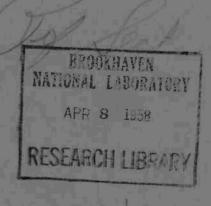
BROOKHAVEN NATIONAL LABORATORY

Annual Report July 1, 1957





Associated Universities, Inc.

under contract with the

United States Atomic Energy Commission

Annual Report July 1, 1957

BROOKHAVEN NATIONAL LABORATORY

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 eighth in a series of unclassified Annual Reports, gives an account of the progress of the Laboratory during the period July 1, 1956 – June 30, 1957, and its plans for the future. It is submitted under the terms of Contract No. AT-30-2-GEN-16 between Associated Universities, Inc., and the Atomic Energy Commission.

Previous reports in this series are:

BNL 74 (AS-4) July 1, 1950 BNL 131 (AS-5) July 1, 1951 BNL 196 (AS-6) July 1, 1952 BNL 246 (AS-7) July 1, 1953 BNL 303 (AS-8) July 1, 1954 BNL 364 (AS-9) July 1, 1955 BNL 426 (AS-10) July 1, 1956

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

PRICE \$5.00

Available from the Office of Technical Services, Department of Commerce, Washington 25, D.C.

December 1957

2450 copies

Contents

Introduction	vii
PHYSICAL SCIENCES AND ENGINEERING	
Physics	3
Instrumentation	21
Accelerator Development	25
Chemistry	32
Engineering	53
LIFE SCIENCES	
Biology	71
Medical Research	93
Technical Operations and Services	109
Administration and Operations	121
Appendix A. unclassified publications	131
Appendix B. officers and scientific staff	145

Brookhaven National Laboratory is operated by Associated Universities, Inc. under contract with the United States Atomic Energy Commission. Nine northeastern universities sponsor Associated Universities, Inc. Two representatives from each university, one a principal administrative or corporate officer and the other a scientist, form the Board of Trustees of AUI. In addition, the Board itself selects three Trustees-at-Large. Their purpose is to insure adequate representation of any scientific discipline in which the corporation may undertake work and to provide general flexibility in methods of operation. The composition of the Board as of July 1957 is shown in the table below. 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. These committees cover the fields of biology, chemistry, engineering, medicine, and physics, and report annually to the Board of Trustees.

BOARD OF TRUSTEES

of

Associated Universities, Inc.
As of June 30, 1957

COLUMBIA UNIVERSITY

Frank D. Fackenthal (Honorary)

COURTNEY C. Brown

CORNELL UNIVERSITY

THEODORE P. WRIGHT

Franklin A. Long

I.I. Rabi

HARVARD UNIVERSITY

EDWARD REYNOLDS

EDWARD M. PURCELL

JOHNS HOPKINS UNIVERSITY

P. STEWART MACAULAY

WILLIAM D. McELROY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

EDWARD L. COCHRANE

NATHANIEL H. FRANK

PRINCETON UNIVERSITY

ELMER G. BUTLER

JOSEPH C. ELGIN

UNIVERSITY OF PENNSYLVANIA

CARL C. CHAMBERS

Francis C. Wood

UNIVERSITY OF ROCHESTER

LAROY B. THOMPSON, Chairman

WILLIAM S. McCANN

YALE UNIVERSITY

C. Hamilton Sanford, Jr.

WILLIAM W. WATSON

TRUSTEES-AT-LARGE

LEO GOLDBERG, University of Michigan CARL K. SEYFERT, Vanderbilt University OTTO STRUVE, University of California Ex Officio LLOYD V. BERKNER, President

VISITING COMMITTEES

BIOLOGY

JOHN T. EDSALL, Chairman Harvard University

ARTHUR W. POLLISTER Columbia University

RAYMOND E. ZIRKLE University of Chicago JOHN S. NICHOLAS
Yale University
S. GRANICK

The Rockefeller Institute for Medical Research

A.M. SRB

Cornell University

CHEMISTRY

CHARLES D. CORYELL, Chairman
Massachusetts Institute of Technology
PAUL D. BARTLETT
Harvard University
GLENN T. SEABORG
University of California

JOHN TURKEVICH
Princeton University
CHEVES T. WALLING
Columbia University
JOHN E. WILLARD
University of Wisconsin

MEDICINE

Frank L. Horsfall, Jr., Chairman The Rockefeller Institute for Medical Research

JOSEPH C. HINSEY
The New York Hospital –
Cornell Medical Center

ROBERT F. LOEB

College of Physicians and Surgeons –

Columbia University

A. BAIRD HASTINGS
Harvard Medical School
EUGENE P. PENDERGRASS
University of Pennsylvania
VERNON W. LIPPARD
Yale University School of Medicine
HAROLD G. WOLFF
The New York Hospital
IRVINE H. PAGE
Cleveland Clinic

ENGINEERING

Lyle B. Borst, Chairman
New York University
Philip Sporn
American Gas and Electric Company
Cyril Stanley Smith
University of Chicago
J.A. Swartout
Oak Ridge National Laboratory

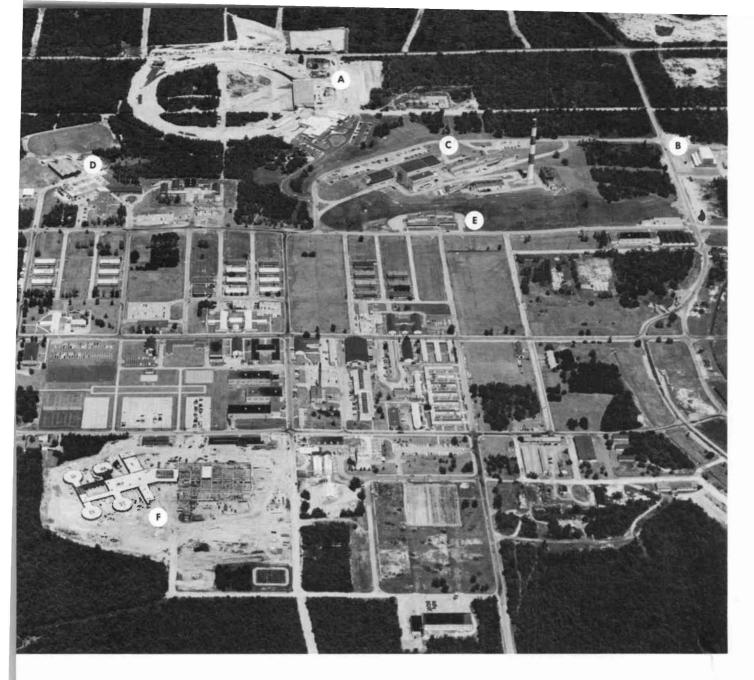
Cecil H. Gay Formerly, Babcock & Wilcox Company

ROBERT LEBARON Formerly, Atomic Energy Research and Development Board

Manson Benedict
Massachusetts Institute of Technology

PHYSICS

EUGENE T. BOOTH, Chairman Columbia University SAMUEL K. ALLISON University of Chicago KENNETH GREISEN Cornell University GEORGE E. UHLENBECK
University of Michigan
MARTIN DEUTSCH
Massachusetts Institute of Technology
HILLARD B. HUNTINGTON
Rensselaer Polytechnic Institute



Aerial View of the Laboratory Site; New Construction and Major Facilities: A. Alternating Gradient Synchrotron; B. Nuclear Engineering Works Area Building; C. Research Reactor and Hot Laboratory; D. Cosmotron; E. Cyclotron and Van de Graaff Building; F. Medical Research Center and Medical Reactor.

Introduction

This annual report of Brookhaven National Laboratory describes its program and activities for the fiscal year 1957. 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. (A list of all publications may be found in Appendix A, and the record of publications since 1946 is shown in Figure 2.)

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

PRESENT RESEARCH FACILITIES

As in previous years the Cosmotron, a 3-Bev proton synchrotron, and the research reactor continue to support the major fraction of the research effort at Brookhaven.

During the first seven months of this report period the Cosmotron operated remarkably well. Circulating beams of 10¹¹ protons per pulse at energies up to 3 Bev were available. Indeed, it became necessary to limit the running time of certain experiments in order to keep personnel exposure to radiation below prescribed levels. It was possible to focus the external beam into an area of about 0.5-cm diameter. One interruption in this very satisfactory operation occurred late in October because of the opening up of a bolt connection between copper strips in the main generator rotor. Operation was resumed on November 5, and unusually high beam intensities were experienced until late in January.

A break in the circuit of the main magnet coil occurred on January 24, the second accident of this kind. Unlike the previous one which occurred on November 5, 1954, and was due to a water leak, this failure was traced to a fracture at a right-angle

bend near the end of one of the copper bars, which apparently had been work-hardened by the large mechanical stress at this point during each pulse. All the bars and the vacuum chamber had to be removed from the second quadrant, and six months elapsed before repairs had been completed and operation resumed.

During the repair of the coil, new "kicker" bars to limit the motion of the coils to less than half what it had been were placed on all four quadrants, as well as new coil end clamps. These should reduce the chance of future breaks of this kind if internal damage has not progressed too far.

During the shutdown period, provision was made for the emergence of a second external proton beam from the central beam port of the second quadrant. This beam will be used for the production of intense beams of high energy pions, both positive and negative. The sand under the Cosmotron floor was reinforced both inside and outside the magnet so that it will support the additional heavy shielding required for adequate protection of personnel against radiation.

Interest in high energy physics experiments at the Cosmotron has shown no sign of diminishing. The demand for running time is greater than ever. The additional shielding and the large amount of experimental apparatus required have resulted in a serious shortage of floor space in the vicinity of the Cosmotron beams. Extension of the present Cosmotron experimental area has therefore been planned by an addition, approximately 100×200 ft, that will be connected to the present structure. Arrangements will be made to direct the Cosmotron external beams to different points of the new floor area. Switching the beams from one experimental setup to another is expected to make possible more nearly continuous operation of the Cosmotron and more effective use of running time.

The research value of bubble chambers has been well established. The large hydrogen bubble chamber now under construction should be ready for use early in 1958. The installation of the new hydrogen liquifier has been completed, and pro-

duction of hydrogen at the rate of 60 l/hr was realized in October.

