the converse, i.e. irradiation of the head with the body shielded. Furthermore, it has been found that removal of the gonads plus irradiation produces a pituitary tumor specific to the cells producing gonadotrophic hormone. These experiments give radiation an essential but nonspecific role in tumor production. Two explanations of its action seem equally tenable: the production of a carcinogenic toxin or action as a nonspecific stress. Experiments are under way to test these theories.

It was reported last year, in a preliminary report, that when rats are subjected to radiation there is a toxin produced in the animal which can be detected by injecting small amounts of the plasma into adrenalectomized mice. Such a toxic factor has been long suspected in connection with radiation damage but this was the first demonstration of it. This has now been abundantly confirmed here as well as at another laboratory. Furthermore, it has been found that this toxin reaches its highest concentration in the blood about 48 hours after the radiation. It also acts in the same way as radiation in that it is additive with it. The toxin is destroyed on standing for 30 minutes at room temperature but will keep overnight at 0°C . The effect of the toxin is to produce symptoms which are qualitatively similar to those produced by radiation.

One hypothesis for the hemoglobin synthesis following radiation injury is that it is due to a deficiency in erythropoiesis. The fall and subsequent rise in two classes of reticulocytes following irradiation of duck red cells substantiate this hypothesis. If one then plots the numbers of the two classes as a function of time following x-irradiation, it is found that the curves can be explained very well, assuming that Class I reticulocytes develop into Class II reticulocytes, which in turn develop into erythrocytes. By studying the incorporation of radioactive iron, it was found that hemoglobin synthesis takes

place only in Class I reticulocytes. The Class I reticulocytes are very sensitive to radiation, and these facts seem to account completely for the events in the erythropoietic system after irradiation.

The problem of the defects in physiological function associated with radiation damage have been under active study for several years. Factors such as blood sugar levels, liver glycogen levels, adrenal ascorbic acid and cholesterol levels have been studied. One of the most accurate indices of damage is the body weight, and as little as 50 r can be detected by this method.

These studies have shown that the ability of the pituitary-adrenal system to respond to irradiation is dependent upon the nutritional state of the animal. However it is now apparent that the radiation syndrome is quite different from that of starvation alone. Tests indicate that actually the protein synthesis involved in the synthesis of the hormones is relatively unimpaired, but the target organs are not as able to respond as one would expect from a comparable stress.

It has been known for several years that radiation can induce premature aging in animals. A program has been initiated to attempt to elucidate this phenomenon. Animals have been treated on various regimes and are now developing symptoms of aging. Methods are being worked out for a dynamic study of the capillary circulation in relation to aging and radiation damage in mice.

BIOCHEMISTRY

A study has been under way for several years on the isolation of C^{14} -labeled intermediates in plant metabolism, and the isolation and identification of the enzyme systems responsible for the reactions that are involved.

An important recent finding is that the pathway for glucose metabolism in the plant depends upon the age of the tissue being investigated. Young tissue in the plants studied so far tends to metabolize sugar via the Embden-Meyerhoff glycolytic scheme; and as the tissue grows older it tends to shift to the hexosemonophosphate shunt pathway. This is one of the few quantitative observations that have ever been made which indicates that physiologically speaking old tissue is different from young tissue.

An investigation of the $C^{14}O_2$ fixation by *E. coli* has been undertaken when the organism is ferment-

ing pentose. Present indications are that the organism possesses at least two sites of CO_2 fixation: 1) the normal Wood-Werkman reaction and 2) probably a C_2+CO_2 reaction.

An investigation has been undertaken on the carbohydrate metabolism of root tissue. The metabolism here is found to be very similar to that of the leaf tissue with two very interesting exceptions: 1) the aldolase concentration appears to be very low and 2) plants grown in gravel in which there is excess oxygen surrounding the roots have a much lower aldolase concentration than those grown in sand in which there is a low oxygen concentration. These observations are in harmony with the ones indicating a different pathway for young and old tissue.

The primary carboxylation reaction of photosynthesis is the carboxylation of ribulose diphosphate to give two molecules of phosphoglyceric acid. The enzyme responsible for the reaction is associated with the chloroplasts of high plants, and can be isolated from them by destroying the chloroplasts.

A study of the distribution of this enzyme has been undertaken and it has been found that it is not only associated with chloroplasts but exists in photosynthetic organisms, nonphotosynthetic organisms and in other specialized tissues of plants, other than chloroplasts.

The stem of the Lombardy poplar contains systematically arranged preformed root primordia which are produced as part of the normal development of the plant. When cuttings of the stem are suspended in a damp chamber in darkness for 5-6 days, these root primordia emerge, while even very small amounts of light inhibit emergence. This reaction is thus a photosensitive one, and apparently depends upon some substance elaborated by the roots which, acting in conjunction with the light normally present at the stems, keeps the reaction inhibited.

A study has been under way for several years of the fundamental mechanisms of enzyme action as elucidated by tracer techniques. The general approach to this problem is to label substrates in specific places. Then, by analysis of the enzymatic degradation products, the exact pathway of the breakdown is determined and, from this it is attempted to deduce the way in which the enzyme was able to effect the breakdown. Phosphorylation reactions have been the principal reactions studied.

As a result of these studies, it has been possible to formulate a tentative theory of enzymatic reactions. This theory essentially implies that no basic change in mechanism occurs on going from simple organic and inorganic catalysis to the protein enzymes. It can be shown that this hypothesis can lead to an explanation of stereochemical changes in enzymatic reactions, and to a generalization relating enzyme specificity to the point of cleavage in hydrolytic reactions.

Work has started on a study of the incorporation of labeled sugars into more complex molecules by feeding the labeled sugars to mice to determine the factors responsible for the regulation of carbohydrate metabolism in animals.

Methods have been worked out for measuring in the dog the rate of body glucose turnover by means of C^{14} -labeled glucose. Preliminary results were obtained which indicate that hypophysectomized dogs have about twice the normal rate of body glucose turnover. Furthermore, in normal dogs the injection of insulin causes a very rapid decline in the blood sugar levels which is accompanied by a fall in the glucose utilization rate.

Present indications are that the deficient secretion of glucose by the liver in response to hypoglycemia is the critical factor in the insulin hypersensitivity of the hypophysectomized dog. Also, hypophysectomized dogs have smaller glucose pools than do normal dogs.

A method for an accurate indication of the rate of glucose metabolism in dogs by means of constant intravenous infusion of C^{14} -labeled glucose has been developed. In both the normal and hypophysectomized dogs about 50 percent of the glucose which disappears from the plasma is converted rapidly to CO_2 . This amounts to about 15 percent of the total respiratory CO_2 formed.

MAMMALIAN PHYSIOLOGY

A study has been under way under highly controlled conditions of the factors responsible for the exchange of substances between cells and the circulation. An apparatus has been perfected which measures the capillary permeability in the blood-perfused hind limb of the cat with considerable accuracy. Use of labeled substances in conjunction with other metabolites makes it possible to obtain a dynamic picture of the capillary permeability.

The resultant theory of capillary permeability explains most of the known phenomena of capillary exchange. The theory postulates a dual mechanism for the diffusion of substances through the capillary wall; one class of substances goes through the wall as by diffusion through an inert porous membrane, and the other class of substances is soluble in the membrane itself and is thus able to penetrate the membrane very rapidly.

Capillary permeability to fluid, protein and sucrose, and pre- and post-capillary hydrodynamic resistance were measured in the perfused hindquarters of normal and adrenalectomized rats. No permeability difference between the two groups was observed, nor was permeability affected by adding adrenal extract to the perfusion fluid. Aqueous adrenal cortical extract was found to contain a vasoconstrictor agent readily destroyed by oxidation in alkaline solutions and therefore presumed to be epinephrine. The reported effects of such extracts on capillary permeability are attributed to this vasoconstrictor action.

A study was undertaken to determine the way in which various substances perfused into the tissues from the circulation. It was found that for all solutes the diffusion curves were double exponentials. A theoretical analysis of these curves has been made in terms of permeability and blood flow. This analysis led to the conclusion that the vascular bed of the perfused tissues is divided into two parallel regions, one well perfused and one poorly perfused, and differing by a factor of ten in their rate of perfusion.

In a study of the way in which antigens invade tissue and evoke antibody formation, diphtheria toxoid has been labeled with I^{131} and injected in the foot pad of guinea pigs. Its rate of elimination from the skin, lymph nodes and blood has been followed and compared with control experiments with labeled sodium iodide and diiodotyrosine. It was found that the antigen was not eliminated more rapidly than would be expected from normal catabolism. The antigen was, however, retained longer in the antibody-producing tissues. The time-concentration curves of the antibody have been followed in a) the skin of the foot pad which was the site of inoculation, b) the draining popliteal lymph node antibody and c) the serum. From these data it was concluded that lymph node antibody is a measure of the rate of antibody production and that serum

antibody represents the accumulation of antibody liberated into the blood stream. The antibody found at the injection site is supplied from the blood and is not produced locally in significant amounts.

The basic mechanism by which various odors are perceived is almost completely unknown. Work was initiated two years ago to attempt to elucidate this mechanism by means of electrical recording methods from microelectrodes, combined with precise labeling and autoradiographic techniques.

Electrical recording from single cells in the olfactory bulb of rabbits revealed the presence of at least three different groups of neurons in the olfactory bulb. Cells in the first group discharge spontaneously, irregularly and with no relationship to the animal's respiratory cycle. Units of the second group discharge intermittently in bursts and these bursts of activity are synchronized with the respiratory cycle occurring during inhalation. These first two units are not sensitive to olfactory stimulation. Units of the third group are characterized by the fact that their discharge patterns may be altered by olfactory stimulation. They give a response to specialized odors, and will respond to some odors but not respond to very closely associated odors. This is the first demonstration of electrical activity as a result of olfactory stimulation. It also gives, for the first time, considerable reason for believing that the olfactory bulb serves some functions besides olfaction.

A problem was undertaken about a year ago to work out, from a pathological point of view, the course of development of hepatic cirrhosis in sheep. A series of animals has been infected and sacrificed at appropriate times. The tissues are now being studied. A preliminary survey seems to indicate that the connective tissue arises from the periphery of the bile ducts and gradually involves the entire liver.

Another problem presented itself when a group of guinea pigs was received which was infected with a hitherto undescribed disease. It is characterized by swollen leg muscles and impaired locomotion which is not of nervous origin. The disease is quite infectious, and the nature of the organism and the infection it causes is under investigation.

In work on deficiencies in vision in cats a condition was found which appears to be a degeneration of the brain and retina. It is probably due to a nutritional disturbance, and the present indications are that some foods contain fairly high concentra-

tions of the enzyme thiaminase which hydrolyzes thiamin. Thus the lesions are essentially those of thiamin deficiency.

This work arose from some studies of the lesions produced in the retina and optic nerve by the virus of canine distemper. This disease has long been known to have ocular symptoms but the pathological basis has remained unknown. This study has described the course of the disease, demonstrating demyelination of the optic nerve, neuronal degeneration in the ganglion cell layer of the retina and perivascular lymphocytic infiltration in the optic nerve layer of the retina.

MEDICINE

During the past year the senior staff of the Medical Department has been augmented by four scientists. In addition, nineteen scientists from seven institutions held extended appointments as research collaborators at the Laboratory, and twelve students from eleven colleges and universities engaged in the medical student program. Several consultants from other medical centers have continued to collaborate with staff members here on mutual research problems. Two foreign scientists, from England and South Africa, participated in the laboratory work under the Exchange-Visitor Program sponsored by the US State Department.

Further increases and changes in staff are being planned, to coincide with the availability of facilities in the Medical Center now in the design stage. To assure optimum benefit from the medical reactor for Brookhaven scientists and research collaborators from other sites, the Department staff has devoted considerable study to facilities at other research institutions. The final engineering plans are now being drawn up; it is hoped that construction will be under way before the end of the present fiscal year.

Work on the several scientific programs of the Department has continued steadily during the year. With increased experience in the use of the Laboratory's facilities, the future research program is expected to expand in its variety and in its effectiveness. The many difficulties inherent in clinical investigation are being overcome, and a marked increase in this type of investigation is planned over the next few years.

CLINICAL INVESTIGATION

The heart of any medical research program is that portion concerned with clinical investigation. At Brookhaven, this phase of the program has been gradually growing, both in its extent and in the approach to more basic problems.

Radioisotopes have provided tools for elucidation of complex disease processes, the evaluation of classical therapy, and in a few fields, for the therapy itself. In all these areas studies are under way in the Medical Department. For convenience the discussion to follow is written in two parts: 1) cancer, 2) disease states other than cancer. In some instances both conditions are studied and when this has occurred the discussion is found under the second section.

Cancer

When cancer is isolated in the body, frequently it can be removed surgically in its entirety and a cure effected. Sometimes, however, when the patient seeks the physician's aid the malignancy has become

Figure 1. Alpha tracks produced by thermal neutron bombardment of mouse brain containing boron. There are also some spurious proton tracks that cannot be differentiated from alpha tracks. Work done by Dr. P. Gerald Kruger on leave from University of Illinois.

Figure 2. Medical facility at the reactor; the treatment cone, arrangement of shielding materials and the shutter are shown.

widespread through many body structures. For this, no effective chemical, x-radiation or radioisotope therapy is known. Studies are under way to explore the usefulness of different radioactive isotopes in control of such metastatic cancer and also in alleviation of some of its more distressing manifestations. Two years ago Dr. Dudley at St. Albans Naval Hospital, together with Dr. Foster, both BNL Research Collaborators, noted that some pain alleviation seemed to result after radioactive gallium tracer studies in patients whose cancer had spread to the bony structures.

At this time the Department was interested in establishing a means of predicting the hazard of a given dose of radioisotope to the blood-forming organs. Therefore, a combined study was begun on radioactive gallium to determine if tracer studies with gallium would give the same prediction of hazard to the bone marrow as was achieved with radioactive iodine for thyroid cancer, and at the same time to evaluate the effect of isotopic radiation on pain alleviation. Patients were sought with metastatic

cancer for whom present methods for control of severe pain had failed. Since many meticulous studies were required for each individual, the number who could be treated was small if data were to be accumulated at an assimilable rate. Thus far, seventeen patients have been studied, nine with metastatic cancer of the breast, three with metastatic cancer of the prostate, four with multiple myeloma and one with osteogenic sarcoma. About one out of three patients was significantly relieved from pain for periods extending up to several months, although no significant retardation of disease ravages can be seen. The hematologic response to gallium-72 in these patients is different from the response to iodine-131 by thyroid cancer patients with metastases. The same prediction observations therefore cannot be made. However, as a result of these studies some very significant observations on the blood have been made. These relate not only to the time of response to radiation and recovery therefrom but also to therapy of bleeding states after radiation and the mechanisms by which blood clots and tissue hemorrhages can be prevented. These will be discussed briefly elsewhere under blood studies.

During the past year no further tests were made in the control of cancer arising in the liver or arising elsewhere and metastasizing to that organ. However, tracer studies were done on a patient with a bile fistula which yielded valuable information on the rates of excretion from the liver via the bile ducts—the primary pathway. Previous tests had shown a severe hematologic disturbance followed manganese-56 therapy and additional data on complexing agents for manganese were desirable before the therapeutic trials were resumed. With information now available it is believed the safety factor can be materially enhanced, and therapeutic studies are planned for renewal this year.

The use of the nuclear reactor for neutron capture therapy has continued. The neutrons can react with a capture element, boron-10, which has been injected into the blood stream as a soluble borate and has diffused into brain tumor tissue. The B^{10} will disintegrate into Li^7 and He^4 and these atoms, being energetic, will then be utilized to destroy brain tumor glioblastoma multiforme for which there is no satisfactory treatment at hand. Five patients with this disease were treated during this fiscal year, at a

Figure 3. Histology of tumor in patient A.H. before neutron capture therapy. Figure 4. Histology of tumor in patient A.H. after neutron capture therapy. Note extensive scarring and nuclear variation.

higher thermal neutron flux than was previously given, and one additional patient previously treated was given a second exposure. Although it will probably be a long while before this therapeutic method can be expected to reach its full effectiveness, life span in general in the second series was almost doubled over that observed in the first. It is hoped that with further improvements life span will be extended for more than one year after treatment. Thus far as of this writing no patient in the second series has survived a full year, the maximum survival being 337 days. Maximum survival in the first series was six months.

Severe skin changes have presented a serious problem with the new, higher flux, facility. The exact mechanism by which these are produced is not known. Animal experiments as well as instrumentation studies now under way will, it is hoped, solve this complication. Extensive studies on the pharmacology and toxicology of boron are reported elsewhere. These have made it possible safely to increase the dose of boron administered to one far larger than was believed feasible when this project began in 1951. It is clear that with these larger boron doses extensive animal studies are required to establish the innocuousness of the procedure for normal brain tissue.

Diseases Other than Cancer

Hypertension—There is no known approach to therapy of hypertension through radioactive isotopes, but some aspects of the disease and response to treatment have been studied by the Department at least in part with radioactive isotopes. It is a well established observation that many persons suffering from hypertension will on a low sodium diet experience a fall in blood pressure which may be very significant. The mechanism by which this is accomplished is not known, nor is it known whether dietary sodium *per se* may cause or produce hypertension. The studies in this Department have been concerned with elucidation of the role of sodium, whether it be primary or secondary, in hypertensive disease. What happens to body economy when sodium intake is restricted and what, if any, compensatory changes occur in the other electrolytes? Various projects are planned from year to year and groups of patients with hypertensive disease are admitted for extensive study, with the use of radioactive isotopes. Usually five or six patients constitute a group which is admitted generally for a

period of three months each. During the past fiscal year 15 such patients were admitted for study in three groups. Some of the results have been reported in detail and will be found in the list of departmental publications. (See Appendix A.)

Studies on the blood and its constituents—Work has begun on the coagulation defects noted in thrombocytopenia and the effects of platelet transfusion to patients in such a condition after radioisotope therapy. While effective therapy has been achieved for a hemorrhagic state in one individual, observations made during the study have raised many questions on the role of platelets, which will require additional studies and experiments to elucidate.

Investigation of thyroid disturbances—Some disturbances of the thyroid result in hyperfunction, which can be distinguished without too much difficulty and, when indicated, can be adequately controlled with radioactive iodine. Much more prevalent is a condition of hypothyroidism; it is more difficult to diagnose and the total changes in body economy are not fully known. As with other tissues of the body, the thyroid occasionally becomes cancerous, and if initial surgery is not successful in eliminating it, repeated doses of iodine-131 appear to be useful in controlling it. Clinical investigations bearing on all three of these disease states have been carried on during the past year.

In the markedly hypothyroid person a condition called myxedema exists. It is characterized by an increase in extracellular body water which, contrary to normal situations, contains measurable amounts of protein. No exact knowledge was available regarding the protein quantities present in this fluid. By utilizing normal human serum albumin labeled with I^{131} , it is possible to study the protein and to observe the effects of various thyroid hormonal substances. A complex study on the extravascular albumin compartments in myxedematous and euthyroid (normal) states was carried out.

Collaboration with investigators from the Sloan-Kettering Institute has made possible, with reference to a three-compartment doubly open schematic model, analysis of plasma and urine data from euthyroid and myxedematous patients given I^{131} -labeled human serum albumin. Rate constants and compartment sizes derived from the analysis showed a 70-percent increase in the size of the extravascular albumin compartments in the myxedematous state. This was associated with an outward capillary transport constant

approximately twice normal, while little change was found in the proportional rate of feedback to plasma.

The study of long-term therapy of thyroid carcinoma with repeated doses of I^{131} is continuing. At present, attention is centering on an analysis of hematologic response to initial therapeutic radioiodine compared with the response to subsequent isotope administration. These data are of importance in giving information on the recovery of hematopoietic tissue after repeated insults.

Hyperthyroid patients who required I^{131} for control of their disease have been the subject of appropriate additional scientific studies simultaneously carried out to further knowledge regarding radioisotopic therapy of this disease.

Studies on the nephrotic syndrome—This very complex disorder has been under investigation for several years. The nature of the disease with disturbances in mineral metabolism, protein metabolism, and body water distribution constitutes a real challenge to the clinical investigator. Studies have been carried out with radioactive isotopes on distribution of electrolytes; apparent hyperfunction of the thyroid gland has been shown with radioactive iodine; abnormalities of urinary protein excretion have been studied with isolation of a low molecular weight protein during the past year. Studies on abnormal calcium metabolism are in progress. As more information has been obtained regarding protein metabolism it has been possible with labeled proteins to carry out studies of considerable interest on the albumin pool in these patients. Further detailed studies on many facts of both protein and lipid metabolism are planned.

Diabetes Mellitus—Despite the enormous accumulation of data in regard to this widespread disease, many aspects of it still cannot satisfactorily be explained. Hypotheses concerning intermediate metabolites can in many instances be tested with appropriately labeled substrates. During the past year intensive studies have centered on a few patients to establish whether or not alternate pathways exist during a diabetic state for conversion of fat to carbohydrate. The use of carbon-14 in specific positions of various compounds appears most useful in study of this complex phenomenon. The studies were carried out in patients with labile diabetes during a short interval when complete control had not been effected.

LABORATORY INVESTIGATION

As can be seen from the preceding section, laboratory data on the effects of radiation on living tissue can be very useful in the design of new approaches to the treatment of malignant disease with radiation. One of the first problems is the relative biological effectiveness of different forms of radiation.

The effects of the thermal neutron beam from the medical facility of the Brookhaven reactor have been compared with the effects of cobalt-60 gamma radiation. The lethality and the ability of these two types of radiation to depress the weight of the spleen and thymus of mice by the third day after radiation were taken as measures of their biological potency. If a dose of 19 micrograms of boron-10 was injected per gram of mouse 5 minutes before exposure, the rem dose rate resulting from the reactor beam was approximately doubled. The relative biological effectiveness of the heavy particles from slow neutron capture by boron relative to gamma radiation was found to be approximately 1.4. On the other hand, the LD-50 dose for alpha rays arising from thermal neutron capture by boron in a unicellular organism, *Diplococcus pneumonia*, appeared to be about 10,000 rep, the same as for gamma rays.

An instrument containing three ionization chambers is being used in the medical facility of the reactor to evaluate radiation received by tissue from the various components of the beam. The first ionization chamber is constructed of materials which simulate the radiochemical properties of tissue. The second is similar but contains no nitrogen so that the neutron capture effect of nitrogen is eliminated. The third is similar to the first but also contains boron which produces conditions paralleling those found in the therapeutic experiments. The chambers themselves were developed at the Radiological Research Laboratories of Columbia University.

Borates injected into the blood streams diffuse more slowly into normal brain tissue than into tumor tissue. Consequently a neutron beam that passes through tumor and adjacent normal brain tissue immediately after an intravenous injection of a soluble B^{10} borate causes, by the alpha emission from the B^{10} , a destructive effect limited chiefly to the tumor. Conditions for improving the treatment have been explored by studying the properties of different boron compounds and their behavior on intravenous

injection into animals. Several types of borates and their coordination compounds with glucose have been studied. Glucose in combining with borates increases the solubility of the borates, decreases their toxicity, and may retard the rate at which they diffuse from blood into tissues. These effects have been subjected to quantitative studies.

There are reasons to expect that giving the borate infusions by injection into the carotid artery, instead of into the arm, may have advantages. Because the carotid artery leads directly to the brain, it should be possible to maintain the desired concentration of boron in the brain circulation with smaller amounts than when the injection is made into the arm; in this way the possibility of toxic borate effects will be decreased as well as the amount of boron that gets into the skin circulation. The latter effect should decrease the severity of skin burns from the neutron beam used in brain tumor treatments. These effects are being studied in animal experiments.

Before any isotope can be used in radiation therapy, it is necessary to know how it is distributed in the body. A study has been made of the distribution of manganese in experimental animals. Mn^{52} was injected in two forms, as manganous chloride and as a coordination compound with ethylenediaminetetraacetic acid. Manganese injected as manganous ion disappeared rapidly from the plasma into the tissues where it was concentrated in mitochondria. It was excreted into the feces via the bile. When manganese was coordinated with ethylenediaminetetraacetic acid, the major part of the dose was excreted as the chelate into the urine. By means of the Shubert ion exchange method, the coordination constants for the reaction of manganous ion with plasma protein, certain bile pigments, several bile acids, and with the adenosinephosphates have been measured.

Since the distribution of metal ion can be so strongly influenced by coordination prior to injection, a comparison was made of the distribution of copper-64, coordinated as copper protoporphyrin with the distribution of copper-64 injected as ionic copper. Mice, some of them carrying tumors, were used in this study. The concentration of the copper protoporphyrin in the tumors was usually several times that in the surrounding tissues. However, the concentration of copper protoporphyrin in the liver, spleen, and lungs was even greater than in the tumors.

Studies of the effects of radiation on animals are being continued. One important facet of radiation injury is the pronounced fall in circulating platelets which occurs. Sulfur-35 labeling has been used in studies on the formation and destruction of platelets. An effort is being made to obtain a better understanding of the role of platelets in the hemorrhagic conditions following radiation.

In studies of the skin lesions of rats exposed to beta radiation from a strontium-yttrium $Sr^{90}Yt^{90}$ source, it has been found that semistarvation has a preventive effect. A skin ulcer 5×5 mm or larger and lasting 5 or more days was chosen as a critical endpoint. Twenty of 21 normally fed controls showed such an ulcer, but only 4 of the 22 semistarved animals showed a reaction of this intensity.

The functional disturbances associated with damage to the intestine in the intestinal phase of radiation injury have hitherto not been thoroughly studied. Intestinal loops have been prepared in dogs and the rate of transfer of electrolytes between the lumen and the blood are being studied before and after radiation.

As one of the physiological factors that may be affected by radiation, choline esterase has been studied. In homogenates of the electric eel organ the enzyme showed resistance to gamma radiation from Co^{60} . On ultracentrifugation a sediment was obtained. The acetylcholinesterase activity of the supernatant was then sensitive to radiation. When the sediment was resuspended, the former resistance to radiation was restored. This would indicate that the acetylcholinesterase is protected by factors present in the sedimentable fraction.

The carcinogenic effect of radiation from both internal and external sources is being studied. When male Sprague-Dawley rats were given small doses (from 2 to 50 microcuries) of I^{131} and their progress was followed for approximately two years, no increase in the incidence of pituitary and thyroid carcinoma was noted. Increasing the amount of I^{131} to 400 μc had no effect on the incidence of carcinomas in the Sprague-Dawley rats, but did produce an increased incidence of pituitary tumors in Long-Evans rats.

From another series of experiments it would appear that whole body irradiation from a Co^{60} gamma

source, in the sublethal range ($120\mu\text{-}400\lambda$) significantly shortens the induction time for mammary tumors in rats. On the other hand, graded local beta radiation of rat skin with a Sr^{90} applicator (1316-2635 rep) has failed to produce malignant lesions.

Astatine, element 85, is a cyclotron-made halogen of atomic weight above iodine in the periodic table. At^{211} has a half-life of 7.5 hours and emits alpha particles at 5.9 and 7.4 Mev. Astatine-211, therefore, has two very desirable features. Its precise intracellular location can be determined by radioautographic techniques, and the energy of its α -particles is such as to suggest that it might be therapeutically effective against tumors and microorganisms. If antibody protein could be combined with astatine a great deal of information could be obtained on the distribution of antibody protein in infection, hyperimmune reactions, and malignant disease. Furthermore, astatinated antibody protein might serve as a vehicle for delivering α -radiation to therapeutically desirable targets, viz. tissues with which the antibody may combine. It has been found that immune globulins can indeed be astatinated, although astatination does not appear to be chemically analogous to iodination of tyrosine residues. The distribution of some astatinated globulin injected into rabbits and mice is now being studied.

Since astatine is a halogen, it is perhaps not surprising to find that, like iodine, it is concentrated by the thyroid. However, the thyroid gland apparently cannot synthesize astatine into an analogue of the thyroid hormone. Studies with Re^{188} , which lies between iodine and astatine in group VII of the periodic table, but which is a member of subgroup A rather than a true halogen of subgroup B, is also concentrated by the gland, but again it is probably not incorporated into a thyroxine-like compound.

The effects of several factors on the uptake of iodine by the thyroid gland have been studied. It had been reported that the antihelminthic, thiophenylamine, lowers the thyroidal accumulation of ^{131}I in rats. Experiments carried out with this material indicate that the effect was due to contamination of the substance with small amounts of stable iodine that had not been removed from the compound during its synthesis. Statements in the literature that *N*-methylphenylethylbarbituric acid increases the

thyroidal accumulation of ^{131}I in rats have been confirmed. The effect does not occur when the pituitary is removed. Cortisone has been previously observed to decrease the uptake of ^{131}I by the thyroid. Experiments with 3-day old chicks indicate that the effect, in this case, is directly on the thyroid and does not involve the pituitary.

The rapid diffusion equilibrium of inert gases between tissue and blood makes the rate loss of such a gas from tissue dependent upon blood flow when the arterial blood is free of the gas. Radioxenon, which is almost entirely cleared from the blood stream with a single passage through the lung, might theoretically be used to measure organ blood flow. The radioxenon and Kety-Schmidt methods for cerebral blood flow gave values in good agreement. The values for muscle and hepatic blood flow were reproducible and within the expected range. Xenon was found to have an affinity for hemoglobin which required use of a correction factor.

A technique utilizing radioactive K^{42} and coronary sinus catheterization has been used to study potassium transport between the plasma and interstitial fluid and between the interstitial fluid and intracellular fluid of the dog heart. The data suggest that one of the actions of digitalis is an inhibition of the influx of potassium into the heart muscle. Other studies with K^{42} indicate that most of the cerebrospinal fluid is formed by the choroid plexus and by the capillaries deep in the brain which are surrounded by Virchow-Robin spaces.