The Brookhaven research reactor operated very satisfactorily throughout the year. Its in-pile and beam facilities have been used in a variety of programs both by Brookhaven scientists and by visiting scientists and engineers from other institutions. Thirteen industrial companies, three universities, and one governmental agency have used reactor space under various contractual arrangements for their own research projects, carried out by scientists from the respective institutions, during this report period. Except for scheduled shutdowns, the reactor has been operated continuously at an average power level of 23 Mw. Fifteen neutron spectrometers are now in almost continuous use at different experimental stations - 8 by Brookhaven, 4 by industries, 2 by universities, and 1 by a government laboratory.

In December 1956, approval was received from the Atomic Energy Commission to replace the natural uranium fuel elements with new enriched fuel elements (>90% U²³⁵). A central region consisting of 35 channels in a cylindrical pattern was reloaded with the new enriched elements between December 21 and January 1. The thermal flux in the central core attained a maximum of 1.2×10¹³ neutrons/cm², about double the former value. However, the resonance flux as seen with the fast chopper equipment had only half its previous value in this central region. An interim adjustment was made by reloading the most central region with fuel elements of even higher enrichment and thus raising the resonance flux to about its former value. These more highly enriched elements will be removed during later stages of reloading of the reactor, and ultimately identical fuel elements will be used throughout. The second step of the reloading will take place in September 1957, when about 120 additional central channels will be reloaded with the new elements.

The increased thermal neutron flux due to the reloading resulted in increased specific activities in many of the exposed materials and equipment. It therefore became necessary to extend the duration of the regularly scheduled shutdown periods to include one additional day for "cooling off" radioactive items before removal from the reactor. In order to keep shutdown time to a minimum, the former interval of 10 days between shutdowns was extended to 14 days. The present schedule

calls for shutdown on alternate Fridays at 12:01 A.M. and resumption of operation during the late shift on the following Saturday.

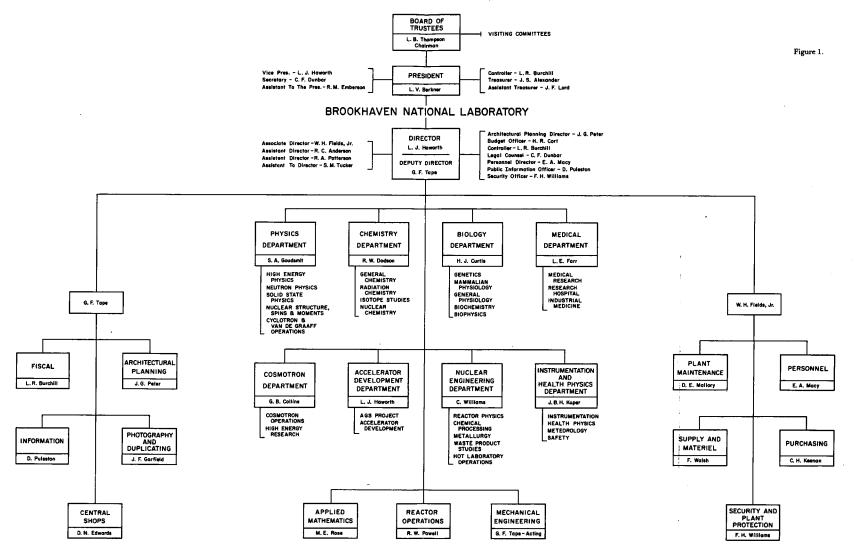
Although the number of shipments of radioisotopes and other materials irradiated in the reactor increased somewhat over that for fiscal year 1956, the present rate is about 30 shipments per week, the same as a year ago. Since 1951 over 64,000 shipments have been made to about 200 different customers. The shipments go to industries (35%), hospitals (35%), universities (20%), and government laboratories (10%). The Laboratory also activates annually about 15,000 curies of Co⁶⁰ for use in special kilocurie gamma-ray sources. Up to the present, the demand for these sources has exceeded the Laboratory's supply.

For the second successive year the 60-in. cyclotron has had a good performance record. Two shutdown periods of one week each, and one of two weeks, were required for repairs. The interruptions were due to water leaks attributed either to corrosion or to velocity erosion. The demand for cyclotron time has been met by operating the machine up to midnight two or three times a week. External beams of protons, deuterons, and alpha-particles have been available at energies of about 10, 20, and 40 Mev, respectively.

The usefulness of the 18-in. cyclotron as a research instrument has been greatly increased during the past year. An examination of the magnetic field during the summer of 1956 revealed serious distortions. New pole tips and shims increased the proton energy to 3.0 MeV, as compared with 2.5 MeV previously available. Stability of operation has resulted from improved frequency stability in the rf system. The proton energy variation is now only about ± 9 keV at 3 MeV. A focused external beam of 100 microamperes is available, double that obtained previously.

Improved performance of the electrostatic generator was experienced following the installation of a newly designed acceleration tube in the spring of 1956. Operation for 1500 hr at proton energies ranging up to 3.7 Mev suggests that this improvised composite electrode tube developed here is electrically more rugged than the gradient column in which it is used – the first time in the history of the development of the electrostatic accelerators that this has been achieved. Sparking, however, developed inside one of the support columns on November 20. Attempts to eliminate it by scrap-

ASSOCIATED UNIVERSITIES, INC.



ORGANIZATION CHART AUGUST, 1957

Table 1 Organizational Expenditures - Fiscal 1955, 1956, 1957 (Includes Operating, Services to Fixed Assets, and Work for Others. Direct Costs of A.G.S. and Other Fixed Assets Are Not Included, see Table 3)

		Salaries, Wages, Insurance							Man-Years				
		Staff	Consultants & Temporary Employees	Travel	Material & Supplies	Sub-contracts & Special Procurements	Power	Miscellaneous (Net)	Total Organizational Costs	% of Total	Scientific (Incl. Guests)	Others	Total
Physics & Chemistry Research	1957 1956 1955	2,118,366 1,951,118 1,734,418	121,136 88,882 74,767	62,664 81,998 53,330	690,781 464,265 338,452	53,805 7,054 24,193	60,355 64,491 38,337	— (13) (753)	3,107,107 2,657,795 2,312,7 44	21.6 22.4 21.6	196.0 199.5 181.5	164.0 146.5 134.0	360.0 346.0 315.5
Biology, Medicine & Biophysics Research	1957 1956 1955	1,305,467 1,125,070 1,036,260	44,023 38,319 46,240	50,315 40,884 30,702	258,493 213,772 216,930	7,647 8,214 11,101	-	(5,103) (15,626) (6,899)	1,660,842 1,410,633 1,334,334	11.5 11.9 12.5	92.5 81.0 85.5	154.0 149.5 147.5	246.5 230.5 233.0
Nuclear Engineering Research	1957 1956 1955	1,178,375 914,145 780,197	26,320 20,629 16,362	47,742 43,093 23,777	390,294 383,957 305,769	931,284 190,602 112,154		 (276) (2,658)	2,574,015 1,552,150 1,235,601	17.8 13.1 11.5	82.5 77.5 67.5	111.0 82.5 71.0	193.5 160.0 138.5
Radiation Protection	1957 1956 1955	265,909 237,004 220,567	1,073 1,768 1,201	1,378 2,141 947	46,270 34,268 41,532			(8,514) (14,358) (13,298)	306,116 260,823 250,949	2.1 2.2 2.4	10.0 14.0 13.5	37.0 35.0 32.5	47.0 49.0 46.0
Supporting Scientific & Technical Services	1957 1956 1955	1,766,212 1,579,781 1,485,085	10,277 6,705 8,298	15,405 15,066 8,236	274,860 256,976 239,298		496,884 470,945 427,389	(270,775) (244,127) (175,040)	2,292,863 2,085,346 1,993,266	15.9 17.5 18.6	27.5 29.0 31.0	263.5 257.5 255.5	291.0 286.5 286.5
Security & Plant Protection	1957 1956 1955	459,383 448,685 460,006	<u>-</u>	762 392 1,569	10,171 10,541 5,764	<u>-</u>		2,088 (35) —	472,404 459,583 467,339	3.3 3.9 4.4	_ _ _	82.0 86.0 95.5	82.0 86.0 95.5
Miscellaneous (including Lighting, T & T, Heating Fuels, Special Maintenance, etc.)	1957 1956 1955	=		431 1,127 1,394	132,780 86,541 72,923	=	195,640 176,154 140,833	572,920 513,413 382,994	901,771 777,235 598,144	5.7 6.5 5.5		=	=
General and Administrative	1957 1956 1955	2,460,312 2,222,434 2,027,971	20,279 10,798 7,520	66,672 58,524 57,133	272,598 243,278 262,029	822 —	=	(150,010) (153,256) (151,304)	2,670,673 2,381,778 2,203,349	18.5 20.1 20.6	5.0 5.5 5.0	441.5 424.5 406.5	446.5 430.0 411.5
Laboratory Total	1957 1956 1955	9,554,024 8,478,237 7,744,504	223,108 167,101 154,388	245,369 243,225 177,088	2,076,247 1,693,598 1,532,697	993,558 205,870 147,448	752,879 711,590 606,559	140,606 85,722 33,042	13,985,791 11,585,343 10,395,726	97.0 97.6 97.1	413.5 406.5 384.0	1,253.0 1,181.5 1,142.5	1,666.5 1,588.0 1,526.5
AUI Administration	1957 1956 1955	=	_ _		=	, =	= .	150,000 150,000 161,400	150,000 150,000 161,400	1.0 1.3 1.5			=
Total AUI and BNL	1957 1956 1955	9,554,024 8,478,237 7,744,504	223,108 167,101 154,388	245,369 243,225 177,088	2,076,247 1,693,598 1,532,697	993,558 205,870 147, 44 8	752,879 711,590 606,559	290,606 235,722 194,442	14,135,791 11,735,343 10,557,126	98.0 98.9 98.6	413.5 406.5 384.0	1,253.0 1,181.5 1,142.5	1,666.5 1,588.0 1,526.5
Work for Others, Direct Costs Only	1957 1956 1955	97,155 70,853 43,296	11,451 10,582 65	35,045 5,809 1,367	92,118 41,496 48,785		=	49,377 ——	285,146 128,740 146,523	2.0 1.1 1.4	11.0 6.0 2.0	14.0 8.5 6.0	25.0 14.5 8.0
Grand Total	1957 1956 1955	9,651,179 8,549,090 7,787,800	234,559 177,683 154,453	280,414 249,034 178,455	2,168,365 1,735,094 1,581,482	993,558 205,870 200,458	752,879 711,590 606,559	339,983 235,722 194,442	14,420,937* 11,864,083** 10,703,649†	100.0 100.0 100.0	424.5 412.5 386.0	1,267.0 1,190.0 1,148.5	1,691.5 1,602.5 1,534.5

Note: Certain adjustments have been made in 1955 and 1956 costs as previously reported in order to make them comparable to those for 1957.