A study of the effect of lack of oxygen on circulation in the lung was undertaken in dogs. Measurements were made of pulmonary arterial pressure, while cardiac output was determined by an isotope dilution technique employing K^{42} . The resistance to blood flow through the lungs increased as did the pulmonary volume. These effects were attributed to pulmonary vasoconstriction.

A study of S^{35} -labeled methionine in chick embryo has given valuable information concerning tissue organization and protein synthesis. It had been observed that if a piece of adult chicken spleen was grown on the chorioallantoic membrane of a chicken egg the spleen of chick embryo enlarged until it was completely out of proportion to the rest of the embryo. The protein of adult birds was tagged with S^{35} .

labeled methionine and pieces of their labeled spleens were transplanted onto the chorioallantoic membrane. When the embryos were sacrificed, the concentration of S^{35} in the embryonic spleens was at least 2.4 times that of the other embryonic tissue, and the data indicated that 15 percent of the protein of embryonic spleen was derived from the graft spleen. In control experiments S^{35} -labeled methionine was injected into the yolk sac of eggs carrying unlabeled grafts. Under these conditions the specific activity of the embryonic spleen was no greater than that found in other organs. There appears to be good evidence, therefore, that the stimulation of embryonic spleen growth is accompanied by the transfer of adult spleen protein to the embryonic spleen.

When an animal is infected with trichinae (commonly caused by eating infected pork) the larvae pass from the intestines into the muscles, where they become encysted and remain indefinitely. It has been uncertain whether in the cysts the organisms are entirely dormant, or continue active metabolism, with exchange of materials with the host, in which case they might be open to attack by antibiotics. The problem was approached by feeding infected mice C^{14} -labeled amino acids. The incorporation of C^{14} into the larval protein indicated that there is an active metabolism, even in the encapsulated state.

Monoamine oxidase is an enzyme that oxidizes amines in the body, and thereby limits their effects. The activity of the enzyme has been found to be reversibly affected by aliphatic hydrocarbons and alcohols. At 4° the effect is to retard the activity. With straight chain compounds the effect varied markedly with the chain length; chains of 7 and 8 carbons showed the most effective retardation. At higher temperatures the retarding effect diminished. At 22° to 23° there was no effect by the hydrocarbons. At 60° the effect changed to one of acceleration of the enzyme action.

It is known that certain unsaturated fatty acids are indispensable parts of the animal diet; lack of these fatty acids retards growth and causes skin lesions. Experiments are in progress to find what part these fatty acids play in metabolism. Glycerol labeled with C^{14} was fed to two groups of rats; one group was normal, the other suffering from the deficiency. An hour after feeding the rats were killed and the fats

in their livers were studied. It was found that the deficient rats incorporated only about one-third as much of the glycerol C^{14} into their liver fats as the normal rats. Apparently deficiency of the essential fatty acids produced a condition in which the utilization of fats in general was affected.

Studies on the structural chemistry of proteins have centered on the α -1 glycoprotein of plasma, and on collagen, the structural protein of bone, skin and connective tissue. The study of the α -1 acid glycoprotein of plasma began when an investigation of the trichloroacetic acid soluble protein excreted by nephrotic urine revealed that this was the same α -1 acid glycoprotein previously reported as a constituent of human plasma. It had the same electrophoretic mobility, gave a precipitin reaction with antiserum from rabbits immunized with α -1 glycoprotein and had the same nitrogen, galactose, mannose, and glucosamine contents. Present studies are directed at an understanding of the nature of the bond which links the protein and carbohydrate residues, the nature of this linkage being unknown for any of the ubiquitous glycoproteins found in the body.

Hydroxylysine is an amino acid that has been found only in collagen. Its mode of introduction into the collagen molecule and its contribution to the properties of collagen are under study. By feeding young rats uniformly C^{14} -labeled lysine it has been shown that the hydroxylysine incorporated into the collagen was formed entirely from lysine. Recent experiments in which C^{14} -labeled hydroxylysine has been similarly fed showed no incorporation into the collagen. It appears that the animal must first incorporate lysine, into either the collagen or some intermediate compound, and thereafter hydroxylate it to form hydroxylysine.

ADMINISTRATIVE REPORT

The major administrative efforts during the year centered around studies of procedures considered most efficient for work in the new Center, but which could be initiated, at least on a trial basis, in the present facilities. Preliminary reviews of all hospital activities were conducted by appropriate personnel in preparation for an accreditation inspection by the Joint Commission on Accreditation. The technical staff of the hospital was strengthened with the addition of a registered medical records librarian and an ADA dietician.

Total patient days in the hospital were 6,457 compared with 7,028 the previous year, and admissions were 79 compared with 95; this change reflects the time required for evaluation of technique and findings as reported earlier. Care of research patients accounted for 6,326 or 98 percent of the total patient days. Out-patient visits of research patients increased from 188 to 226, and the number of research admissions from beyond New York State increased from 50 percent to 60 percent of the total. The Occupational Therapy program, so important to patients away from home and visitors and particularly those confined for several months, was curtailed due to loss of the head theapist who had conducted an outstanding program during the past several years. By arrangement with the local school district, the children of school age were tutored by a trained teacher on a part-time basis.

Total clinic visits to the Industrial Medicine Di-

vision again increased considerably with 9,500 visits for the year compared to 8,850 last year and 7,392 the year before. Total x-ray visits decreased slightly to 1,894 from 1,947 the previous year.

Two exhibits on neutron capture therapy were constructed for the Laboratory by Copeland Displays, Inc. Identical except for language, one was loaned to the United States Information Agency for use in the atomic energy exhibit at the Sao Paulo, Brazil Worlds Fair; the other, translated into German, was purchased by the Agency for showing in Europe.

An A. Cressy Morrison Prize in Natural Science awarded annually by the New York Academy of Sciences was won by Dr. L. V. Maynard and Dr. George C. Cotzias for the work reported in their paper entitled, "*In vivo* partition of manganese among some organs and intracellular organelles of the rat."

TECHNICAL OPERATIONS AND SERVICES

In direct support of the research program, a number of organizational units in the Laboratory provide the necessary technical services and facilities. These essential functions are described below, under the appropriate headings.

REACTOR OPERATIONS

The reactor has continued to support research of all the scientific departments of the Laboratory, of a number of outside organizations under the auspices of the Reactor Department, and of many others by arrangement with other BNL departments.

Five members of the Physics Department of Columbia University continue as guests—two working full time on the Columbia spectrometer program, in investigations on nonmagnetic neutron-electron interactions; one full time with Brookhaven's Neutron Physics group; and two others using the Columbia spectrometer intermittently. The Westinghouse Atomic Power Division completed one project here during the third quarter. However, negotiations are presently under way in connection with several programs to be carried out here by personnel of this organization. The General Electric Company's Research Laboratory continues its spectrometer studies, handled on a rotating visit basis; these researches are enumerated in this report in the section on Solid State Physics. California Research Corporation personnel visited Brookhaven three times during the year, to use the reactor in the development of organic reactor coolants and moderators. In their work, over 170 samples of organic materials were irradiated under various conditions. In conjunction with this program, a study of slow and resonance neutron fluxes was made with the use of various monitors. Some of the other outside groups availing themselves of Brookhaven's reactor research facilities are: Monsanto, Bell Telephone Laboratories, Rensselaer Polytechnic Institute, and New York University. In most of these cases, Reactor Department staff provides technical assistance wherever necessary.

During the year, representatives from the US Army Ordnance Corps and the US Military Academy

were stationed here as guests working on shift operations, for education and observation purposes.

Two new subdivisions have been organized in the Department: a Special Services Group to fabricate replacement fuel elements and to prepare irradiated fuel for shipment and reprocessing, and an Enriched Fuel Project Group, manned by personnel from various departments on a loan basis, assigned full time to the development phases of the plan to reload the reactor with enriched uranium.

The reactor operated at an average of 24.64 Mw per hour of operation. The maximum power level reached was 26 Mw. As of June 30, 1955, there were 31,500.23 megawatt days accumulated: a total of 8,041 megawatt days for the year as against 7,244 during the preceding year. Downtime averaged 9.7 percent, as against 16.89 percent for last year. This downtime included a special experiment as well as an extended maintenance shutdown during December, 1954.

A study made of the emergency shutdown system and its past performance has resulted in several major modifications of the circuits without any sacrifice of the safety factor. Improvements have been made in the instrument power supply system by the addition of automatic transfer and self-resetting equipment. The galvanometer system was completely rebuilt. The period circuits and temperature recorders have also been modified for more efficient and accurate operation. The latter modifications were the result of a study of operating procedures versus fuel element failure which determined the advantages of limiting temperature increases and decreases during startup and shutdowns to 2°C per minute. Maintenance of the control rod drives and the cooling tower and primary fans included complete routine inspection, service, and overhaul of these systems. However, no major emergency breakdowns were experienced.

The shutter of the medical neutron therapy facility on top of the pile was rebuilt after it jammed because of expansion of some of its shield materials.

The water-cooled irradiation facility (at W-24) developed a leak which led to its being rebuilt. De-

mand for use of this facility resulted in a second, larger facility being installed (at W-52).

One of the less routine operations jobs was the removal of a block of bismuth from the core hole. It was originally used as a gamma ray filter in connection with the Physics Department's fast chopper. Removal was effected through the south plenum chamber to avoid disturbing the chopper equipment installation.

Several extensions of balconies and floor loading capacities have been made to accommodate the ever-increasing array of experimental equipment installed at the vertical faces of the pile.

Studies of the physics, metallurgy, and aerodynamics involved in the use of a new type of enriched uranium fuel element have led to the design and preliminary testing of a few sample elements in the reactor. These tests have demonstrated feasibility and a test program of enlarged scope is planned for the immediate future. In connection with the tests, air flow measurement instruments have been developed. Figure 1 is a photograph of the fuel element under development. If these fuel elements, of highly enriched uranium-235, were distributed over approximately the same number of fuel channels as are presently loaded, it has been calculated that the maximum central neutron flux will be increased from its present level of $5 \times 10^{12}/\text{cm}^2\text{-sec}$ to about $3 \times 10^{13}/\text{cm}^2\text{-sec}$.

ISOTOPE DISTRIBUTION AND SPECIAL MATERIALS

RADIOGRAPHY

Development work on radiography has continued. In particular, it has been found that Polaroid self-developing film can be used where rapid results without fine detail are desired. Total time for exposure and developing to a finished picture is about 3 min by this method. This technique has been used in the past year to determine liquid levels in closed metal loops.

Further development work has included fabricating a 37-mc iridium "point" source weighing only 1.5 mg. This has been used satisfactorily for making direct enlargements of small objects being radiographed (as opposed to a photographic enlargement of a small "contact" radiograph).

Figure 1. Proposed type of new fuel element of enriched uranium which is now under development.

Uses for the radiographic service have been extended to include locating internal reinforcing bars and conduits embedded in floors and walls prior to drilling or cutting holes. This application was used to advantage in connection with moving some bolted-down machinery in the Hot Laboratory building; with this technique it was possible to relocate the machinery in such a way that metal already embedded in the floor did not interfere with bolt-down in the new location, and a considerable number of man-hours were saved in installation time thereby.

A source has been mounted permanently in one of the experimental loops in order to speed up and simplify repeated radiography of a section of this loop; source-to-film distance has been standardized and repeated transportation of a heavy shield has been eliminated.

A series of radiographs of ten thin aluminum-clad fuel elements were made with thulium-170 for the source of radiation. The soft gammas from this source permitted precise location of the fuel inside the cladding prior to sectioning.

Sources now in use include Co^{60} , Ir^{192} , Tm^{170} , and Cs^{137} . A total of 1431 service radiographs were made during the year.

The volume of radioisotope and service irradiation shipments, which increased 12 percent last year,

Table 1
Three-year summary of shipments

External users	1955 — 1954		1954 — 1953		1953 — 1952	
Target conveyor	894	\$42,907.00	799	\$40,899.00	737	\$40,590.00
Pneumatic tubes	57	2,990.00	41	1,316.00	68	1,495.00
Air-cooled holes	49	5,914.00	28	6,492.00	12	4,175.00
Water-cooled holes	48	3,591.00	16	1,726.00	24	825.00
Thermal column	12	456.00	6	330.00	18	912.00
Experimental holes	76	13,011.00	42	7,633.00	24	6,533.00
Tunnels	2	604.00	....	.....	....	.....
Liquid N ₂ cooled facility	4	1,032.00	....	.....	....	.....
Core hole	1	925.00	....	.....	....	.....
Gas facility	2	.....	....	.....	....	.....
Special	105	1,872.00	36	50.00	12	190.00
Iodine-132	27	1,768.00	....	.....	....	.....
Fluorine-18	7	315.00	....	.....	....	.....
Yttrium-90	4	200.00	....	.....	....	.....
Sub-totals	1288	75,585.00	968	58,446.00	895	54,720.00
Multicurie Co ⁶⁰	10	50,025.00	3	15,185.00	5	52,382.00
Rentals		71,615.00		68,943.00		61,493.00
Sub-totals	1298	197,225.00	971	142,574.00	900	168,595.00
Cyclotron	27	4,762.00	4	275.00	....	.....
Biology	1	249.00	....	.....	....	.....
Totals	1326	202,236.00	975	142,849.00	900	168,595.00

showed a 36 percent increase this year. The rate of these off-site shipments, over the last quarter, was approximately 30 per week. A total of 522 shipments was made to 17 hospitals; 374 were to 25 universities; and 430 went to 61 industrial organizations and government agencies. The total number of customers served increased from 123 to 156. In addition to irradiation services at the Brookhaven reactor, three processed radioisotopes, iodine-132, fluorine-18, and yttrium-90, in special forms developed by the Hot Laboratory, are now available commercially. The Biology Department has established a service for biological irradiation with neutrons, x-rays, and ultraviolet. Off-site use of the Brookhaven 60-inch cyclotron increased substantially. At the request of the US Atomic Energy Commission, several cyclotron-bombarded shipments were made to the Oak Ridge National Laboratory to aid their rubidium-82 production, since the Oak Ridge cyclotron was shut down most of the year.

The formulation of a satisfactory over-all Commission pricing policy has been a continuing problem. Several discussions were held with Commission personnel at which time cost estimates for BNL reactor services were prepared. On September 1, 1954, a new price schedule was put into effect which

covers standard reactor radioisotope units. This price schedule allows for a premium to be placed on higher flux reactors. At the time these prices were put into effect, the BNL handling charge was reduced to \$20.

On March 15, 1955, on an interim policy basis pending final Commission approval, a revision was made in the BNL pricing formula for nonroutine service irradiations. This schedule calls for a standard irradiation charge of \$10 for the first day, plus \$2 per day thereafter, to which is added a standard handling charge, and, in some cases, a surcharge based specifically on the particular irradiation facility used. This change resulted in about a 75 percent average reduction in the price for service irradiations in the reactor.

The brochure detailing the services available at the Brookhaven National Laboratory, together with the revised pricing schedules, has finally been reviewed by the Commission, and will be available in the near future.

A total of 199 orders, requiring prior Commission approval, were processed; there were 100 for radioisotopes, 57 for stable isotopes, and 42 for sources and special materials. Against these orders, 259 shipments were received, processed, and distributed.

Figure 2. Monthly shipments from the Isotopes and Special Materials Group.

HOT LABORATORY OPERATIONS

DEVELOPMENT

Work has continued on the fabrication of beta-emitting sources which, while very small in size, produce a very intense radiation level; a number of such sources have been produced.

A manually operated rectilinear manipulator incorporating considerable improvements over the previous two manipulators was completed and is ready for installation. All motions on the new manipulator are direct push-pull and friction has been reduced to a minimum.

An articulated tongs of a design which is considerably different from any previously known tongs was completed. Tests have shown it to be satisfactory in operation; it gives greater freedom of motion than conventional ball-swivel tongs.

A motor-driven, mechanical can opener has been fabricated for opening containers used for irradiating samples.

LIQUID WASTE OPERATIONS

Operations of the liquid waste collection area and the waste concentration system handled about the same volumes of waste as in the previous year. The activity level of the "F" Waste released to the Laboratory sewer system and the activity processed by the concentration unit showed a considerable increase over the previous period, an indication of the increased work loads and the stepping-up of work with radioactive materials.

The efficiency of the concentration operation was greatly improved during the year and gave a 45 percent increase in the volume reduction achieved. Also the time interval required between descaling operations was increased greatly by the addition of a water softener to the feed solution.

The figures in Table 2 indicate the magnitude of the liquid waste operations for the past year.

Table 2

"F" Waste Discharged to the Sewer				
Period	Volume (gal)	Average activity level (c/ml)	Total activity (mc)	
Fiscal 1954	2,078,471	2.05×10^{-11}	163.89	
Fiscal 1955	2,837,985	3.10×10^{-11}	332.40	
Waste Concentration				
Feed (gal)	427,885			
Average volume reduction	130			
Drummed concentrate (gal)	3,298			
Number of drums of concentrate	121			
Waste Inventory				
	Fiscal 1954		Fiscal 1955	
	"D" Waste	"A" Waste	"D" Waste	"A" Waste
Volume on hand at beginning of fiscal year (gal)	168,704	1590	157,340	1758
Volume received during year (gal)	424,589	168	365,650	443
Volume to evaporator (gal)	435,953		427,885	
Volume on hand at end of fiscal year (gal)	157,340	1758	95,105	2201

HEALTH PHYSICS

The work of the Health Physics Division of the Instrumentation and Health Physics Department in keeping track of radiation and contamination levels throughout the Laboratory becomes increasingly complex each year. The reactor and the Cosmotron are the areas of major responsibility, but the other accelerators, the Hot Laboratory and the Biology, Chemistry and Medical laboratories require frequent attention.

There has been a great reduction in the number of cases of gross contamination of the reactor building, which reflects improved techniques of operation. In the pile canal area, however, gamma levels are usually 100 mr/hr or less, but beta exposure rates of 3 to 18 times those due to gammas are encountered, and gross contamination from the canal water must be controlled.

Levels at the Cosmotron continue to increase with values as high as 60 mrem per hour in the control room for full intensity operation at 3 Bev. The control room average for the year was 123 mrem per shift week, but for the 25 weeks during which the machine was actually operating the average was 256 mrem per shift week. Some improvements in shielding were made during the year, and more will follow, to keep pace with the improved efficiency of the machine. Health physics surveys at the Cosmotron were time-consuming because of the diverse modes of operation and the large areas with widely varying levels that are involved. Cosmotron survey data were used to predict roughly the radiation levels to be expected from the proposed 30-Bev accelerator. Such an estimate was needed as a guide in choosing the location and shielding arrangements for the new machine.

An intensive series of background radiation measurements was made at selected locations in the area to be occupied by the proposed new medical center. The levels observed varied widely in the range 0.01—1.0 mr/hr because of pile effluent and the effect of the Co^{60} source at the nearby Biology greenhouse.

As a part of the area survey program, daily measurements were made of the radioactive fallout present in rain and settled dust. These data have a bearing on the local contamination control program and are of considerable general interest. Figure 3 shows a plot of weekly averages in disintegrations per minute per square meter of horizontal surface per day

Figure 3. Weekly averages of the rate of fallout of radioactivity at BNL.

for the year ending June 30, 1955. The total fallout for the year amounted to $1.7 \mu\text{c}$ per square meter, or an average rate of $10,500 \text{ dis/min/m}^2/\text{day}$.

RESEARCH AND DEVELOPMENT

As in the past, the Division has carried on a small research and development program consisting of projects concerned with radiation dosimetry, or closely related to practical problems of radiation protection. The only major improvement in facilities was the construction and standardization of a high level Co^{60} calibration range providing 29.9 r/hr at a distance of 1 meter.

Detailed dosimetry methods for determining thermal neutron and gamma ray exposures in the Biology

thermal column during rat irradiations were worked out and used for a specific experiment in cooperation with one of the biologists.

The values of energy per ion pair expended in air and in six different gases during the absorption of 2-Mev gamma rays were determined in a joint program with the Instrumentation Division. Relative values were obtained with an improved extrapolation chamber and absolute values by means of the ferrous sulfate reaction.

Considerable effort was spent in developing sensitive threshold detectors for use at the Cosmotron. Values of neutron flux above approximately 2, 11 and 20 Mev were obtained with the use of sulfur, sodium iodide and anthracene detectors, respectively. The necessary sensitivity was achieved by using large scintillators mounted on photomultiplier tubes and by means of a scintillator-phosphor combination sometimes called a "phoswich." Much more work along these lines remains to be done.

WASTE DISPOSAL

The scope and complexity of problems connected with the disposal of radioactive wastes increased considerably during the year. This was partly caused by an increased level of waste-producing work at the reactor and partly because long-lived activities are continually becoming more prominent in fuel elements and other components discharged from the pile.

A one-year accumulation of waste packaged in 55-gal drums for sea burial was shipped to Floyd Bennett Field in May and was dumped at sea by

the Navy. The shipment consisted of 685 barrels containing an estimated 597 c of radioactivity as compared with 476 barrels and 233 c for the previous year.

Arrangements have been set up for using the active concentrate from the liquid waste evaporation plant as the liquid component of the concrete used to line and top the 55-gal drums used for solid wastes. Thus, both liquid and solid wastes are combined in the same barrels and considerable saving results.

An increasing amount of difficult decontamination work is being done at the waste disposal area. Cleaning of tools used by reactor operations personnel and of tubes used to store discharged fuel elements are important examples. In the case of the tubes, a machine which automatically rotates and scrubs them in a detergent bath was designed and constructed locally and has been very effective in reducing exposures and speeding up the job. This work not only saves the cost of new equipment but avoids the necessity for disposal of discarded items, which is often very difficult and costly, both in terms of money and of personnel exposure.

The liquid waste system operated much as in the past except that about twice as much activity was discharged. This increase was due to controlled release of dilute wastes but it brought the total activity discharged up to only 18.5 percent of the value permitted by present policy. A summary of operating data for the liquid waste system is presented in Table 3, together with the averages for the previous year.

Table 3
Summary of liquid waste data

Item	July—Sept 1954	Oct—Dec 1954	Jan—March 1955	April—June 1955	1954-55 Average	1953-54 Average
Input to filter beds (gal/day)	401,000	308,000	308,000	995,000	503,000	332,125
Output from filter beds (gal/day)	354,000	291,000	316,000	332,000	323,250	279,000
Net loss in filter beds (%)	11.7	5.6	— 2.7	16.0	7.7	16
Stream above discharge point (gal/day)	127,000	342,000	914,000	575,000	489,500	107,625
Stream at site boundary (gal/day)	505,000	855,000	1,467,000	982,000	952,250	507,000
Rainfall (in./mo)	7.7	4.54	2.52	3.02	4.45	3.02
Activity concentration at input to filter beds (c/cc)	4.2×10^{-13}	5.4×10^{-13}	3.8×10^{-13}	7.2×10^{-13}	5.2×10^{-13}	2.84×10^{-13}
Activity concentration at output from filter beds (c/cc)	1.1×10^{-13}	1.1×10^{-13}	1.2×10^{-13}	2.7×10^{-13}	1.5×10^{-13}	0.63×10^{-13}
Reduction in activity concentration (%)	73	80	69	61	71	75
Activity at input to filter beds (mc/mo)	18.8	18.4	12.8	31.7	20.4	9.79
Activity at output from filter beds (mc/mo)	4.7	3.7	4.2	10.2	5.7	1.93
Percent of permissible	14.3	21.9	12.8	25.1	18.5	9.5

PERSONNEL MONITORING

The scale of operations of the Personnel Monitoring group as shown in Table 4 remained about the same as last year except for a continuing gradual increase in the use of nuclear track films for monitoring at the Cosmotron. The off-site neutron monitoring service continued at a fairly even rate which averaged 381 badges per week.

Table 4

Use of personnel monitoring equipment

	1954-55	1953-54
Pairs of pocket chambers	1,082	1,313
Regular film badges	960	903
Visitors' film badges—On-site	125	167
Visitors' film badges—Off-site	156	135
Total film badges	1,241	1,205
Neutron films used	409	369
Neutron films read	286	223

Figures have been averaged on a per week basis.

Personnel exposures for the year showed a significant increase but were still very low except for the Reactor Operations Group and the individuals working regularly with the Cosmotron. The prescribed exposure limit of 300 mrem per week averaged over any 13-week period was exceeded in only one instance, the value for the case being 310 mrem. Exposure control at the pile has required continual improvement in pile operations techniques. An analysis of the personnel monitoring records of 160 individuals who worked regularly at the pile from July to December 1954 showed an average exposure of 39 mrem/week. This represents an increase from the value of 27 mrem/week for the same period of 1953. Forty individuals averaged 20 percent or more of the 300 mrem per week limit, the highest being 73 percent. Investigations of all cases of exposure over 300 mrem in any one week were continued and averaged 23 per week as compared with 5 for the previous year. The increase noted in the exposure levels, like the increase in radioactive waste, results from the increased volume of work and the increase in long-lived activities to be handled.

A detailed study was made of the cost of the various services provided by the Personnel Monitoring group. The results were as follows:

\$1.04 per off-site neutron film badge

0.88 per BNL neutron film badge

0.37 per BNL β/γ film badge

0.13 per pair of pocket chambers processed.

In computing these costs the standard laboratory charges for insurance and overhead were included, as well as direct costs for material and labor.

METEOROLOGY

The meteorological research activities* have been largely devoted to the power spectrum analysis of wind and oil-fog data; this was initially described in the last annual progress report. The development of a program for accomplishing this work on the Atomic Energy Commission's Univac, at New York University, has occupied much of the past 6 months. The main program for the analysis itself is completed, and the subsidiary program designed to translate raw data into suitable form is currently being tested. From the fragmentary information available so far, it would appear that, during the daytime, convective eddies generated from the heating of the earth's surface by the sun are by far the most important fluctuations. Figure 4, showing the power spectrum derived from a test made during typical daytime conditions, reveals the strong contribution of the eddies having periods of 8 to 10 min. In addition, a smaller peak exists at approximately 2 min, and it is believed that this represents the contribution of mechanical turbulence generated primarily by the flow of air over the rough terrain surface.

The oil-fog program has included a review of all the earlier data obtained here. This was undertaken after comparisons between the photometric densitometer measurements and the new filter analyses gave nearly identical results in a series of tests. These indicated that the oil-fog data were probably at all times accurate to within a factor of two and were, therefore, worth reanalyzing. The review of the older test data showed clearly that some improved means of classifying dispersion conditions were desirable. Up to the present time, a gustiness classification based upon the variation of the horizontal wind direction has been used. It is hoped that the

*The US Weather Bureau continues to support a program here, in conjunction with Brookhaven's meteorological work, with a staff of two.

Figure 4. Power spectrum of smoke concentration, smoke run 54-8.

power spectrum analysis will also provide a foundation for a new classification for dispersion conditions by revealing the importance of eddies of various sizes. This almost certainly will suggest an alteration of the existing instruments.

Two new instruments have been developed since the summer of 1954. One device is designed to provide a numerical measurement of the gustiness classification now in use by the group. With suitable alteration, it should be adaptable to any new classification that may be adopted in the future.

One aspect of atmospheric dispersion that has been neglected in the past two years by this group is that of the temperature inversion, in which the effluent stays aloft for an indefinite distance. Many attempts were made to obtain concentration measurements aloft during the earlier years of the meteorology program. Even the development of a special airborne densitometer did not achieve the purpose, however, because of the great difficulty of utilizing the equipment in the field. The inversion condition is very important since it accounts for 40 per cent of all hours at this site. Basic requirements for an instrument suitable for this work are extreme simplicity, durability, and light weight, since it must be carried aloft by a small number of balloons or kite-balloons.

Within the past month, a device has been completed that appears suitable for airborne measurements. Essentially, it is a modification of the Millipore filter samplers previously developed for ground level use. The new device is a combination of a light

piston pump with a small 6-volt model motor and an appropriate gear train. The total weight of the unit is approximately 2 pounds and it will require only a single line to the balloon or the Kytoon support. The volume air drawn by the pump is extremely small, approximately .005 cfm, but the effluent concentrations within the inversion plumes are correspondingly high and the results are expected to be comparable to those obtained at ground level with a more powerful pump. This device has been tested to the extent of determining that it will operate with nearly constant efficiency for 1 hour on four standard flashlight batteries.

In addition to the research in turbulence and dispersion, the Meteorology group continues to perform a number of general services for the Laboratory as a whole. Routine meteorological data are recorded on a 24-hour-a-day basis, even though the scheduled staff hours cover only the normal working day. In addition, teletype facilities provide the minimum information necessary for protection against extreme meteorological conditions and permit forecasts for special purposes.

During the summer and early fall of 1954, the Laboratory obtained some unusual data from hurricanes "Carol" and "Edna," both of which passed quite close to the site.

In July, 1954, a set of semipermanent installations was begun to provide soil temperature measurements on the site of the alternating gradient synchrotron. The purpose of these installations was to ascertain whether significant subsoil temperature variations existed between stations separated horizontally by several hundred feet, and to determine the diurnal and annual range of temperature at depths extending to 20 ft below the surface. These data are important in the design of an adequate foundation for the accelerator. To provide records of suitable quality, four Leeds and Northrup recorders were modified for use with 100-ohm copper Thermohms, which are extremely durable and stable in their electrical characteristics. Four measuring points were located north, south, east, and west on a 600-ft diameter circle. Individual Thermohms were installed at 2.5, 5, 10 and 20 ft below the surface in each case.

Within a few months after the records began, two items of importance appeared. In the first place, it was noted that at all depths the southern station had cooler temperatures than any of the others. Since this site happened to be in a rather thick

grove of pine trees, whereas the others were more completely exposed to the sun, it seemed reasonable to investigate the possibility of altering the subsoil temperature regime by varying the surface cover. To test this, two more stations were set up: one under the center of a 200-ft square concrete ice rink, and the other under grass close to it. At present, with nearly a full year's record available, it is apparent that a significant warming of the subsoil temperatures can be accomplished by paving the area. The second item of importance was the discovery that the range of temperature variations could not be correctly predicted on the basis of the thermal diffusivity of sand, as given in the literature. In practice, the annual range was found to be very much larger than anticipated. It is believed that this results from the propagation of surface effects downward by the movement of rain water, so that computations of diffusivity from annual data differ from those based on diurnal data.