*\$447,475 of this total was distributed to Fixed Assets and as services to Work for Others.

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

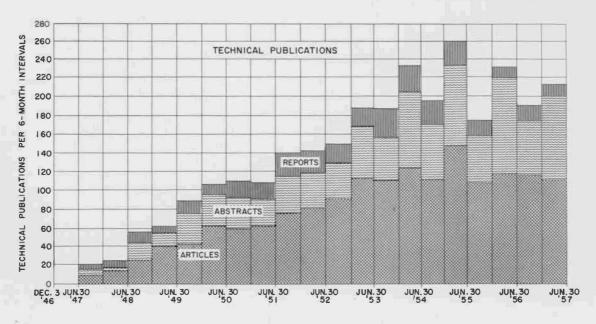


Figure 2.

ing and reglyptalling failed. A spare tube had to be cleaned and dried several times after installation before normal operation was resumed in February, and it was some time before continuous operation at 3 to 4 Mev could be realized. A beam of over 40microamperes can be focused through a ¼-in.-diameter aperture about 15 ft from the analyzing magnet, which increases the current density by a factor of about eight over that previously available. Operation on a two shift per day basis was necessary to meet the demand for running time during the summer.

CONSTRUCTION PROGRAM

The complex of structures for the Alternating Gradient Synchrotron, Project AGS, is nearing completion and has been proceeding on schedule. The construction area may be seen at the top of the aerial view which serves as frontispiece. The AGS service building was completed in November 1956. At that time the Accelerator Development Department transferred its activities from barracks buildings to its new quarters. The circular concrete shell that will enclose the magnet and the tunnel for the linac injection system has been completed. The floors for these enclosures have been laid. The concrete tunnels are being covered with a 10-ft thickness of sand and gravel. Construction of the building that will cover the target

area is well along, as well as that for the injection equipment. Installation of the various utilities has begun. It is expected that heat will be turned on in the tunnel, injection, and target buildings so that they can be occupied by early 1958.

Construction of the new Medical Research Center (shown in the lower portion of the frontispiece) is also progressing well. The physical characteristics and functions of this complex of buildings, including the adjoining Medical Research Reactor, were described in some detail in the last Annual Report. The Medical Department is expected to move from the temporary wooden army buildings now occupied to the new quarters sometime next spring.

The new works area building, 10,000 ft² in area, with a high ceiling, has been completed. Its chief function will be to house certain large test loops now under design or fabrication for the Liquid Metal Fuel Reactor Project.

In the last Annual Report it was stated that budget requests had been approved by Congress for a new physics building (approximately 51,000 ft²) and an enginering building (40,000 ft²), but funds for these two projects were held up by a broad government policy covering new building construction. Design work has begun, however, on housing for the Reclamation Facility and Hot Laundry (7500 ft²), and a 5800-ft² addition to the cyclotron – Van de Graaff building to house the

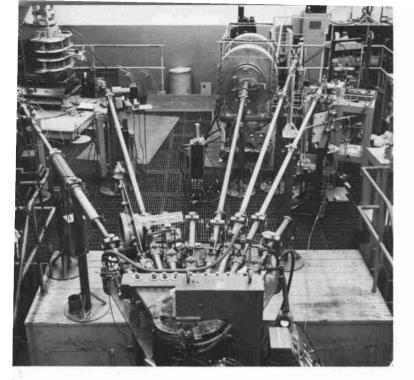


Figure 3. A number of experimental equipments used in studies of beams from the electrostatic generator.

18-in. cyclotron, and construction will proceed in fiscal 1958. Additional experimental space is urgently needed at the Cosmotron in order to meet more adequately the demands of experiments for access to high energy beams and to provide for more efficient use of the running time of this machine. A request for funds to proceed with a major enlargement of the target area and provision of complete shielding has been submitted to the AEC and to Congress for approval.

The physicists are still scattered in various temporary structures, and the increasing staff of the Nuclear Engineering Department is crowded into a badly deteriorated wooden structure, formerly the Enlisted Men's Service Club. The Laboratory has reassessed these needs with respect to space and timing, and has requested provision of funds for a physics building in its budget for fiscal year 1959. This will be followed by a similar request for an engineering building in fiscal 1960.

A number of minor construction projects were completed during this report period. The principal projects under this heading are briefly described under "Architectural Planning" in the Administration and Operations section of this report. The program of restoration of temporary buildings has been continued for another year and will have to be maintained until more permanent structures replace the wooden buildings that have been occupied for the past ten years.

MAJOR RESEARCH PROJECTS

Liquid Metal Fuel Reactor

The use of a liquid metal as a reactor fuel has been under investigation at Brookhaven for several years. These studies, both theoretical and experimental, have dealt with the feasibility of developing components that might later be coordinated into a complete reactor system. Over a year ago the Atomic Energy Commission added the Liquid Metal Fuel Reactor (LMFR) to the official list of reactors under development. In November 1956, the Commission contracted with the Babcock & Wilcox Company first to study the scope, preliminary design, and required research and development, and then to undertake the detailed engineering design and construction, and finally the operation of a LMFR Experiment (LMFRE). The Laboratory shares in the responsibility for the research and development directly required for this program.

One of the interesting aspects of the LMFR is the possibility of continuous removal of fission products to maintain a low concentration of these reactor poisons in the fuel. Earlier investigations had indicated that a large and important fraction of the nonvolatile fission products can be extracted in fused salts. During the past year a more intensive study has been undertaken of the behavior of a few fission products in the liquid metal and salt phases. It has been possible to interpret their partition between the liquid metal and liquid salt phases in terms of their thermodynamic properties and those of other components of the system. Because precision in distribution experiments has been far more difficult to attain with uranium than with other elements, it seemed advisable to investigate the state of uranium in salt mixtures by methods other than salt-metal partition experiments. Some progress has been made with spectroscopic, polarographic, and electrometric techniques both at Brookhaven and in the laboratories of subcontractors. Some of these show promise for development into instrumental methods for monitoring the salt phase composition in a continuous extraction process. In scaled-up salt extraction experiments 200-fold greater than earlier ones, the ratio of cerium to uranium was 200 to 2000 times greater in the salt than in the liquid metal, a very satisfactory ratio from an engineering standpoint.

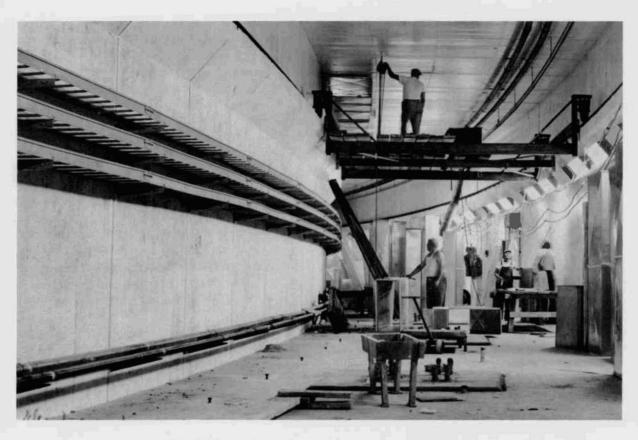


Figure 4. The interior of the tunnel under construction that will house the magnet for the Alternating Gradient Synchrotron.

The problems of corrosion and metal transfer involving the liquid metal fuel and its containing vessel have not yet been completely solved; however a large amount of useful information has been accumulated from the thermal convection loop program. The container material in most of these experiments has been a low chrome steel. If the zirconium and magnesium concentrations in the uranium-bismuth metal are maintained at approximately 250 and 360 ppm, respectively, these loops will run for long periods without plugging. However, the hot leg was attacked quite severely in some experiments in which the temperature differential exceeded 100°C. The experiments are being continued in an effort to determine a set of conditions with respect to inhibitors, container materials, and temperature ranges under which the corrosion and mass transfer effects will be reduced to a satisfactory level.

Further studies on blanket materials have been made. Satisfactory dispersions of thorium bismuthide in bismuth have been produced in batches as large as 90 lb. A number of different techniques are being investigated for the reconstitution of thorium bismuthide dispersions, some by subcontractors. An ultrasonic technique shows promise.

Since it is proposed to use graphite as a moderator in the LMFRE, bismuth uptake has been studied in a number of graphite specimens at various pressures at a temperature of 550°C. Two of the types tested appeared satisfactory for LMFR use. A number of experiments have been planned to test other phases of the behavior of graphite in relation to its use in an LMFR. Preliminary measurements have been made on the diffusion of thermal neutrons in both graphite and bismuth.

Several important test loops have been designed and are in the process of fabrication. One is a 4-in. pipe size pumped loop consisting of a primary loop and a secondary loop connected by an intermediate heat exchanger, which is to be used for uranium-bismuth fuel service. When available it will be used to obtain engineering scale information on the design and operation of components of the

size required for an LMFRE. An in-pile radiation loop is being fabricated that will convey a solution of uranium-bismuth, zirconium, and magnesium through a pipe in the Brookhaven reactor in order to determine its corrosion effect on various steels in the presence of radiation (neutrons and fission products). Another large complex loop now in fabrication will be used for testing various column designs and operating conditions for the extraction of fission products from liquid metal fuels with fused salts. An all stainless steel loop which should be ready for operation within the next few months will be used to test and develop instrumentation, pumps, and other hardware units for fused salt service. All the work under way is being carried out in close cooperation with the staff of the Babcock & Wilcox Company with the objective of determining the necessary engineering data for the design and construction of the LMFRE.

Alternating Gradient Synchrotron

The Alternating Gradient Synchrotron is designed to provide a beam of protons of 25 to 30-

Bev energy. In general, progress in the development of this machine has been kept on schedule. During the past year the status of this project has been moving from the stage of experiment and design into that of construction. Experimental studies of the various magnet models and steels progressed sufficiently so that final design of the main magnet coil and cores could be completed. Contracts for the fabrication of these two major items have been prepared and submitted to the AEC for approval. (These contracts have since been executed.) It is anticipated that pilot models for test purposes will be received from the fabricators in the first half of 1958. Delivery of all the cores and coils is expected to be completed early in 1959. Specifications for the complete magnet power supply system have been finalized, and a contract has been awarded. Delivery of the component parts is expected by the summer of 1958.

The injection system will consist of a 750-kv Cockcroft-Walton set feeding protons into a 50-Mev linear accelerator. The Cockcroft-Walton injector has been delivered and assembled for stud-

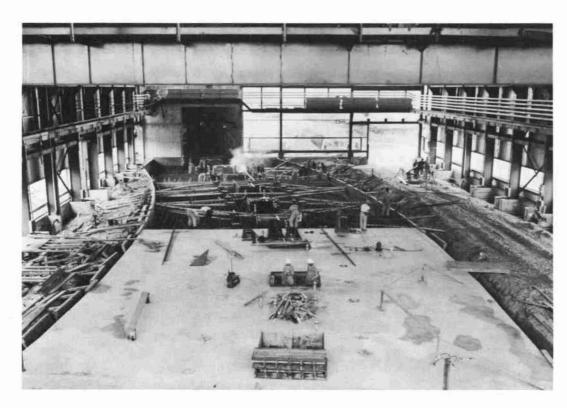


Figure 5. The magnet piers and target area of the Alternating Gradient Synchrotron during the laying of the floor.

ies of its performance characteristics. The high voltage terminal to house the ion source and ancillary equipment are on order. The accelerating column in which the protons are led from the high voltage terminal to ground and so into the linear accelerator has been designed. Construction is in progress or about to begin on all components of the linear accelerator. The inside diameter of the linear accelerator tank has been frozen at 95 cm. Drawings of all eleven sections, each 10 ft long, are complete and will be sent out for bids shortly. Computation of the drift tube shapes on the Univac was completed in January. Design of the pulse quadrupoles to be embedded in the drift tubes for focusing the proton beam has been completed, and they have been ordered. Radio-frequency power for the linear accelerator will be supplied by a 5-Mw klystron now under development. Although construction of this tube is behind schedule, there is little doubt of its eventual success. Designs of the quadrupole focusing elements to guide the beam from the linear accelerator to the synchrotron, a debuncher, and a pulsed inflector are in progress.

Some of the original concepts of the radiofrequency system for accelerating the circulating protons have been revised and modified during the past year. The design of the low level system is based on beam feedback and double mixing circuits. In principle, the double mixing of the signal frequencies makes it possible to accomplish all phase control at a constant frequency. The model test power amplifier designed and built to drive the model ferrite cavity has performed adequately. As now visualized, the rf power amplifiers will have only the final stages located in the magnet enclosure. The low level, driver, and cathode follower stages will be located at some convenient position remote from the ring. Rf will be fed from the cathode follower stage to the 12 final stages at the ring over 24 coaxial cables. A contract for the fabrication of all the ferrite rings required for use in the cavities has been prepared and submitted to the AEC for aproval. (This contract has since been approved and executed.) A completely transistorized de amplifier is under construction that should prove adequate to drive the cavity directly and should be relatively free of any unwanted frequencies.

An Evapor-ion pump with a number of modifications and improvements has consistently maintained a pressure of about 1 to 2×10^{-6} mm mercury. When the largest dimension of the vacuum chamber was reduced from 8 to 7 in., a chamber of Inconel X with a wall thickness of 0.078 in. without rib supports was found to be feasible and has been adopted. The cross section of the vacuum chamber will be approximately elliptical in shape, 7 in. wide and 3% in. high.

PROJECT COLOMBO

Early in 1956, the Laboratory undertook a detailed study the purpose of which was to assist the U.S. Government in drawing up plans for the installation, operation, and administration of a regional nuclear research and training center in Asia, toward which this country would make a major financial contribution. The International Cooperation Administration, the agency initiating the project, transferred funds through the AEC to cover the Brookhaven study, and a group, known locally as Project Colombo, was established. In addition to several Laboratory staff members, specialists in various fields were assigned to the project on a temporary basis from other institutions.

A ten-man field group was sent on a ten-week tour of fourteen of the Asian countries within the Colombo Plan, while the remainder of the project staff explored sources of information in this country and in general prepared for the reporting phase of the project when the entire staff was reunited. A firm of architect-engineers, the Ralph M. Parsons Company, was engaged to prepare architectural ideas for the Center, with preliminary layout plans and schematic drawings of the various buildings, together with rough construction cost estimates.

On June 25, 1956, the Asian tour was completed, and the project staff reassembled at Brookhaven to prepare the necessary reports. The comments of many scientists and administrators from the Laboratory staff were solicited in finalizing the Brookhaven concept for the Center. A number of discussions were held with officials of the International Cooperation Administration, State Department, and Atomic Energy Commission based on working papers and preliminary drafts. The final report was prepared and issued in November. The main conclusions of the study group may be summarized as follows:

The establishment of an Asian Regional Nuclear Center is considered to be entirely feasible, and capable of contributing significantly to the scientific and technological development of the region.

The Center must achieve eminence in the applications of atomic energy to the regional problems of agriculture, medicine, and industry. Since practical advances depend upon the basic sciences, a strong research program in the physical and life sciences is essential.

In order to achieve its objectives, the Center must be staffed by men of high competence and diverse specializations. The recruitment of well qualified scientists will be a major problem. The total staff including students is expected to increase in phase with the ultimate, long-range growth of the program to a stable level of about 1000. In the initial phase, the number of students at all levels that could be accommodated at one time is estimated at about 200. Although eventual staffing by scientists and technicians of the region is imperative, much of the early key staff will have to be drawn from western countries.

A well balanced Center must contain laboratories and equipment for research in the basic sciences; general nuclear facilities such as a research reactor, a hot laboratory, radiation sources, and isotope laboratories; and extensive special facilities for application studies in medicine including a clinical and research hospital, agriculture, and industry; ultimately, a demonstration power reactor should be considered.

Because of the critical shortage of technically trained people, an education and training program must be undertaken. During the early years, emphasis would be placed on this training, and on immediate applications of atomic techniques to regional problems. A student training program, to begin immediately upon authorization of the Center, is proposed. Special training of prospective scientific staff members should also be initiated as soon as possible.

To function effectively, the Center must be an integral unit in one location. It must be supported wholeheartedly by the participating nations; all those nations must share in its management, financing, and staffing.

The relationship between the Center and the Colombo Plan nations should be determined

by the participating nations. To establish the Center itself, the employment of an organization experienced in major undertakings of a similar kind is recommended.

Copies of the final report were distributed by the State Department to the delegates attending the Colombo Plan Consultative Committee meeting at Wellington, New Zealand, in early December. In presenting the United States proposal to the delegates, Mr. Walter Robertson, Assistant Secretary of State for Far Eastern Affairs, suggested the establishment of a working group as the best means of discussing the Brookhaven report and of formulating specific recommendations to the respective governments. Later the United States Government invited all the countries of the Colombo Plan to send their delegates to a twoweek Asian Nuclear Center Working Group meeting to be held in Washington in July 1957. Dr. Haworth was invited to serve as Senior United States Scientific Consultant to the meeting. At the request of the International Cooperation Administration the Laboratory provided both an annotated agenda and a series of working papers covering details of the scientific and technical aspects of the proposed Center to show how the programs in staffing, training, research, and construction could be started and how they would develop during the early years. Arrangements were made for a three-day visit to Brookhaven by the working group prior to their discussions in Washington to provide them with the opportunity of examining the scientific and technical problems in the atmosphere of a cooperatively managed nuclear research institution. A series of talks and conducted tours by key staff members, covering the program of most direct concern to the Center, have been planned, together with less formal meetings for individual interest groups.

REACTOR HAZARD STUDY

At the request of the Division of Civilian Application of the Atomic Energy Commission, the Laboratory undertook a study of the potential hazards to the public of nuclear power reactors. The technical phase of this study was analyzed by a team composed of staff members of the Laboratory with the assistance of a number of consultants and experts from other organizations. A steering committee composed of scientists and

engineers from the staffs of the AEC and the Laboratory guided the study. It was necessary for the group to frame hypothetical circumstances under which harm and damage could occur, since, fortunately, there had been no reactor accidents involving public liability.

The portion of the study dealing with consequences of theoretical accidents started with the assumption of a typical power reactor, of 500,000-kw thermal power, in a characteristic power reactor location. Accidents were postulated to occur at a time when essentially full fission product inventories had been built up. Three types of accidents which could cause serious public damages were assumed. Pessimistic (higher hazard) values were chosen for numerical estimates of many of the uncertain factors influencing the final magnitude of the estimated damages. These theoretical damage estimates are believed to be greater than the damage which would actually occur even in the unlikely event of such accidents.

For the three types of assumed accidents, the theoretical estimates indicated that personal damage might range from a lower limit of none injured or killed to an upper limit, in the worst case (a combined series of the most adverse circumstances), of about 3400 killed and about 43,000 injured. In the case of a major release of fission products under adverse meteorological conditions it was estimated that people could be killed at distances up to 15 miles and injured at distances of about 45 miles. Land contamination could extend for much greater distances. Theoretical property damages ranged from a lower limit of about one half million dollars to an upper limit of about seven billion dollars. This latter figure is large because of assumed contamination of land with fission products. In the large majority of the theoretical reactor accidents considered, the total assumed losses would not exceed a few hundred million dollars.