This project, although it is properly categorized as applied research, actually represents a unique meteorological investigation. As far as can be determined, it is the first attempt to define such variations over a very large horizontal area of homogeneous soil.

AIR FORCE METEOROLOGICAL STUDY

The second project conducted by the Meteorology group for the Geophysical Research Directorate of the US Air Force was begun on July 1, 1954. It will be remembered that the first project was devoted exclusively to the abstracting and transfer of a complete 2-year micrometeorological record to machine punch cards. The second project is a logical outgrowth of the first: namely, the analysis of the punch card data. The Air Force is particularly interested in the development of methods that will permit the prediction of micrometeorological data from the readily available synoptic information. For this reason, the climatological analysis is being conducted from the point of view of separation by standard weather elements, such as cloud condition, geostrophic wind speed, and temperature advection.

The first portion of the work completed this year consisted of the addition of code figures that could be used for such separations. For example, a code was developed to represent current and past cloudiness; another was included to permit the comparison

of similar hours in reference to the solar calendar. In addition, the cards were given consecutive code numbers to simplify sorting and computing procedures. As of the present, most of the temperature cards have been completely processed and a very large amount of information is available on the relationship of lapse rates to cloud cover and solar time. Additional work will be done with these cards in order to define the influence of wind on the lapse rate patterns. Processing has begun on the wind cards but is currently in the early stages.

DESIGN AND CONSTRUCTION

MECHANICAL ENGINEERING AND DESIGN

The Mechanical Engineering Division is organized to provide engineering services and designs of equipment to the research departments of the laboratory. In developing new machines it is highly desirable that theorists, experimental physicists or engineers, and the designing group live in a common locality to constitute a family in which ideas will be generated and discussed. To this end the individuals who comprise the division have offices in the departments of major interest to them.

The system of electrostatic lenses, supports, vacuum enclosures, and pumps which comprises the electron analogue for the AGS was designed, installed, and calibrated. Concrete piers were cast directly on the old concrete floor of the test shack, and it is interesting to note that the relative locations of adjacent piers remained in true alignment to better than $\pm .002$ in., with a maximum excursion of .007 in. of any single pier from the true 45-ft diameter circle. Each assembled lens was calibrated, and the observed average deviation of $\pm .002$ in. is within the specified limits of tolerance.

The down period of the Cosmotron was employed advantageously to cut a window in a pump port at a location suitable for the ejection of an external beam. Paired quadrupole magnets were designed and built to focus the emergent proton beam. The shielding has been relocated to accept the focusing magnet, and additional shielding has been added as partial compensation for the anticipated increased radiation intensity. The work on liquid hydrogen targets continues, and several forms of styrofoam liquid hydrogen containers are in current use.

Several types of neutron spectrometers have been designed in the central group not only for BNL's own departments of Physics and Chemistry but also for teams of research workers from Columbia University and the Bell Telephone Laboratories. Facilities for the irradiation of mice have been built for the Medical Department, a device for effecting blood separation in a refrigerated centrifuge was built for the pathologists, a hydrostatic compression apparatus capable of creating pressures up to 10,000 psi was built for Biology, and a facility was designed for testing the aerodynamic properties of enriched reactor fuel rods.

The staff of the Division, working with the Nuclear Engineering Department, continues to devote a considerable fraction of its time to the design of liquid metal loops, pumping systems, and devices in which irradiation tests may be conducted. During the past year the "in-pile" loop has been successfully operated on the floor of the reactor. The safe disposal of fission products in the form of insoluble ceramic bodies is another project of major interest, and studies have been carried to the pilot plant stage. In the field of fluid waste disposal, the conditions that will obtain at processing production centers were simulated in a large tank and its associated equipment.

The personnel of the Division is currently working in the following localities:

	Engineers	Designers
Cosmotron	4	5
Accelerator Development	8	11
Nuclear Engineering	3	6
Central Design	2	6
Reactor Operations, Cyclotron, Van de Graaff, Physics		5
Secretarial — 3		

MACHINE SHOPS

The year past has been one of close scrutiny of Laboratory shop problems, and particularly of the role of the centralized facilities as compared to the decentralized or departmental shop facilities. Sufficient evidence was found to support the need for both kinds of facilities. A strengthening of the departmental shops was indicated so that they might be better able to assume more of the small, general type of machine work, especially the short order and

rush jobs. The short order burden represents 51.13 percent of the number of jobs the central shops handle, although in manhours it accounts for only 6.55 percent.

A three-point program was initiated:

1. an evaluation of the total central shop manpower requirements and the distribution of manpower by job classification;
2. a study of the machine tool complement to result in recommendations for a complement more nearly meeting the demands peculiar to the Laboratory;
3. based on these, the design of a shop layout incorporating all the currently scattered central shop facilities in one building. The resulting layout will be proved in the existing scattered buildings so that any required modifications can be made prior to the setting up of permanent centralized shop facilities.

There has been a marked change in shop organization and policy. The machine maintenance and shop porter functions formerly carried on by the shops were transferred to the Plant Maintenance Division. By and large, this has relieved the shops of all activities not directly associated with the production of machines and equipment for the Laboratory's research effort.

The shops' supervisory force has been reduced from eight to six, a 25 percent cut, with an additional cut to five possible with the consolidation of central shop facilities. The clerical help was cut one-third, and services by 63 percent. The total shops' manpower level has been established at a normal complement of 70 persons. An 18 percent increase in productive manpower has resulted. The concept of the centralized facilities as an agency to provide service to the scientific staff was renewed. In order that the shops better fulfill this role, the scientific staff has been encouraged to work closely with the craftsmen on their projects. A new job classification, the Master Craftsman, was conceived to aid in developing mutual understanding and respect, and to aid in the expeditious and intelligent processing of projects. The Master Craftsman is visualized as a craftsman possessing the highest competency in any one of the three crafts—metal working, machining, and welding—and at least minimum competence in the other two crafts. This classification makes it possible to have at least one craftsman following a major project through all its phases in the shops,

Table 5

Relative contribution of regular and short order workloads by Shops section.
July 1954 — June 1955

Shops Division section	ILR job contribution to Shops Division workload				Other* job contribution to Shops Division workload			
	No. of jobs	% of total jobs	No. of mhr	% of total mhr	No. of jobs	% of total jobs	No. of mhr	% of total mhr
Heavy and special equipment	708	29.55	60,247.05	68.98	587	24.50	3387.25	3.88
Sheetmetal and welding	437	18.24	19,216.45	22.00	486	20.38	2058.75	2.36
Maintenance	26	1.09	2,158.50	2.47	152	6.34	276.65	.31
Over-all Shops	1171	48.87	81,622.00	93.45	1225	51.13	5722.65	6.55

*Jobs requiring less than 10 hr.

Table 6

Departmental contributions to Shop workload
July 1954 — June 1955

	% ILR mhr	% Other* mhr	% Total mhr	Load ranking
Major Users				
Nuclear Engineering	37.78/1	26.30/1	37.03	1
Reactor	18.82/2	12.57/4	18.41	2
ADD	13.57/3	1.48/10	12.78	3
Physics	10.01/4	13.65/2	10.25	4
Cosmotron	9.04/5	12.84/3	9.29	5
Percent of workload 87.76				
Minor Users				
Chemistry	4.07/6	5.23/8	4.15	6
Biology	3.97/7	6.70/7	4.14	7
Medical	1.70/8	8.26/6	2.13	8
Instrumentation and Health Physics	.44/9	9.39/5	1.03	9
Miscellaneous	.60/10	3.57/9	.79	10
Percent of workload 12.24				

*Jobs requiring less than 10 hr.

and opens up the way for a craftsman-scientist team attack on a project not heretofore possible.

The workload contributed by the several departments varied widely. Table 5 gives the over-all picture. While ADD appears as ranking third, this does not properly reflect its true demand for machine work because of the large amount of ADD work contracted out over the last year.

To a certain degree the load contribution follows the departmental shop facilities. Thus, Nuclear Engineering and Reactor, both departments which are fairly limited in facilities, passed on large work loads

while Physics and Cosmotron departments, having considerably more extensive shop facilities, passed on lesser loads. The correlation is particularly striking for short order work. Nuclear Engineering, having the least shop facilities of the major users, built up a short order work load approximately twice that of any of the other major user departments.

Work has also been done for a number of special accounts including Westinghouse Atomic Power, Columbia University, Pratt and Whitney Aircraft, Bell Telephone Company, Massachusetts Institute of Technology, and the Monsanto Chemical Company.

The Shops Division has operated with a varying work backlog; every effort is being made to reduce this backlog, by contracting work out as necessary and possible.

TECHNICAL INFORMATION

Some important changes in the future operations of the Technical Information Division were becoming noticeable toward the end of this review period. These changes will result from the AEC's recently inaugurated Civilian Application Program, by which a vast volume of technical information, both classified and unclassified, is being made available to industrial organizations in the United States. As one phase of this program, many classified reports of possible interest to industry, mainly in the fields of reactor technology and chemical engineering, are now being reviewed for downgrading or, where the newly liberalized AEC classification requirements will permit, for declassification. It is anticipated that during the coming year these new trends will result in significant shifts in the activities within the Division.

There has been a continued increase in the use of the Research Library, which has necessitated a review of library procedures. This review was made with a two-fold purpose: first, to examine and modify working procedures so that the staff could discharge its increasing workload more effectively, and second, to provide greater assistance to the library users through the book catalog. This second purpose was largely due to the increased use of the Library during evening hours, when librarians are not present. A system of fuller cataloging, and the expansion of subject headings, are the obvious steps to be taken.

In the Reference Section, a marked increase in detailed bibliographic work has occurred. During this period, fifteen major bibliographies were compiled to fulfill staff requests. Presently in preparation is a bibliography on the effects of ionization on plants which is expected to contain over 1200 references.

With the elimination of outside library service from the AEC's New York Operations office, the BNL Research Library contains the only complete card index to unclassified reports in this region. A significant number of requests for reports and jour-

nals have been received from the contractors who formerly obtained loans from the NYOO. The Library here has provided loan service only in such cases; requests for permanent copies have been referred to the TIS, AEC, Oak Ridge.

During the past few months, much interest has been shown by Brookhaven scientists in Russian articles in high energy particle physics, particularly those resulting from research performed with the recently announced 670-Mev synchro-cyclotron in the USSR. The Library has assisted in the prompt translation of some of these articles, others have been assigned for translation to Argonne National Laboratory and University of California Radiation Laboratory, in a cooperative "share-the-load" plan. Such translations have also been made available to the project in general, through TIS, Oak Ridge.

In the Classified Library, an intensive report retirement program was recently completed. The annual inventory of classified research and development reports revealed that over 25,000 items are held here, although almost one-third of these are in microcard form. Over 1500 classified titles were received during the year, the average number of copies of each being three. The increased tempo of the AEC's declassification program, mentioned above, the more liberal limitations of the new unclassified areas of research, and a continuing report destruction program at Brookhaven, account for the very small increase in classified report holdings.

The demand for service from NYOO contractors has also been experienced here, as in the Research Library. Over 25 organizations have requested documents they would formerly have obtained from New York. The Babcock and Wilcox Co. LMFR study group has created a very heavy increase in the workload during the last half of the year.

Last year, 304 persons were authorized access to the Classified Library. This year, the figure has risen to 348. Of these, about 150 use the facilities frequently, and 122 have material charged out to them, for storage in properly approved safes. In addition, 25 consultants hold similar privileges.

The Publication Group has edited and otherwise processed for issuance 51 major technical reports; of these, 22 were classified. The Weekly Selected Reading list has continued to appear regularly; it is now distributed to nearly 600 staff members and 800 scientific workers at other laboratories.

The steady rise in the number of technical manuscripts originating from Brookhaven research, to be published in the scientific and professional periodicals, is still continuing. Last year, the total figure (including published abstracts of speeches) was 381; this year, it stands at 418. Since a single member of the Division was responsible for the processing of all such papers this growing workload has now necessitated the hiring of an additional person.

The Distribution Group has continued to add to the lists of persons and institutions receiving the Laboratory's unclassified reports, in various subject categories. For each report 325 copies are shipped direct to the office of Technical Services, Department of Commerce, Washington 25, D. C., for public sale. In addition, 100 more copies have been requested by TIS, Oak Ridge, for distribution to the growing number of industrial participants in the program. It can be anticipated that these distribution figures will continue to rise as United States industry becomes further involved in the peacetime applications of atomic energy.

PHOTOGRAPHY AND DUPLICATING

At the close of the year the staff of the Division stood at 33, an increase of 4 which was necessitated by a general growth of activity and the assumption of additional responsibilities.

The processing of nuclear emulsions was undertaken and considerable effort has been devoted, in cooperation with particle physics group, to increasing the output. Plans were drawn for moving the operation into more adequate quarters in T-109 and constructing equipment with which to handle the larger emulsions.

The figures for photographic production show a general increase, with the lower figure for photostats

Table 7

	Fiscal '53	Fiscal '54	Fiscal '55
Photographic negatives	4,488	4,662	6,055
Photomicrographs	1,334	1,435	1,837
Lantern slides	3,487	4,489	5,788
Prints	29,491	30,302	36,008
Photostats, Xerox	30,271	22,226	18,969
Ozalid prints	197,429	233,821	276,968
Recording film processed	10.8 mi.	13 mi.	13.6 mi.

representing success in utilizing processes which are less expensive.

The duplicating group experienced a rise in production and absorbed two of the additional people.

Table 8

	Fiscal '53	Fiscal '54	Fiscal '55
Offset pages	2,175,640	3,819,809	4,036,991
Offset negatives	3,672	4,445	5,035
Offset plates	1,454	1,125	1,066
Mimeo impressions	1,716,480	1,702,165	1,850,795
Stencils cut	2,387	1,176	1,992
Stencils run	10,201	8,312	10,168
Sheets collated and bound	589,065	1,324,089	1,377,050
Report copies issued	31,335	30,419	40,304

The illustration section completed 2,920 drawings for slides and publications and was active in the design of exhibits and displays. Mr. George Cox submitted the winning design which was selected by the Post Office Department for the Atoms for Peace stamp.

The entire Division was variously involved in preparations for the Geneva Conference which produced an all-time peak of activity.

SCIENTIFIC COMPUTATION

The past year was essentially the first full year of scientific computation service operations. Two electronic computers were again available to the scientific staff of the Laboratory: the AEC's New York University Univac and the Remington Rand 409-8R digital punch card computer which is located at BNL. The latter installation is used jointly with the tabulating section of the Fiscal Division. This fiscal section provides all the auxiliary punch-card machine operations. However, as the scientific computation workload has increased it was decided to increase the staff and equipment of the computation center and have the center handle all its own punch card operations. This new mode of operation went into effect July 1, 1955.

Demand for computations on the local computer increased during the year and it became quite evident that the present Remington Rand computer would soon be unable to satisfy the requirements of the Laboratory's scientific community. Consequently, a

Table 9

Breakdown by departments of time used on the Univac

Accelerator Development	48	percent
Nuclear Engineering	35	
Chemistry	8½	
Physics	8	
Reactor	½	

study group was set up to survey the characteristics of presently available small and medium sized electronic digital computers. It is expected that during the course of the next fiscal year this group will recommend one particular computer which will be particularly suited to the needs of the Laboratory, and that it will be possible for BNL to acquire this machine.

During the fiscal year of 1955 the Brookhaven staff utilized 628 hours of Univac computing time. Table 9 shows the breakdown of total computing time by department.

In the local computing center, problems of six BNL departments were programmed and solved. Most of these problems were nonrepetitive problems and only two were of the type which require con-

Table 10

Breakdown by departments of time used on the BNL computer

Physics	33	percent
Reactor	30	
Nuclear Engineering	23	
Accelerator Development	8	
Chemistry	5½	
Cosmotron	½	

tinuous data-handling on a daily basis with the same program. Of actual computer time, 843 hours were used, and 1545 hours of auxiliary punch card machine time were required to back up the computing effort. In addition, about 200 hours of computer time were utilized for general program research and program debugging. Table 10 gives a breakdown of the BNL computer time used by the various departments.

Colloquia on the computers and a series of lectures on the Remington Rand machine and its programming procedures were given during the year. Furthermore the computation center library was substantially increased to provide information on computers and techniques of numerical analysis.

ADMINISTRATION AND OPERATIONS

Included in this section are reports on the personnel, business and operational activities of the Laboratory. Since the period covered by the last Annual Report, the major administrative change to be reported here is the separation of the Architectural Planning and Plant Maintenance Department into two divisions. The Architectural Planning Division, under the Architectural Planning Director, continues to be responsible for planning construction, supervision and contract administration; the Plant Maintenance Division, under Assistant Director W. H. Fields, provides routine laboratory maintenance services.

PERSONNEL

Scientific Staff

The composition of the scientific staff on May 31 for the past 2 years is given in Table 1. Research Associates, who hold appointments similar to those of postdoctoral fellows for a maximum of 2 years, are included for statistical purposes under the heading of "visitors." During the past year there were

63 additions to the regular staff and 46 terminations, a net increase of 17 or 62 percent. The number of both salaried and nonsalaried visitors has also increased. This increase is almost wholly in the category of intermittent visitors—i.e., scientists who work at the Laboratory for a day, or a few days, at intermittent intervals.

There has been an increase in the participation by individuals from other institutions in the work of the Laboratory each year since its establishment. A detailed analysis of this participation is given in Table 2. The review period of June 1, 1954, through May 31, 1955, has been selected in order to include information on one summer program only, that of 1954. Under two groupings, the table gives the number of salaried and nonsalaried (guest) scientists who participated in the Laboratory program. The first group includes those scientists who worked at the Laboratory for more than 3 months and the second includes those who worked at the Laboratory from 1 to 3 months. Scientists who worked at the Laboratory on a continuous or an intermittent basis

Table 1
Scientific staff on May 31, 1954 and 1955

	Regular Staff		Salaried		Visitors	
	1954	1955	1954	1955	No Compensation 1954	No Compensation 1955
By Appointment Category						
Senior scientist	34	35	1	1	6	11
Scientist	61	74	2	—	31	57
Associate scientist	148	149	4	3	35	48
Research associate	—	—	16	20	3	2
Junior scientist	29	30	—	—	4	8
Junior research associate	—	—	15	10	8	7
Research assistant	1	2	—	—	3	11
Total	273	290	38	34	90*	144**
By Academic Degree						
PhD or MD	164	178	23	22	50	91
Master	32	43	15	11	26	27
Bachelor	72	64	—	1	1	24
No degree	5	5	—	—	1	2

*60 of these appointees work intermittently at BNL.

**113 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, 1954—May 31, 1955

	More than 3 months		Less than 3 months		Total	
	Salaried	Guest	Salaried	Guest	Individuals	Institutions
University staff	23	26	20	22	91	43
Thesis students	15	6	3	3	27	13
Student helpers	—	—	88	—	88	44
Special students	3	7	2	20	32	12
Total	41	39	113	45	238	69 different
Industry	1	11	—	10	22	18
Other institutions	1	18	—	11	30	15
Total	43	68	113	66	290	102 different

for less than 1 month (about 72 in number) are not included in this summary.

There were 290 different individuals from 102 different institutions who participated in the program for one month or more during the 12-month period indicated. The number of scientists from educational institutions increased by 6 percent over that of the previous year. While there was a decrease of 34 in the number of visitors who worked at the Laboratory for from 1 to 3 months, an increase of 42, or 61 percent, occurred in the number who worked here for 3 months or more. Twenty-seven graduate students were engaged in their doctoral investigations; nine of them completed their theses.

The man-days of service rendered by consultants are shown in Table 3 in which comparisons are made between the current report year and the 2 previous fiscal years.

Table 3
Consultants' services

Item	1953	1954	1955
Total contracts in effect June 30	94	94	81
No. consultants used	48	54	52
No. of man-days of service	466	580	535

Summer Program for 1955

Faculty members numbering 107 from about 48 different educational institutions plan to work at the

Laboratory for periods up to 3 months during the summer of 1955.

For the fourth successive year, a summer program has been arranged for students. Announcements were sent in January to about 100 educational institutions in the northeastern region. From 97 different colleges and universities, 382 applications were received and 119 appointments were offered of which 96 appointments have been accepted—63 undergraduate and 33 graduate students representing 48 different educational institutions.

Including the Radiological Physics Fellows and 18 additional graduate students who will be brought here by faculty members to work as their research assistants, the scientific staff will be increased during the summer months by about 230 additional workers—a larger influx than in any previous year. This influx will for all practical purposes saturate present laboratory and on-site housing facilities.

Employment

The number of people on the Laboratory payroll as of June 30, 1955 was 1,533, excluding guests, research collaborators, and temporary appointees. The net increase in employment over June 30, 1954 was 87, which is greater than that of the previous 3 years combined, and is the largest net gain since the fiscal year ending June 30, 1949. However, the ratio of 1 scientist to 3.7 nonscientists which existed on June 30, 1954—and which represented the lowest proportion of this type in the history of Laboratory operations—still existed on June 30, 1955. The maintenance of this ratio indicates a balanced growth with

Table 4

Staff Data		Fiscal 1954		Fiscal 1955		
Total Number of Employees		1446*		1533**		
Turnover Data	Total Numbers	Annual Rate (%)	Average Monthly Rate (%)	Total Numbers	Annual Rate (%)	Average Monthly Rate (%)
Accessions	231	16.17	1.35	277	18.64	1.55
Separations (turnover)	216	15.11	1.26	190	12.59	1.05
Net accessions	15	1.17	0.10	87	6.05	0.50
Replacements (net turnover)	168	11.76	0.98	185	12.26	1.02

*Not including 119 temporary appointees.

**Not including 135 temporary appointees.

respect to the relative increase in the number of scientists and nonscientists. Pertinent personnel statistics are set forth in Table 4.

The augmentation of staff, combined with the usual turnover, necessitated accelerated employment activity. Recruiting has become more difficult as a result of increasing demands for well-trained non-scientific personnel, primarily in such categories as specialized technicians, designers, and registered nurses. As with scientific personnel, recruiting must cover a broad geographic area. It has become increasingly difficult to recruit skilled maintenance and shop personnel in the immediate area, and this necessitates recruitment in these categories primarily from Western Suffolk and Nassau Counties, as well as from New York City.

To reduce the clerical workload in the Employment Office, and to consolidate all personnel security functions at one location, responsibility for the duplication of personnel security questionnaires, the issuance of individual identification cards, as well as other related functions was transferred to the Security and Plant Protection Division.

Labor Relations

Maintenance and Service Employees: The collective bargaining contract negotiated with Federal Labor Union No. 24426, AFL, on July 21, 1950, covering maintenance and some service employees, expired on June 30, 1955. Negotiations for a new agreement commenced during May, and extended through July. A new agreement which expires on December 31, 1956, was executed on August 3, 1955.

The new agreement eliminates the cost-of-living and productivity allowances which were provided in the previous contract and substitutes fixed wage rates effective July 4, 1955 and April 2, 1956. The modified wage rates provide for scaled increases, with the larger amounts going to the skilled craftsmen whose classifications are at the upper end of the labor grade structure. Nonwage modifications in the new agreement relating to such items as vacations, shift premium, death leave, holidays and overtime are identical with those announced for nonbargaining unit employees on July 1, 1955 and are reported in greater detail below under "Policy Modifications, Revisions and Supplements."

The nature of the relationship between the Laboratory and this Union during the past year is best evidenced by the limited use of the terminal provisions of the five-step grievance procedure provided in the contract. No grievance was processed to the fourth step of the procedure which provides for top management review of grievances, or the fifth step of the procedure which provides for arbitration on a limited number of issues. Effective administration by line supervisors, combined with the exercise of responsibility by top Union officials, is considered largely responsible for this excellent situation.

Patrolmen: On August 8, 1954, United Security Employees Union, Local No. 1, the collective bargaining representative for the patrolmen, notified the Laboratory of its intention to affiliate with the International Guards' Union of America. Following a consent election, on October 11, 1954, Long Island Guards' Union, Local 37, International Guards' Union of America, was certified as the collective bar-

gaining representative for the patrolmen by the National Labor Relations Board. The contract with the United Security Employees Union expired on September 30, 1954 and negotiations with the newly certified bargaining representative were commenced on October 19, 1954. Contract negotiations continued through December, the protracted negotiating period resulting primarily from difficulty in resolving a matter of seniority. A contract was executed on December 23, 1954, with an expiration date of November 30, 1955. The essential modifications from the previous agreement related to wages, holidays and maintenance of uniforms.

As with the Union for maintenance and service employees, no grievance from members of the patrolmen's Union reached the final two steps provided in the grievance procedure; this, again, is considered the best evidence of the excellent nature of the relationship between this Union and the Laboratory.

Wage and Salary Administration

The periodic wage and salary survey for this area indicated a moderate upward trend in the rates for the more technical classifications of nonmonthly personnel, while the area rates for the occupations which are essentially clerical remained constant. Accordingly, the nonbargaining unit rate schedule for wage employees was divided into two separate schedules: viz., "Schedule II-T" in which all essentially technical classifications were included along with modified rates therefor, and "Schedule II-C" in which the clerical classifications previously contained in "Schedule II" were continued without change.

A complete audit of all job classifications covering personnel in the bargaining unit for maintenance and service employees was concluded during the year as an essential precursor to effective collective bargaining over the new contract. As a result of this audit many job classifications were rewritten, re-evaluated, combined with other classifications or eliminated. This procedure was in conformance with existing policy which requires that job descriptions properly reflect work actually being performed and the related evaluation appropriately rates the job within the established labor grade structure. In keeping with this policy, certain monthly, and several nonmonthly classifications primarily in police, fiscal and medical groups, also were audited and were then modified appropriately.

The performance and progress of all personnel were examined at the semiannual reviews and appropriate adjustments within established ranges were made on the basis of merit.

Employee Benefit Programs

A detailed study of the benefits available to employees and their families under the previously established system for insuring hospital and surgical costs, as related to actual cost of these services, revealed that the available plan was inadequate in many respects. Alternate plans were investigated, along with various means of financing the cost of a more adequate program. It was determined that the optimum arrangement in terms of maximum employee protection and minimum expense to both employee and employer could be achieved in a plan offered by the Connecticut General Insurance Company. This plan provides considerably greater benefits than previously were available, and also includes a provision for medical catastrophe coverage. The plan provides, in all, for hospitalization, surgical, in-hospital medical and medical catastrophe insurance for employees and dependents. The new plan was offered to employees as a substitute for the previous plan and was accepted overwhelmingly. It became effective on October 1, 1954. Employee contributions to the premium cost of the new plan are approximately equal to those under the previous plan; the balance of the premium cost is underwritten by the Laboratory, which formerly paid no part of the cost. Although participation in this program remains on a voluntary basis, approximately 92 percent of all eligible employees have enrolled. Maximum participation under the previous plan never exceeded 80 percent of eligible employees.

At the same time that the new plan of medical insurance was instituted, the group life insurance plan was revised to provide for double indemnity in the event of accidental death or dismemberment as the result of occupational accident. The cost of this additional protection was borne entirely by the Laboratory in recognition of the moral obligation of an employer to supplement the modest benefits available under workmen's compensation for an occupational accident resulting in death or dismemberment. In order to make this desirable protection available to as many employees as possible, participation in the basic group life insurance plan was made a condition

of employment for all employees hired after October 1, 1954.

It may be noted that both the group life insurance program, as well as the new program for medical insurance, are underwritten by the Connecticut General Insurance Company. Agreement has been reached with this company whereby both plans will be experience-rated jointly. If experience should be poor under one plan it is unlikely that it would be poor under the other plan in the same year. Thus, by spreading the risk, there is greater assurance of rate stability than could otherwise be obtained.

The retirement plan continues without modification. On June 30, 1955 approximately 70 percent of the staff were participating.

Policy Modifications, Revisions and Supplements

Continuing appraisal of the trends in the survey area indicated the desirability of liberalizing certain personnel policies. Accordingly, on July 1, 1955, policy modifications were introduced which provided: (a) an increase in the shift differential from 10 percent to 12 percent for work performed on the "mid-night" shift; (b) application of overtime rates to work performed on the sixth and seventh scheduled days in the work week; (c) a minimum guarantee of four hours' pay for any work performed on the sixth or seventh day in the scheduled work week; (d) guaranteed holidays; (e) improved premium pay for work performed on a holiday; (f) an increase of three days' vacation a year for employees with more than five years' service; and (g) leave privileges as a result of death in the family.

Other modifications of personnel policy introduced previously during the year provided for a statement relating to "outside employment," specifying "time-off" privileges when such were necessary to conform with Selective Service requirements, allowing a special "per diem" in connection with travel outside the United States, and a revision of the sick leave policy permitting restoration of all sick leave required by an individual as the result of an occupational injury whenever full reimbursement for wages paid to the individual as a result thereof was obtained by the Laboratory under workmen's compensation.

Selective Service

The deferment of draft eligible technical and scientific personnel at the local board level has become

increasingly difficult in the past 12 months, and it has been necessary in many cases to go to Boards of Appeal for necessary deferment actions. This has been particularly true with draft eligibles who have had several deferments. During the past year five members of the technical and scientific staffs have been lost directly to the draft. At the end of the year, approximately 30 members of the scientific and technical staffs were subject to the provisions of the Selective Service Act. The Laboratory continues to notify local boards whenever an employment offer has been accepted by a draft-eligible technical or scientific employee, and subsequently advises the boards of an individual's contribution to the Laboratory program after employment has begun.

Residence Services

Increased activity has been evident in the usage of apartments, dormitories and guest houses during the past year. The apartments ran at nearly full occupancy for the entire year, members of the LMFR Study Group providing an added load to the normal flow of traffic. The heavy demand for temporary housing during the winter as well as the summer months, combined with anticipated future requirements, has indicated the desirability of renewing the contract for off-site apartment facilities at Stony Brook.