Numerical estimates of a quantity so vague and uncertain as the likelihood of occurrence of major reactor accidents have little if any meaning, and many experts therefore declined to make any numerical estimate of this probability. However, there was no disagreement in the opinion that the probability of major reactor accidents is exceedingly low. For comparison, in the United States in any year, under the most pessimistic assumptions used and with 100 power reactors in opera-

tion, the chance of a person being killed by a reactor accident should be less than one in 50 million, whereas the present chance of being killed by an automobile accident is about one in 5000.

The findings of the study were submitted by the AEC to the Joint Congressional Committee on Atomic Energy in March 1957 for use in its formulation of the Anderson-Price indemnity bill. The final report of the AEC, under the title Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants, WASH-740, will be issued by the Government Printing Office.

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;
- the use of nuclear tools, such as neutrons, charged particles, gamma-rays, and isotopic tracers, in all branches of scientific research; and
- 4) research and development, not necessarily of a nuclear nature, directed at the specific problems of atomic energy development.

The research activities and more important developments of the year are described in more detail in the sections of this report following the introduction under the headings "Physical Sciences and Engineering" and "Life Sciences."

Fundamental Studies of Nuclei

These studies make use of probes to disturb the nuclei and of various techniques to determine the resulting events. The probes range from protons at 3 billion electron volts of energy from the Cosmotron to neutrons of fractions of an electron volt of energy from the reactor. The work at high energy has excited most attention and enlisted the active collaboration of scientists from a number of universities. Unfortunately, because of the breakdown of the Cosmotron, the high energy

beams from this machine were available only during the first half of the present report period. The studies undertaken were concerned mostly with the production and behavior of heavy mesons and hyperons and their modes of decay in an attempt to learn more about the role they play in the structure of nuclei.

An account was given in the last Annual Report of the first experimental confirmation of the existence of a neutral K-meson, $\theta_2{}^0$, having a mean life much longer than 10^{-10} sec. It has been shown that the mean life of this particle is of the order of 10^{-7} sec and that it exhibits three modes of decay – into a pion, muon, and neutrino; into a pion, electron, and neutrino; and into three pions.

An investigation of the unstable neutral particles produced by negative pions in a propane bubble chamber was carried out by a group from Columbia University with members of the Brookhaven staff collaborating. Analysis of the pictures obtained established the existence of the very short-lived neutral form of the sigma hyperon, Σ° , together with its decay into two neutral particles,

a lambda hyperon, Λ^0 , and a gamma-ray. The decay of the hyperon, Λ^0 , into two neutral particles, a neutron and a pion, was discovered. Strong evidence was found for the decay of the short-lived neutral K-meson, θ_1^0 , into a pair of neutral pions.

The threshold energy of protons required for the production of negative K-mesons in emulsions was found to be about 0.7 Bev higher than that for positive K-mesons. This confirms the production scheme proposed by Gell-Mann and Pais, according to which the production of a negative K-meson is always accompanied by that of a positive K-meson, whereas the positive K-meson can be made in association with a hyperon. The interaction cross section for the negative meson in passing through an emulsion was found to be more than twice that for the positive meson.

The questioning of the validity of the principle of conservation of parity in weak interactions by Lee and Yang, which developed from discussions held at Brookhaven, proved to be the most stimulating development of the past year in the study of elementary particles. Experimental confirma-

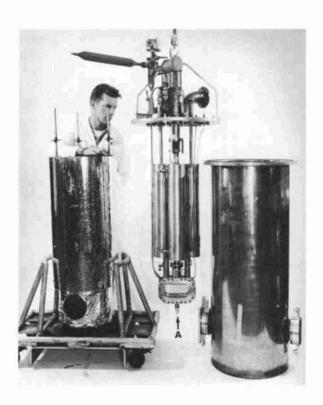


Figure 6. A small liquid hydrogen bubble chamber (A) with the housing disassembled.

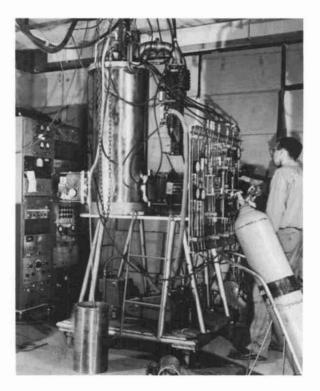


Figure 7. The hydrogen bubble chamber assembled with accessory equipment for analysis of Cosmotron beams.

tion was quickly obtained by investigators at Columbia University. Further confirmation was sought at Brookhaven by an investigation with a hydrogen bubble chamber of the angular distribution of the electrons emitted in decays of muons. An asymmetry was observed directly in their distribution which showed that parity is not conserved in muon decays.

While the physicists have used the high energy beams from the Cosmotron primarily in efforts to elucidate the interactions that occur between elementary particles, the chemists have pursued the study of reactions between complex nuclei and protons with energies in the Bev region. In most of these investigations, the radioactive products of the reactions have been identified and measured by means of the characteristic radiations they emit. However, during the past year a method of measuring the relative yields of reaction products by means of mass spectrometers has been developed. In particular, this technique is useful in the measurement of very long-lived and stable nuclei which cannot be detected radiochemically. For instance, the yields of cesium and ruthenium isotopes from the bombardment of gold with 3-Bev protons have been determined. An upper limit of 0.002 mb has been set for the cross section of the formation of the long-lived isotopes of cesium from gold.

Another new technique employed in the past year to supplement radiochemical data is the detection of reaction products in photographic emulsions. The emission of nuclear fragments heavier than alpha-particles that come from interactions of high energy protons with the silver and bromine nuclei in emulsions has been investigated. The number of such fragments increases from approximately one at 0.4 Bev to about two at proton energies between 2 and 3 Bev. Improved track measuring techniques being developed should make it possible to determine the nuclear charges of some of the fragments. It is hoped that it will be possible to correlate these emulsion studies with the radiochemical investigations on the emission of light fragments from heavy nuclei. Along this line the results of studies of the formation of carbon-11 from a variety of target elements by billion volt protons are qualitatively similar to those described in last year's report for the production of F18 and Na24. They strongly support the idea that different mechanisms are responsible for the formation of these fragments from light target elements and from heavy target elements.

Because of the Cosmotron breakdown, only fragmentary results are available from experiments undertaken to gain further insight into the various mechanisms suggested in the last Annual Report that appear operative in the interaction of 3-Bev protons with the heaviest elements. Some observations have, however, been obtained that indicate a decrease in the probability of small energy transfers to the bombarded nucleus with increasing bombarding energy.

The researches with probes of much lower energy than those from the Cosmotron are primarily concerned with the energy level structure of nuclei. When charged particles such as deuterons or protons from low energy accelerators or neutrons or gamma-rays interact with the nucleus, new nuclear energy states are produced which are usually unstable. By observing the way in which the unstable nucleus is produced, the steps by which it decays into a stable nucleus, and the types of particles or radiations emitted together with their energies, information is obtained as to the characteristics of the unstable nucleus and the various nuclear energy states that may be occupied in the process of decay. The primary significance of this information lies, as yet, in confirming schemes of classifying the accumulating data or suggesting new ones. These schemes are used in the testing and development of theories that are quantitatively descriptive of the structure and behavior of nuclei. Investigations of the interactions of neutrons with various nuclei have been of particular interest with respect to current theoretical models of the nucleus. Measurements of neutron resonances have been made for a number of elements and separated isotopes whose atomic weights range between 100 and 240. A method has been devised by which measurements can be made in the kilovolt energy region in which the instrumental resolution averages over many unresolved resonances. Results of measurements obtained by this method have been compared with those of other laboratories and have been used to test the predictions of the "cloudy crystal ball" optical model of the nucleus. Numerous studies of the above types have been carried out during the past year with a variety of techniques that have added considerably to the accumulating empirical data concerning the behavior of a large

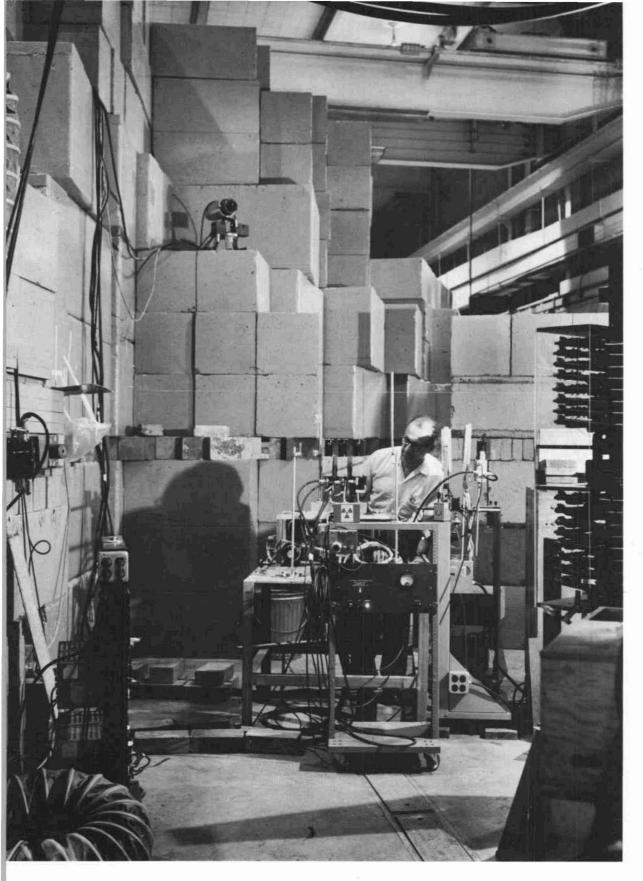


Figure 8. Setting up equipment for accurate measurement of the intensity of the external proton beam from the Cosmotron, Note the massive concrete shielding required.

number of different nuclei. The results obtained are described in the next section of this report.

The establishment this past year of the nonconservation of parity in certain beta decay transformations of unstable nuclei has led to the conclusion that the x-rays produced by these betarays in matter should be circularly polarized, and this conclusion has been experimentally demonstrated.