Four of the dormitories used previously for construction personnel and to handle peak loads during conferences were abandoned, and in their place two large dormitories in better physical condition were further modified and made available for full occupancy. This action results in regrouping into one geographic location all dormitories which are needed and kept open throughout the year; this provides means for achieving a greater efficiency in dormitory servicing. Summer dormitories are grouped into one location also. Two of the all-year dormitories were completely renovated and refurnished.

The annual survey to determine rents charged for private housing facilities in nearby areas was prepared in January 1955. The survey did not reveal any appreciable change in the rents being charged for off-site apartment facilities. The cost of such facilities continues to be comparable to charges for similar accommodations provided by the Laboratory and no need for modification of the rent structure for Laboratory apartment units was indicated.

Safety Engineering

The disabling injury frequency rate for the past year was 2.8 and the cumulative rate for the preceding five-year period was 2.2. An examination and analysis of these rates would indicate that the level of safety performance has been stabilized at a point well within the limits of random variation which may be predicted in a state of statistical control. The continuing objective, therefore, of maintaining approximately the same level of safety performance already achieved has been attained.

A most tangible indication of the effectiveness of the Laboratory's safety program is evident in the magnitude of the savings realized each year in the actual cost of workmen's compensation insurance under the terms of a retrospective rating insurance plan. In the past calendar year the actual premium paid amounted to only $8\frac{3}{4}$ percent of the estimated standard premium which might have been anticipated in the absence of better-than-average safety performance. This rate was achieved even though an increase in workmen's compensation insurance benefits amounting to more than 12 percent was introduced last year.

As a cognate responsibility to the administration of workmen's compensation, the Safety Engineering Group assumed responsibility for administering the new group medical insurance plan described above under "Employee Benefit Programs." In the first 9 months of operation between October 1st and June 30th approximately 500 claims, representing about \$60,000, were reimbursed under the plan to employees for medical expenses incurred.

Substantial progress was made towards the realization of certain basic objectives in the long-range fire protection engineering program. More than \$35,000 was invested in providing various forms of automatic fire protection in some of the more vulnerable structures, including complete automatic spray sprinkler systems in the two major central stores facilities and two large dormitory structures. The objective of raising the degree of fire protection at Brookhaven to that designated as "improved risk" in industry is rapidly being approached. Agreement also has been reached with the responsible groups to provide automatic spray sprinkler protection in the new medical research facility and in the service building for the alternate gradient synchrotron. It is anticipated that an investment of more than \$150,000 will be required to provide requisite fire protection

in these two structures. The fire loss ratio has remained at zero for the fifth successive year which may be compared with that attained throughout AEC facilities in which, during the past year, a fire loss ratio of \$0.035 for each \$100 of assessed valuation was established.

Cooperation with Architectural Planning and other interested groups in the review of all plans and specifications for proposed construction or major modification of existing facilities to insure the inclusion of adequate safety and fire protection features has continued as heretofore. Major efforts have been directed to consideration of the plans and specifications of facilities proposed for medical research and accelerator development.

As the research program of the Laboratory expands, a collateral increase in the demand for the industrial hygiene engineering services of the Safety Engineering group has become evident. Toxicological studies were undertaken on a number of substances used in research experiments to ensure that potentially harmful substances were handled properly and maintained well within the limits of maximum permissible concentrations. At the request of interested members of the staff, chemical safety data sheets were prepared on a variety of substances such as biphenyl, lead azide, perchloric acid and chlorine trifluoride. Several new instruments were procured in the past year to increase the versatility of the group in its ability to handle the ever-widening range of industrial hygiene problems.

In line with the growth of the Laboratory's reputation as a center of research and special knowledge, the Safety Engineering group has participated in the activities of outside groups concerning themselves with pertinent problems of mutual interest to the Laboratory, the AEC and industry. Of particular note is the designation of a member of the Safety Engineering group to serve with the Joint Fire and Marine Insurance Committee on Radiation and also with the Education Committee of the National Fire Protection Association.

Employee Activities

The Brookhaven Employees Recreation Association continues to sponsor some twenty social, cultural and physical activities which operate without direct subsidy from the Laboratory. Of these, the Theatre Group and the Bowling League were the most active. The Association's program helps to meet the

need for recreational activities outside working hours for all employees, but particularly for those employees who find it necessary to live on the Laboratory site.

The power tool rental service, now in its third year of operation, continues to be very popular and several new pieces of portable equipment have been added.

SECURITY AND PLANT PROTECTION

Activities of the Security and Plant Protection Division are of three general types: Security, Police and Fire group operations.

The Security Office is concerned primarily with security clearance of personnel, processing of visits to the Laboratory by visitors, processing of visits to other AEC facilities and to foreign countries by Laboratory staff members and consultants, maintenance of files for clearance information, 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.

A statistical analysis of Security Office records provides some indication of the volume of detail required of the Security Office in complying with AEC requirements and the policies and procedures of the Laboratory.

Police activity has generally followed the same pattern as last year; however, there was an increase in service demands caused in part by the very large increase in numbers of visitors and in part by the greater number of subcontractor's employees working on site and in restricted areas.

Table 5

	Fiscal 1953	Fiscal 1954	Fiscal 1955
Division personnel	116	95	91
Regular visitors	17,667	13,197	19,893†
Conference visitors	2,555	2,017	2,498
Subcontractor's employees	*	7,967**	16,362
Alien visitors	396	553	832
Total visitors	20,618	23,734	39,676
Clearances processed	1,235	739	832

*Included under regular visitors.

**December to June only.

†Includes 5415 visitors during two "open house" days.

A reduction in force of 10 percent was however achieved through resignations and transfers to other departments. This was made possible because of a further easing of security requirements by the AEC and the acceptance of a greater calculated risk in protection practices by the Laboratory.

Approximately 6714 hours were expended to cover special posts and details compared with approximately 5445 hours during the previous year. These special assignments occur constantly on a nonscheduled and sometimes emergency basis so that the size of the Police group cannot be based solely upon the number of fixed posts the Laboratory is obliged to maintain.

Fire group activity has been of about the same order as the previous year. Other than the primary duty of fire fighting, the fire prevention and the inspection programs, which are of extreme importance to the protection of the Laboratory, require constant attention throughout the year. That these two programs are effective can be understood in the light of the fact that there were no fire losses of any significance during the entire year.

The statistical record of activities is as follows:

	Fiscal-1954	Fiscal-1955
Responses on site	75	65
Responses off-site	3	9
No response— investigation	18	12
	—	—
Total alarms	96	86

The cause for each alarm was established in each case that occurred on the Laboratory site. Except for one careless smoker, other causes were mainly the result of mechanical failure or were unavoidable accidents.

ARCHITECTURAL PLANNING

Early in fiscal year 1955, a significant organizational change was initiated by the Laboratory in separating the two parts of the former Architectural Planning and Plant Maintenance Department.

The transition occurred during July and August. Since then the primary responsibility of this Division has been planning, construction, supervision and contract administration. In addition to the professional application of architectural and engineering skills to the solution of facility problems, the responsibilities of the Division include concern for the long-

range aspects of Laboratory growth, liaison on scientific requirements of the various Departments, fiscal responsibilities, estimating for budget purposes, collaboration with the Brookhaven Area AEC office and, most importantly, close support of the Director and his staff in their considerations of over-all planning both for the research program and the future of the site.

The personnel strength of the Division remains constant at 23.

During the past year all Departments of the Laboratory received architect-engineer services on a total of 127 projects, various in size and complexity. The initial stages of each of these required extended consultation with technical and scientific members of the Laboratory staff. Some of the projects were concluded with preliminary drawings only; in other cases of a highly technical nature, administrative services only were rendered; more than 60 projects were actually undertaken which required complete architect-engineer services with detailed drawings, specifications, job administration of construction and installation supervision.

A representative list of projects completed in FY 1955 includes:

Physics staff shop	\$ 8,000.
Water chiller and refrigerant piping for electron analogue	20,400.
Tank surge test building	53,500.
Magnet water systems improvements— Cosmotron and cyclotron	8,500.
Electric power system for Nuclear Engineering laboratory	12,000.
Exponential and critical experiment facility	34,500.
Physical measurements laboratory— Hot Laboratory	6,400.
Experimental DC system— cyclotron building	9,200.
Medical Department pilot laboratory	13,000.
Sprinkler systems for 2 dormitory buildings	14,300.
Overhead system substation, increased load capacity	9,600.
Strong focusing magnet—Cosmotron	56,000.
Jobs in progress at the end of FY 1955 include:	
Steam plant improvements and alterations	\$34,500.
Applied chemistry laboratory— Hot Laboratory	27,000.

Special lighting—constant growing
room—Biology 6,400.

The following projects, with preliminary engineering investigation completed, were authorized recently and will be undertaken beginning in July and August 1955:

Hydrogen liquefier facility
(building and equipment) \$135,000.
DC power supply for beam ejection
—Cosmotron 21,000.
Reactor canal water treatment facility 34,000.

The smaller jobs, too numerous to mention specifically, involve changes to and extensions of various laboratory services, equipment and facilities as well as additions to and modifications of certain site-wide facilities.

In March 1955, the Brookhaven Area Office of the AEC contracted with the Architect-Engineer firm of Eggers and Higgins for the design of the Medical Research Center. The current budget estimate of \$6,440,000 (including the Medical Research Reactor) gives an indication of the size of the project. The preliminary (Title I) design was essentially complete by July first and working drawings and specifications (Title II) are to be started about August first. In all this work the Architectural Planning Division has acted as professional adviser to the Medical Department, collaborating with them, the local AEC office and Eggers and Higgins in refining the architectural and engineering criteria for the buildings, equipment and utilities as well as the estimates of costs and time schedules.

Further, the BNL Reactor Department, in designing the Medical Research Reactor, looks to this Division for the development of the design of the building to house it. The architect-engineering information when fully developed will be turned over to Eggers and Higgins for incorporation in their work as part of the entire building project.

PLANT MAINTENANCE

The services of the Plant Maintenance Division continued to be of the same nature and scale as of previous years. A gradual transition was made during the first two months of the fiscal year to separate the Plant Maintenance Division from the former Architectural Planning and Plant Maintenance Department.

The old low pressure heating plant supplying heat to the central Laboratory area was closed down com-

pletely at the end of the heating season in anticipation of the completion of the 60,000 lb/hr boiler at the main heating plant in Building 610. Except for a possible emergency, it is not planned to reopen this heating plant. This move permitted a reduction of five in personnel within the Heating Section.

Work for the scientific departments increased somewhat over previous years. Slightly over 18 percent of the Plant Maintenance Division's effort was directed toward working for the scientific departments and on Laboratory facilities. In this connection, one of the larger jobs was the removal of shielding at the time of the Cosmotron breakdown, much miscellaneous work in connection with the Cosmotron repairs, and the reinstallation of the shielding at the completion of the repairs. During the time the shielding was not in use at the Cosmotron, it was used in connection with a soil loading test made by the Plant Maintenance Division for the AGS project. This test involved handling approximately 1350 tons of concrete and steel four times.

During early spring, a substantial maintenance program was undertaken with both maintenance personnel and outside contractors on certain of the permanent and semipermanent Laboratory buildings. In general, the work consisted of the most urgently needed restoration and repairs to the roofs and exteriors of some ten permanent and semipermanent masonry buildings, and to seven wooden frame buildings that are expected to continue in service for 8 to 10 years.

Work accomplished on the wooden frame buildings included replacing rotted floor joists, framing members and windows, ventilating under the buildings, installing asbestos shingles, painting of all exposed wood, and repairing or replacing roofs. Aluminum louvers, gutters, and window screens were installed where necessary.

On the reactor, Hot Laboratory, Cosmotron office and machine shop wings, and the Research Staff lounge, the exterior walls were repaired and waterproofed or painted as necessary. Roof repairs were made and aluminum screens provided.

Roof repairs were made on six other masonry buildings and new roofs applied on three other wooden buildings. Five wooden buildings, where the expected usage may be only a few years, were painted on the exterior. Interior painting was limited to the Cosmotron office wing and the Research Staff lounge and lobby.

Contracts and Purchase Orders were awarded for approximately \$180,000 in connection with this program, of which \$137,000 was completed by the end of the fiscal year.

BUSINESS OPERATIONS

Fiscal

As reported in the previous year a large portion of the fiscal work of the Laboratory has been placed on the Remington Rand punch card installation. Improvements and refinements to the initial systems have been made throughout the report year with particular emphasis on the development of management information. Some personnel statistics are now being reported by means of punched card analyses with further applications currently being planned. Placing fixed asset records on punched cards has progressed more slowly than the Laboratory management had planned. This application of machine accounting is presently near completion and is expected to be fully operative at June 30, 1956.

During the report year increasing effort has been devoted to the Laboratory internal audit program in order to comply with the AEC policy of establishing a strong internal audit function in each integrated contractor's organization.

Supplies, Materiel and Inventory Management

During the past fiscal year, Supply and Materiel Division and Inventory Management pursued further the problem of reducing inventory and still giving to the user efficient service. It was concluded that this could be accomplished:

- 1) by eliminating materials in which the Laboratory no longer was interested;
- 2) by examining usage for establishment of proper stock levels;
- 3) by tailoring the requisition program to reduce investment in inventory and to increase turnover in dollar value.

The Laboratory's efforts to minimize inventory investment by the use of open-end orders seemed to produce encouraging results. Effects of these efforts are reflected in Table 6. The number of months' investment in active inventory on June 30 for the past three years has been:

1953	1954	1955
7.9 months	6.5 months	4.1 months

Increased attention was devoted to the capital equipment problems of the Laboratory. The objectives set were:

Table 6
Inventory changes

Type of Inventory	Fiscal Year		
	1953	1954	1955
Active Inventory			
Opening active inventory July 1	\$552,139	\$418,609	\$396,564
Net of purchases, stores issues, adjustments, additions to inventory, transfers to excess	—133,530	—22,045	—121,990
Closing active inventory June 30	418,609	396,564	274,574
Excess Inventory			
Open excess inventory July 1	311,855	154,198	0
Net of transfers from active inventory, dispositions and adjustments	—157,657	—154,198	45,026
Closing excess inventory June 30	154,198	0	45,026
Total Inventory			
Opening total inventory July 1	863,994	572,807	396,564
Net of purchases, stores issues, adjustments, transfers to excess and dispositions	—291,187	—176,243	—76,964
Closing Total Inventory June 30	\$572,807	\$396,564	\$319,600

- 1) formal establishment of a property catalogue,
- 2) effective use of capital equipments on hand,
- 3) development of a consistent program of disposal of property no longer of use to the Laboratory,
- 4) reduction in investment of such property. It is anticipated that considerable progress toward these objectives will be accomplished during fiscal 1956.

Under the direction of Inventory Management, the Supply and Materiel Division took part in declaring excess approximately 1750 items, with a book value of \$45,000.00. All categories of the inventory were reviewed and those items considered no longer of interest to the Laboratory were declared excess. These items are being processed and disposal will be made during the ensuing fiscal year.