Experiments undertaken in an effort to observe the nuclear capture of the neutrino, described in the last Annual Report, have been continued during the past year with improved techniques. One thousand gallons of carbon tetrachloride were irradiated with a high flux of neutrinos from one of the production reactors at the Savannah River Plant, and an attempt was made to detect the production of radioactive argon-37 from the capture of neutrinos in chlorine-37. Unlike the negative results of a year ago, the data obtained indicate that argon-37 was produced in amounts much larger than can be ascribed to any background radiation. On the assumption that all the neutrinos emitted by the reactor are of the kind which may be captured by chlorine-37 to form argon-37, the experimental interaction cross section has been calculated to be 1.1×10^{-45} cm².

According to the theory accepted until about one year ago and also according to the new, parity nonconserving, two-component neutrino theory of Lee, Yang, and Oehme, reactors should emit antineutrinos which cannot produce argon-37. Thus, the result of this experiment indicates that these theories are incomplete. Recent modification of the two-component theory suggests that a mixture of neutrinos and antineutrinos is emitted from reactors. With this modification the theoretical cross section for argon-37 production by reactor "neutrinos" on the basis that all are of the proper kind would be 5.2×10-45 cm2. Thus, if the modified theory is correct, approximately one fifth (1.1/5.2) of reactor "neutrinos" are of one kind and the remainder different. Because of its theoretical significance, this investigation is being continued with larger quantities of carbon tetrachloride and other improvements in an effort to obtain more definitive results.

Effects of Radiation

Some of the effects produced by the irradiation of materials and of living things that have been

studied during the past year are described here. These studies also frequently reveal characteristics of the materials and internal processes of organisms.

It was reported last year that the oxidation rate of graphite in the temperature range 250° to 400°C was increased markedly by prior reactor irradiation. This effect was interpreted as catalytic in the sense that the displaced atoms did not appear to have been oxidized preferentially but did apparently facilitate the over-all oxidation. Ionizing radiation (gamma-rays only) increased the rate of oxidation in unirradiated graphite, but by a very much smaller factor. Further investigations have given results that are generally consistent with the increased rates reported last year, with one notable exception. The rates of oxidation at 350° and 400°C found for graphite exposed to high flux in the reactor were lower than the rates at 300°C. Moreover, the rates at 400°C at the high flux are lower by a factor of six than the rates for virgin graphite in the absence of any radiation. The rates at 350° and 400°C under the low intensity flux in the reactor are higher than the rates at 250° and 300°C but lower than those for virgin graphite not subjected to irradiation. These experiments are being repeated, and the results thus far obtained indicate that this effect is real. Because of its practical implications, the investigation is being continued in an effort to find an acceptable explanation.

It has been known for some time that radiolysis in the laboratory of pentane and other hydrocarbons results in gaseous products having a high ratio of hydrogen to methane. On the other hand, geological evidence shows that petroleum gases actually contain much methane and little hydrogen, and that the presence of uranium in sedimentation formations has provided long-time irradiation of the precursors of these products. Consequently, it seemed interesting to investigate the effect on the hydrogen to methane ratio of dispersing an organic compound on mineral surfaces. Samples of silica, alumina, montmorillonite, attapulgite, and iron oxide on which pentane had been distilled were irradiated with gamma-rays from Co⁶⁰. Analysis of the volatile products indicates that interactions between the pentane and the solid are quite profound. There was a transfer of energy from the finely divided silica and alumina to pentane, as shown by the increased hydrogen yield. This reached its maximum at ap-



Figure 9. Placing rats in position for x-ray treatment. Biochemical analyses will be made on these rats to determine the course of the latent effect of radiation on these animals.

proximately the concentration of pentane required to produce a monolayer on the solid surface. The iron oxide, however, showed a tenfold increase in methane formation, which indicated an energy transfer in the opposite direction. These results, which have obvious potential industrial value, are of interest also in connection with a hypothesis on the origins of petroleum and natural gas. According to this hypothesis, oil and gas were produced in rock and sediment by radiolytic action of naturally radioactive substances on organic matter. The difficulty until now has been that the distribution of products formed by irradiation of organic material derived from rock was dissimilar to that found in natural gas and oil. The new results show that this dissimilarity does not constitute evidence against the validity of the radiation hypothesis, but on the contrary is to be expected.

The effects of radiation on neutral water systems have been studied with the 60-in. cyclotron. The 20-Mev deuterons and 40-Mev helium ions available from this machine give ionization den-

sities intermediate between those of fast electrons and natural alpha-rays. The water decomposed to give H atoms and OH radicals. These radicals are formed inhomogeneously along the track of the ionizing particle, and, as they diffuse out into the bulk of the solution, there is a high probability that they will react together to form hydrogen, hydrogen peroxide, and presumably water. As the particle energy of the radiation is lowered, the ionization density increases, the radicals are formed closer together, and the probability of combination increases. The observable water decomposition yield decreases, as might be expected, with the rate of energy loss of the ionizing particle down to that of 33-Mev helium ions, but it increases again with 5.3-Mev alpha-particles. It is difficult to believe that changes in the primary process are setting in at this energy. This increase probably represents a correlation in the initial positions of the H and OH radicals. In high energy tracks (low density of ionization), these radicals tend to recombine to form water. In low energy tracks (high density of ionization) the over-all radical density is higher and the probability of the original radical partners recombining is decreased, which results in an enhanced yield of H2 and H₂O₂. In the region from 33-Mev helium ions on up in energy, the yields agree well with predictions based on the radical diffusion model.

An analysis of radiation damage in mammals indicates that there are three primary causes of radiation death, each depending on the radiation dose. Animals subjected to high doses die in about 3½ days from acute intestinal injury. Under smaller doses the animals may survive the intestinal injury only to succumb after 10 to 14 days to "bone marrow" death. If they survive this period, they will still die prematurely from some unknown cause. The symptoms are the same as those of "old age." An investigation was undertaken to determine whether or not this late death could also be attributed to damage in bone marrow. It was found that shielding a small section of bone marrow, which prevents the "bone marrow" death, does not in any way affect the radiation-induced aging. Moreover, various bone marrow stimulants applied either as single doses or as repeated doses over long periods of time do not affect the course of the radiation-induced aging. These results indicate that the bone marrow is not involved in the premature "old age" deaths. The assumption

that the irreparable fraction of a dose of radiation was much larger for neutrons than for x-rays has also been investigated. Mice were given doses of x-rays and fast neutrons comparable in their acute effects. These doses were also found to be quite comparable in their effects on the life spans of the animals, a somewhat surprising result since the two radiations seem to affect different organ systems in the mice.

When seeds are subjected to ionizing radiation, all known types of mutations are produced in far greater numbers than appear spontaneously. It has recently been shown at Brookhaven and elsewhere that some of these mutations can be extremely useful. For example, a variety of oats has been developed which is identical to the parent variety in all respects except that it is resistant to a stem rust disease to which the latter is susceptible. Studies have been under way at Brookhaven to investigate the conditions under which such mutations can best be produced. Specifically, the program seeks to determine the factors responsible for mutations in plants, the genetic nature of induced and natural mutations, the types of mutation that can be induced, the types of radiation or treatment that can most effectively induce mutations, and the most efficient methods for isolating mutations in plants.

Most of the radiation-induced mutations are inherited in a simple Mendelian manner. It is of great importance that at least one stem rust resistant mutant in oats has been found to be inherited as a dominant mutation, a situation long considered impossible on theoretical grounds. On the other hand, Victoria blight resistance induced in oats is a recessive mutation. Crown rust resistance in certain oat varieties is closely linked genetically to Victoria blight susceptibility; when Victoria blight resistance is induced in these varieties crown rust susceptibility almost invariably appears in the progenies. However, this apparently is not a simple all-or-none phenomenon, since the induction of Victoria blight resistance results in varying degrees of susceptibility to crown rust. This finding indicates again that characters which are usually considered to be simple and controlled by one genetic locus may in fact be complex and controlled by a number of different genetic loci.

When biological material is subjected to radiation, the direct effects have hitherto been assumed

to be complete at the cessation of the treatment. It has been discovered, however, that following x-ray treatment seeds continue to exhibit increasing injury for considerable periods of time. Seeds germinated immediately after irradiation show far less damage than seeds given the same irradiation but stored for even a few hours before germination. Indeed it appears that under certain special circumstances as much as 95% of the damage initiated by the x-ray may develop in the period following the irradiation, and that the effects are markedly dependent on the water and oxygen content of the seeds both during and after the irradiation. Apparently complex reactions not yet understood are initiated by x-irradiation. In the case of neutron irradiation, however, this effect is almost completely absent.

This is the fifth year of formal operation of the Brookhaven Cooperative Radiation Mutations Program under which plant breeders and geneticists throughout the world have been able to use the radiation facilities at Brookhaven in attempts at crop improvement. The great interest in this program is indicated by the large number of projects initiated. Irradiations of more than 70 different crop plants have been performed for about 150 scientists in the United States and Canada. Cooperative projects have been started with more than 30 scientists in 20 other nations. From the time the radiations are performed, several years may be required for the selection of mutants and the establishment of their usefulness in comparison with existing varieties.

Fruit trees grown in the gamma field where they have been subjected to gamma-rays for one to three years and then removed and permitted to return to normal growth have been under analysis for possible mutations by cooperating investigators. Two possibly beneficial mutations have been reported in the Fairhaven variety of peaches. First observed last year, these two radiation-induced mutations have been confirmed this season. They are potentially capable of increasing by more than a month the season in which fruit of this variety can be available. These represent the first results obtained from the fruit trees subjected to gamma irradiation in 1952 when this program was initiated.

The Medical Department has continued its investigations on the application of neutron capture therapy and in particular its use in the treat-

ment of the malignant brain tumor, glioblastoma multiforme. In this treatment first the patient is given an injection of a boron-10 salt solution and then the tumor area is exposed to a beam of slow neutrons. The interaction of neutrons with boron-10 atoms results in an alpha-particle and a lithium recoil atom of sufficient energy to prove lethal to cells. The efforts of the past year have been directed primarily at improvements in the procedures involved. The first clinical trials have been made with the new boron compound, sodium pentaborate, which on the basis of animal studies appeared to be less toxic and to have other physiological qualities making it more effective than the sodium tetraborate used previously. A new route and a method of controlling administration were developed which make it possible, by properly timing the neutron exposure, to avoid the vexatious skin complications previously experienced. The sodium pentaborate solution was injected into the main artery supplying the hemisphere of the brain in which the tumor occurs. New remotely controlled equipment permits injection of the solution at any desired rate and dose without approach to the patient. While further technical maneuvers remain to be perfected, the treatments carried out this past year indicate that the main problems of administration procedure have been solved. An extensive histological study of the effects of neutrons on various regions of the brain has been undertaken jointly with the Department of Anatomy, Harvard Medical School, and the Armed Forces Institute of Pathology. The entire brain, following autopsy, will be examined to determine whether any changes due to radiation can be detected in those sections free of tumor material, as well as the extent, nature, and intensity of the changes within the tumor tissues. The first results have shown a very gratifying restriction of radiation effects to the tumor cells and to regions in which they had existed but had been eliminated.

The studies on the control of a transplantable highly invasive brain tumor in mice have also been continued. Neutron capture therapy has been used and the treated tumor then transplanted to determine the effects of the treatment. These experiments have clearly demonstrated an increased effectiveness of boron when given as pentaborate rather than as tetraborate. They are being continued in an effort to determine the parameters of effective exposure with regard to

total neutron exposure with a given boron concentration.

In the neutron capture therapy program preparations are now being made so that advantage may be taken of the opportunities presented by the new medical reactor as soon as it is ready for clinical use.

Studies of cancerogenic effects of x-rays are being continued in female rats given from 50 to 600 r whole-body radiation. Suitable groups of animals were given additional local beta radiation over the mammary region. A very large percentage developed mammary tumors, in some groups 56% of the exposed population. Various types of shielding have been employed; and ovariectomized, untreated animals and animals ovariectomized and then implanted with nonirradiated ovaries have been studied. It appears that induction of the tumors requires the presence of functioning ovaries, but that irradiation of breast, ovary, or pituitary is not necessary. A number of histological types of tumors have been found. Further studies concerned with the role of the ovary in the genesis of these tumors and with the doseresponse relationship are in progress.

Use of Nuclear Tools

Extensive use has been made of the available nuclear tools of research during the past year. The arrangements af atoms, ions, and magnetic spin systems in solids have been studied with low energy neutrons from the reactor. Investigations of chemical reactions and of biological processes in plants and animals, including humans, have been pursued with radioactive isotopes used as tracers. A few of these numerous studies will be mentioned here.

The cold neutron facility at the top of the reactor has been completed. It provides a beam of neutrons with very low energies that is 25 times more intense than the beam previously used. The mean energy of these neutrons corresponds to 40°K and is so low that their distribution in energy after passing through many crystalline materials is almost entirely due to the energy that they pick up from the lattice vibrations. Information of this kind is helpful in determining the nature of the forces that act between the atoms of the crystal. Studies of this type have been carried out on several moderator materials because of the importance of their vibrational modes in energy

exchange with neutrons. It has been found, for instance, that zirconium hydride possesses an intense optical vibrational mode at 0.14 ev as well as a continuous distribution of vibration modes at lower energy. A single crystal of germanium has been examined with this technique because its lattice vibrations play an important role in the understanding of its behavior as a semiconductor. It has been found that the scattered neutrons are peaked at a certain value of energy that is independent of crystal orientation. This is also interpreted as due to an optical mode of vibration of high frequency associated with the interaction of individual atoms rather than of unit cells. A systematic study of the scattered neutron spectrum as a function of crystal orientation is now under way. This cold neutron technique appears very promising in the study of the solid state of matter.

Fifteeen neutron spectrometers have been used at the reactor in studies of the arrangement of atoms in solids and the distribution of magnetic scattering centers. An important advance in technique has been the development of polarized neutron beams in which 95% polarization has been attained. A cobalt-iron single crystal is used as the monochromator. A method has been developed by which it has proved possible to determine the direction of the magnetic moments with respect to the crystallographic axes of such materials as Cr_2O_3 and $\alpha\text{-Fe}_2\text{O}_3$.

The determination of the structure of ferroelectric Rochelle salt is nearing completion. Deuterated samples of the salt have been used to take advantage of the difference in the scattering of neutrons by deuterium and by hydrogen in order to determine the positions of the hydrogen atoms in the crystal lattice. The computations that will lead to a refinement of the structure are in progress.

Research in mass spectrometry has been concentrated on problems of high sensitivity techniques suitable for geochemical studies. An ionization source has been developed which permits the analysis of 10⁸ alkali metal atoms in the presence of much larger quantities of undetermined impurities. This technique has been used for the measurement of cesium concentration in the Holbrook meteorite. A value of 0.39 parts of cesium per million parts of silicon was obtained which is in good agreement with Suess and Urey's estimates of its cosmic abundance. The same tech-

nique has been used to determine the yields of zirconium, barium, and rubidium nuclides produced by irradiation of gold targets with 3-Bev protons from the Cosmotron.

A common problem in archaeology is to determine whether objects found in a given location were manufactured nearby or were shipped from some distant source. Information about the geographic origin of such objects has been obtained by neutron irradiation, which causes some of the component elements to emit characteristic radiations. Because the radiations from different elements can be measured separately, the relative amounts of these elements can be determined. Since ceramic pots made in a given region usually show the same relative concentration pattern of these elements whereas pots from another region generally have a common but different pattern, it is often possible to differentiate between pots from different regions of origin. After the test the induced radioactivity will decay leaving the object unharmed. Applications of this method have been helpful in tracing ancient trade routes.

In recent years the dynamic aspects of biochemistry have commanded increasing attention. Life is never static and even where growth is not obvious, as in the adult organism, there is a continuous process of destruction and repair involving not only individual cells but also the chemical constituents of cells. In order to evaluate the importance of whole-cell replacement relative to the replacement of individual constituents, some fixed point of reference is needed, and one constituent of cells, desoxyribonucleic acid (DNA) is proving increasingly useful in this regard. DNA occurs within the nucleus of the cell associated with the chromosomes and appears in fact to be the bearer of the genetic information which each cell passes on to its descendants. This genetic information includes specifications for the procurement or production of every constituent which the daughter cell must have for its normal function and consequently is of a complexity to command respect.

Cells multiply by division into two equal parts, and the primary step in this process appears to be a doubling (duplication) of this genetic material, the DNA. Subsequently, the "mitotic" process sorts these molecules (organized in large aggregates – the chromosomes) so that each daughter cell will have a complete set of information. Since this information must be handed down through

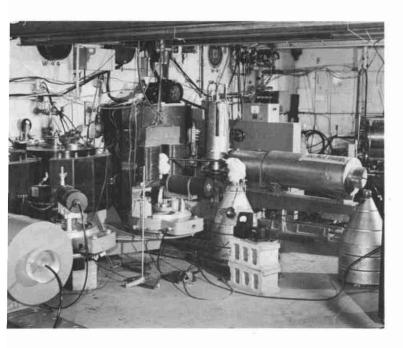


Figure 10. Some of the neutron spectrometers on a balcony at the west face of the reactor.

countless generations, extreme immutability of the DNA molecules would seem desirable, and in fact evidence is accumulating that DNA in a cell is never replaced. Consequently, a radioactive label for DNA should be extremely useful in following the fate of cells in a variety of living processes. While most of the substances utilized in DNA synthesis are also utilized in the synthesis of many other cell constituents, scientists in other laboratories have shown recently that thymidine is utilized uniquely in the synthesis of DNA. In view of this fact, an effort was made to prepare tritium-labeled thymidine. Tritium was chosen as a label because its beta radiation has such an extremely short range that its effects will be almost entirely limited to the cell in which it originates. This is very important for autoradiography because it makes it possible to determine with high resolution the location of the marker within the cell. It is anticipated that such localization of radiation within a cell will also have important implications for radioisotope therapy. Tritiumlabeled thymidine of adequate specific activity was successfully prepared.

In the first autoradiographic studies undertaken, seedlings of the broad bean (*Vicia faba*) were grown in a mineral nutrient solution containing this radioactive thymidine. This plant was selected because it has twelve large chromosomes, one pair of which is morphologically distinct, and because the length of the division cycle and the time of DNA synthesis in the cycle are known. After growth of the seedlings in the isotope solution for the appropriate time, the roots were thoroughly washed with water and the seedlings were transferred to a nonradioactive mineral solution containing colchicine for further growth. At appropriate intervals roots were fixed, stained, and squashed on microscopic slides. Stripping film was applied and autoradiographs were prepared. The colchicine made it possible to determine by inspection how many cell divisions had taken place following its application. Thus, by proper timing cells could be obtained which had undergone one, two, or three cell divisions after labeling by the tritium-labeled thymidine. Analysis of the autoradiographs showed both daughter chromosomes resulting from duplication in the presence of labeled thymidine to be equally and uniformly labeled. After an ensuing duplication in the absence of the labeled DNA precursor, the label appeared in only one of the two daughter chromo-

The autoradiographs showed conclusively that the thymidine built into the DNA of a chromo-

Figure 11. Plant cells grown on an "algae farm" for use in isotope studies of photosynthesis are harvested by a technician.



some is part of a physical entity that remains intact during succeeding replications and nuclear divisions, except for an occasional chromatid exchange. They further showed that a chromosome is composed of two such entities probably complementary to each other. Thus, during cell division each of these entities replicates to form a chromosome with four entities. The chromosome divides so that each chromatid (daughter chromosome) regularly receives an "original" and a "new" unit. On the basis of these results, a chromosome model has been constructed with two complementary units and a scheme of replication analogous to the Watson-Crick model of DNA.