In tailoring the requisition program, it was felt that closer scrutiny should be given to turning over as frequently as possible those items which comprise greatest dollar value. On information obtained from the Tabulating Section, on every item maintained in the inventory, patterns were established for the total dollar value which should be purchased at any given time for inventory. Consideration was given to the costs of ordering, recording and handling to assure

that these costs did not dissipate the gains in inventory investment. Requisitions were then initiated, following the patterns established, with such frequency and in such quantities that the over-all cost was kept at a minimum.

By pursuing this idea further, it became evident that the time factor between requisition and receipt of material must be kept at a minimum. Stock items were screened to determine which of the high dollar value items could be consolidated into classes, i.e., radio tubes, protective clothing, gases, etc. Term contracts with selected vendors were established for these classes. Quicker deliveries made possible a further reduction in shelf inventory. Extension of this plan will be made where circumstances warrant.

All the changes which have been effected in inventory content during recent months have made any current catalogues useless. In cooperation with the using Departments new catalogues are in process. It is anticipated that issuance of the new catalogues will start in the Fall of the coming fiscal year.

The responsibility for Office Machines, Equipment and Furniture was transferred from the Office Services Group to the Supply and Materiel Division. A plan is being initiated to refinish many of these pieces of office furniture which are good, salvage

that equipment which is beyond economical repair and develop a plan to replace that salvaged material with new furniture.

The Typewriter Repair Shop has been set up on a schedule to allow cleaning and maintenance on each office machine at least twice a year. The machines will then also be screened as to condition and obsolescence. Machines which are beyond economical repair will be salvaged and replaced with new machines.

Purchasing

For fiscal year 1954-1955 the Purchasing Division received 15,594 Purchase Requisitions and wrote 16,965 Purchase Orders for a total sum of \$2,736,449.06. Again this year there was an increase in the total number of Purchase Requisitions and Purchase Orders; this increase reflects the pattern of the past eight years.

Table 7

	FY 1954	FY 1953
No. of Purchase Requisitions	14,304	10,890
No. of Purchase Orders & Change Orders	15,977	13,882
Total Dollars	\$2,513,546.41	\$1,922,082.81

Two new employees were added because of the increased activity at the Alternating Gradient Synchrotron. Procedural changes are being made to facilitate the efficient handling of the increase in orders with a minimum of personnel. More of the open type of Purchase Orders, term contracts and broader use of petty cash buying are included. Faster order processing and fast deliveries tend to reduce the amount of warehouse stock on hand.

There has been considerable emphasis on purchasing from AEC contractor excess. The Laboratory made 67 such purchases with a dollar value of \$128,944.08 at an acquisition cost of \$41,415.36.

During the year, thirteen excess sales were conducted. Also, a number of shipments of excess materials, such as graphite, electronic instruments and chemical material, went to other AEC contractors.

Two of the original employees of the Purchasing Division, Mr. Forrest E. James and Miss Edna C. Foster, retired on December 31, 1954. Mr. George W. Maxey assumed the duties of Assistant Purchasing Agent January 1, 1955.

PUBLIC INFORMATION

Activities of the Public Information office were stepped up considerably during the fiscal year. Those activities reflect heightened general interest in "peacetime atomic energy." The greater the demands on the AEC in Washington for press, exhibit and related materials, the greater the number of referrals to Brookhaven as the "least classified" research establishment. Many of the inquiries were related to the translation of atomic energy information in such overseas media as exhibits, newspapers, magazines and radio.

During the fiscal year the Public Information office handled the visits of 125 members of the press, domestic and foreign. In addition to supplying materials thus requested, the office contributed to the following undertakings: 35 magazine articles or special brochures; 29 books, most of them textbooks; 21 newspaper features; and 20 exhibits or school projects. Several Brookhaven staff members participated in radio interviews, or appeared in motion picture footage used on television or in newsreels and educational films. Eighteen news releases describing Laboratory work were mailed to editors in various media.

APPENDIX

A. UNCLASSIFIED PUBLICATIONS, JULY 1, 1954 — JUNE 30, 1955

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, 1954 (BNL 303 (AS-8))
 Quarterly Progress Reports:
 July 1 - September 30, 1954 (BNL 314 (S-23))
 October 1 - December 31, 1954 (BNL 326 (S-24))
 January 1 - March 31, 1955 (BNL 337 (S-25))
 April 1 - June 30, 1955 (BNL 355 (S-26))
 Conference Reports:
 Brookhaven Symposium in Biology No. 7. The Thyroid (BNL 305 (C-20))
 Statistical Aspects of the Nucleus (BNL 331 (C-21))
 Weekly Bulletin 7, No. 50-52; 8, No. 1-49
 Weekly Selected Reading List 7, No. 18-52; 8, No. 1-17

STAFF PUBLICATIONS AND ABSTRACTS

Accelerator Development Department

- Beth, R. A. and Meeks, W. W.
 Investigation of alternating gradient particle focusing action of a TM_{01} guided wave
 BNL 308 (T-52)
 Blewett, J. P., Christofilos, N. C. and Vash, A. M.
 Four-pole permanent magnet rings for focusing beams of charged particles (A)
 Bull. Am. Phys. Soc. 30, 3, 52 (1955)
 Blewett, M. H.
 Design studies for alternating gradient magnets. Part I: Field distributions computed by the relaxation method (A)
 Bull. Am. Phys. Soc. 30, 3, 52 (1955)
 Christofilos, N. C. (See Blewett, J. P.)
 Cottingham, J. G.
 A compensated precision high voltage attenuator with good frequency response
 Rev. Sci. Instr. 26, 876-7 (1955)
 Cottingham, J. G., Plotkin, M. and Raka, E. C.
 Electronic equipment for an electron analogue accelerator
 IRE Trans. Prof. Group on Nuclear Sci. I, 12 (1954)
 Courant, E. D.
 Nonlinearities in the alternating gradient synchrotron (A)
 Bull. Am. Phys. Soc. 30, 3, 52 (1955)
 Graham, M.
 Precision vibrating coil magnetic gradient recorder (A)
 Bull. Am. Phys. Soc. 30, 3, 53 (1955)

*Also included are those listings from the last Annual Report (BNL 303 (AS-8)) for which complete reference information was not then available.

Kassner, D. (See Piccioni, O.—Physics)

Kassner, R. R.

- An analogue of the alternating gradient synchrotron (A)
 Second Ann. Meeting, Prof. Group on Nuclear Sci., Oak Ridge, Tenn., Sept., 1955
 Lambertson, G. R., Lasky, C. and Phillips, R. H.
 Design studies for alternating gradient magnets. Part II: Model measurements (A)
 Bull. Am. Phys. Soc. 30, 3, 53 (1955)
 Lasky, C. (See Lambertson, G. R.)
 Meeks, W. W. (See Beth, R. A.)
 Phillips, R. H. (See Lambertson, G. R.)
 Plotkin, M. (See Cottingham, J. G.)
 Raka, E. C. (See Cottingham, J. G.)
 Vash, A. M. (See Blewett, J. P.)

Architectural Planning Division

- Ruddy, J. M.
 Nuclear energy facility construction costs
 Eng. News-Record 153, 192-5 (1954)
 Ruddy, J. M.
 A proportional liquid sampler
 Nucleonics 13, 48 (1955)
 Ruddy, J. M.
 Radioactive liquid waste control
 Plant Eng. (In press)

Biology Department

- Altszuler, N. (See Steele, R.)
 Anderson, L. F.
 Effects of centrifugation on x-ray-induced chromatid aberrations in *Tradescantia* irradiated in air and N_2 (A)
 Genetics 40, 563 (1955)
 Beevers, H. (See Gibbs, M.)
 Beiser, W. C., Jr. (See Clark, A. M.)
 Bianchi, P. (See Klein, J. R.)
 Bowen, C. C.
 Feulgen staining of cell suspensions
 Stain Technol. 30, 135-8 (1955)
 Budenstein, Z. (See Koshland, D. E., Jr.)
 Caldecott, R. S.
 An inverse relationship between the water content of seeds and their sensitivity to x-rays
 Science 120, 809-10 (1954)
 Caldecott, R. S.
 Effects of hydration on x-ray sensitivity in *Hordeum*
 Radiation Research J. 3, 316-30 (1955)

- Caldecott, R. S.
Effects of ionizing radiations on seeds of barley
Radiation Research J. 2, 330-50 (1955)
- Caldecott, R. S.
The effects of x-rays, 2-Mev electrons, thermal neutrons and fast neutrons on dormant seeds of barley
Ann. N. Y. Acad. Sci. 59, 514-35 (1955)
- Caldecott, R. S.
Ionizing radiations as a tool for plant breeders*
Geneva Conf., 1955
- Caldecott, R. S.
Protection from x-ray induced injury by hydration (A)
Genetics Soc. Meeting, Sept., 1955
- Caldecott, R. S.
Reduction in x-ray sensitivity by hydration (L)
Nature 176, 306 (1955)
- Caspar, A. L. (See Singleton, W. R.)
- Cavaliere, R. (See Klein, J. R.)
- Clark, A. M. and Herr, E. B., Jr.
The effect of certain gases on the radiosensitivity of *Habrobracon* during development
Radiation Research J. 2, 538-43 (1955)
- Clark, A. M.
The relation of genome number to radiosensitivity in *Habrobracon* (A)
Radiation Research J. 1, October, 1954
- Clark, A. M. and Herr, E. B., Jr.
The sensitivity of developing *Habrobracon* to oxygen
Biol. Bull. 107, 329-34 (1954)
- Clark, A. M. and Beiser, W. C., Jr.
The use of haploid and diploid embryos of *Habrobracon* in the study of cell poisons
Science 121, 469 (1955)
- Clark, C. M. (See Woodward, V. W.)
- Dollinger, E. J.
Analysis of a mutable system in maize (A)
Genetics Soc. Meeting, Sept., 1955
- DeMoss, R. D. and Gibbs, M.
6-phosphogluconate dehydrogenase from *Leuconostoc mesenteroides*
J. Bacteriol.
- Deschner, E. and Sparrow, A. H.
Chromosome rejoining capacity with respect to breakage sensitivity to x-rays and thermal neutrons
Genetics 40, 460-75 (1955)
- Deschner, E.
The relationship between chromosome fragmentation and rejoining in *Trillium erectum* following thermal neutron and x-irradiation
Proc. Radiobiol. Symposium, 275 (1954)
- Dollinger, E. J. and Singleton, W. R.
Cytogenetic analysis of a spontaneous pre-meiotic mutation in maize
J. Heredity XLV, 223 (1954)
- Dougherty, E., 3rd, Saunders, L. Z. and Parsons, E. H.
The pathology of infectious serositis of ducks
Am. J. Pathol. XXXI, 475-87 (1955)
- Earl, J. M. (See Gibbs, M.)
- Edelmann, A. (See Mateyko, G. M.)
- Edelmann, A. and Gorbman, A.
Endocrine factors influencing the development of hypophyseal tumors in mice (A)
Proc. Am. Assoc. Cancer Research 2, 13 (1955)
- Edelmann, A.
New evidence for a toxic substance elaborated after irradiation (A)
Federation Proc. 14, March, 1955
- Edelmann, A.
The relation of thyroid activity and radiation to growth of hypophyseal tumors
Brookhaven Symposia Biol. 7, 250 (1954)
- Edelmann, A.
The toxicity of serum from irradiated animals (A)
Science 121, 622 (1955)
- Fluke, D. J. and Pollard, E. C.
Bacterial virus: Radiation and function
Annal. N. Y. Acad. Sci. 59, 484-93 (1955)
- Fluke, D. J. and Marmur, J.
A comparative study of ionizing radiation action on several transforming factors of pneumococcus (A)
Radiation Research J. 3, 225 (1955)
- Fluke, D. J. (See Forro, F.)
- Fluke, D. J. and Marmur, J.
Uniformity of ionizing radiation action on several transforming factors of pneumococcus
Arch. Biochem. and Biophys. 57, 506-14 (1955)
- Forro, F. and Fluke, D. J.
Inactivation of T-1 bacteriophage with cyclotron protons, deuterons and alpha particles (A)
Radiation Research J. 3, 225 (1955)
- Fuller, R. C.
The distribution of the primary photosynthetic carboxylation enzyme (A)
Proc. Plant Physiol. Meetings 30, Suppl., September, 1955
- Gibbs, M. (See Paegle, L. M.)
- Gibbs, M.
Fermentation of ribose-1-C¹⁴ by yeast extracts (A)
Federation Proc. 14, 218 (1955)
- Gibbs, M. and Paegle, L. M.
Fermentative pathways of hexose and pentose dissimilation (A)
Am. Chem. Soc. Meeting, Sept., 1955
- Gibbs, M. and Beevers, H.
Glucose dissimilation in the higher plant, effect of age of tissue
J. Plant Physiol. (In press)
- Gibbs, M., Paegle, L. M. and Earl, J. M.
Metabolism of ribose-5-phosphate-1-C¹⁴ by extracts of *Escherichia coli* (A)
Proc. 55th Gen. Meeting Soc. Am. Bacteriol., 128 (1955)
- Gibbs, M., Earl, J. M. and Ritchie, J. L.
Metabolism of ribose-1-C¹⁴ by cell-free extracts of yeast
J. Biol. Chem.
- 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. (In press)
- Gibbs, M., Earl, J. M. and Ritchie, J. L.
The respiration of the pea plant. Metabolism of hexose phosphate and triose phosphate by cell-free extracts of pea roots
J. Plant Physiol. (In press)
- Gibbs, M. (See DeMoss, R. D.)
- Gorbman, A. (See Edelmann, A.)
- Gunckel, J. E. (See Sparrow, A. H.)
- Hagen, G. (See Sparrow, A. H.)
- Herr, E. B., Jr. (See Clark, A. M.)
- Jakowska, S. and Nigrelli, R. F.
Erythroplastic formation in *Triturus viridescens* exposed to thermal neutrons (A)
Radiation Research Soc. Meeting, May, 1955

*For reference to the papers which were written for the Geneva Conference, see the Introduction.

- King, R. C.
The calculation of radiation doses received by thermal-neutron-treated *Drosophila melanogaster*
Nucleonics 12, 58-9 (1954)
- King, R. C.
Dominant lethal mutations and x-chromosome elimination following x-irradiation of female *Drosophila melanogaster*
Radiation Research J. 3, 143-52 (1955)
- King, R. C.
The effect of a yeast upon the incorporation of phosphorus into the tissue of adult fruit flies
Evolution IX, 93-4 (1955)
- King, R. C.
A method for studying successive batches of eggs laid by treated or control *Drosophila*
Am. Naturalist (In press)
- King, R. C. and Wilson, L. P.
Quantitative studies on the phosphorus balance of adult female fruit flies feeding upon yeast (A)
Anat. Record 120, November, 1954
- King, R. C. and Wood, E. M.
Sex-linked lethal mutations induced by thermal neutrons in male and female *Drosophila melanogaster*
Genetics 40, 490-9 (1955)
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122

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123

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