A detailed study of both the energy metabolism and carbon dioxide fixation of a wide variety of photosynthetic organisms which have a broad evolutionary span and an increasing complexity of chlorophyll containing structures has been carried on during the past year. By use of C14O2 in association with the processes of paper chromatography and autoradiography, all the steps in the fixation of CO2 and the production of sugar have been shown to be associated with the chloroplast in one higher plant (spinach), several green algae, and the more primitive yellow-brown algae, Ochromonas. In contrast, the photosynthetic bacteria, the most primitive of the photosynthetic organisms studied, which contain a plastid bound chlorophyll and energy producing system, do not contain a plastid bound CO₂-fixing system. Thus for the first time an intracellular separation of the energy conversion steps and the sugar synthesizing step of photosynthesis has been demonstrated. Of particular interest is the point that in these primitive photosynthetic sulfur-producing bacteria a new light-dependent carbon-fixing mechanism has been discovered. This is the first time that a second light-dependent CO₂-fixing step has been shown. The classical photosynthetic CO₂-fixing system involves the addition of CO₂ to a 5-carbon sugar to give two 3-carbon acid precursors on the way to sugar synthesis. The new system involves the carboxylation of a 3-carbon acid phosphate to give a 4-carbon acid which is rapidly transferred to an amino acid. This reaction was recently discovered as a dark reaction in other organisms. However, here in photosynthesis are shown for the first time two simultaneous CO2fixing steps dependent upon light, one leading to sugars and one directly to protein.

Enzymes are the key protein molecules which catalyze the dynamic processes in biological systems. They are far more efficient than any manmade catalyst in two particular respects: 1) they can catalyze changes under the mild conditions of room temperature in aqueous solution and 2) they are highly "specific"; i.e., they can discriminate between closely similar structures. An understanding of how enzymes work is therefore of great importance. Because enzymes are large molecules, whereas a number of compounds on which they act are small, it has long been felt that only a small portion of the enzyme actually takes part in the reaction. By choosing an enzyme, phosphoglucomutase, which is known to be phosphorylated, it has been possible to label the protein with P32 without destroying the enzyme's activity. The label was shown to be present at, and only at, the active site. Moreover, it was shown that the label did stay on the same amino acid during the degradation of the protein. In this way serine was found to be the amino acid at the active site to which the phosphate is attached. Furthermore, with this radioactive serine phosphate as a marker it has been possible to "map out" other amino acids at the active site. It has been found, for example, that six of these are the same for the enzyme phosphoglucomutase as they are for the enzyme chymotrypsin. Since these enzymes have different specificities, i.e., they act on very differently shaped molecules, it is concluded that these six amino acids are involved in the bond-breaking function of the enzyme and not the specificity part. This leads to the suggestion that there are sequences of amino acids having the catalytic function and sequences having the specificity function. This is one of the first clues relating the detailed structure of protein to its biological function.

A basic clinical study is under way to find out whether a characteristic half-life can be determined for tagged fractions of serum proteins in cancer patients. It had been previously demonstrated that in both animal and human tumors the growing neoplasm elicited an antibody response that was highest in the gamma-2 globulin fraction. This fraction was labeled with iodine-131. After establishing the turnover rate of normal gamma-2 globulin in the patient, the turnover rate of gamma-2 globulin from a patient with a similar disease is determined in the original pa-

tient in an effort to establish whether or not this procedure can be used as a diagnostic test for cancer. Since the cancer gamma-2 globulin should be destroyed in the antigen-antibody reaction when it unites with the cancerous tissue, its turnover should be more rapid than that of the normal gamma-2 globulin. Tests are also being made with the same preparations in rabbits to see whether the rabbit in its metabolism can distinguish between normal and cancer gamma-2 globulin.

Studies of the metabolism of minerals have been continued. An example of these is the study of the kinetics of distribution and metabolism of manganese. In particular, the kinetics of intracellular distribution of Mn54 and Mn56 in liver and brain have been studied. The behavior of manganese suggested a multicompartment system which probably consists of one very fast component as yet unidentified in anatomical or physiological terms and slower components associated with nuclei, mitochondria, or soluble cytoplasmic material. It has been established that manganous, manganic, and permanganic salts always markedly increase the turnover of radioactive manganese. The specificity of the manganese pathways is attested to by the fact that no major effect on manganese distribution or turnover could be elicited by injection of bivalent salts of copper, zinc, nickel, chromium, vanadium, cobalt, or iron in large amounts at various intervals following the injection of manganese sulfate. Likewise, no effects were noted when bromide, iodide, and rhenatex compounds were used. It was surprising that no effects could be seen on distribution kinetics in the experiments with the other members of the transition group, or with those elements of Group VII in the valences studied.

A major portion of the manganese study was devoted to a further attempt to localize radio-manganese in the liver of rats in order to develop a method for specific internal radiation of this organ that might have application in the control of malignant diseases. A localization of 90 to 100% of the injected dose was achieved when injections were made into the superior mesenteric vein. The isotope appeared to remain almost exculsively in the liver for about 2 to 2.5 hr. Surprising and as yet unexplained is the fact that the deposition in the liver was inhomogeneous; the extreme left segment contained 3 to 7 times the concentration

of the extreme right segment for approximately 3 hr. Thereafter, a slow enrichment of other body sites by Mn⁵⁴ was seen. Data suggested that a large fraction of liver manganese is excreted into the gut while a smaller amount is distributed through the body.

The study of the role of sodium in hypertensive patients has been continued. It seemed desirable to determine the effect of caloric restriction alone when protein intake was maintained constant. Detailed observations were made of exchangeable sodium by use of Na²⁴ in patients placed on diets at various caloric intakes. At the same time, estimates were made of the chloride associated with sodium by use of Br82, of total body water with a tritiated water, and of blood and plasma volume by labeling red cells with Cr51. The results of this study will not be complete until all the data are assembled and analyzed. It has been found that connective tissue acts as a reservoir for sodium in both normal and hypertensive persons. A longterm study of a dog colony subjected to various levels of sodium intake has been under way to determine whether a natural evolution of hypertension can be observed in a larger laboratory

The metabolism of vitamin B₁₂ has been investigated by labeling it with Co60. External counting indicated that a large fraction of the labeled B_{12} goes to the liver; but the turnover as measured by in vivo counting is very slow: over a two-month period the decrease was only a negligible amount both in patients and in animals. Examination of animal tissues showed the highest concentration in terms of activity per gram of tissue to be in the pituitary, adrenals, pancreas, kidney, and gastric mucosa, rather than in the liver. Studies on the plasma clearances of the vitamin in patients and in normal individuals have shown a very slow clearance (hours) in patients with chronic myelogenous leukemia and agnogenic myeloid metaplasia as compared to normal individuals (minutes) and patients with polycythemia vera (minutes). The bound Co⁶⁰labeled B_{12} is carried by the alpha globulins.

Hemorrhage is one complication of heavy radiation. Control of hemorrhage requires replacement of the blood platelets which disappear following radiation. Clinical tests have shown striking control achieved in thrombocytopenic states when platelet transfusions were given. Since the

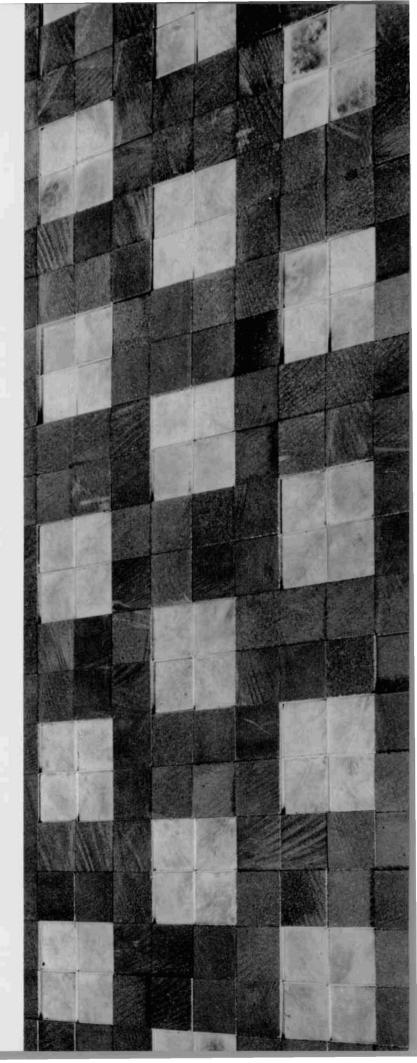
Figure 12. A stacked array of graphite and bismuth stringers simulating the core structure of the proposed LMFR Experiment and used for the experimental determination of the neutron diffusion in such an assembly. The aluminum foils which are laid around the bismuth stringers will later be replaced by Al-U foils in exponential assemblies.

fate of a platelet was not clearly known, it was of interest to label platelets and thereby follow their course. Platelets were successfully labeled with sulfate containing S35 without loss of their physiological qualities. Labeled platelets disappeared when transfused into normal animals. However, when the labeled platelets were transfused into a post-radiation thrombocytopenic rat, autoradiographs of tissues showed a distribution of activity about capillary walls throughout the body. By use of various time intervals for sacrifice and histoautoradiography, it is seen that the capillary bed is well outlined 1 hr after transfusion, but is not well outlined after 24 hr or after a 4-day interval. From studies on the specific activity of labeled platelets it appears that over an initial 4-day period the animal made thrombocytopenic by radiation does not manufacture any platelets.

Related Research and Development

Research and development in areas not necessarily nuclear in nature but important to the development of the atomic energy program have been carried out primarily by engineers. Many of these studies are directly related to the design of reactor components and systems. They are concerned with the problems of heat transfer, chemical processing, and choice of appropriate materials associated with the development of reactors, particularly the Liquid Metal Fuel Reactor (LMFR). The progress made during the past year on the LMFR has been described above; only work not related to the LMFR will be mentioned here.

An investigation has been under way for some time on the feasibility of dissolving natural uranium fuel elements in an interhalogen mixture consisting mostly of bromine trifluoride but containing varying amounts of bromine pentafluoride, uranium hexafluoride, and bromine. A pilot plant having a capacity of 5 pounds of uranium per hour was designed and constructed. Since January eight dissolution runs have been carried out with unirradiated natural uranium fuel elements. Unfortunately, during the ninth run in May, a series



of rapid explosions occurred which destroyed the dissolver section of the plant. Prior to the accident valuable experience with regard to operating procedures was obtained. It was also established that the uranium hexafluoride content accelerates the dissolution rate up to a concentration of 2 mole percent; beyond this concentration the dissolution rate decreases.

Investigations have been under way during the past year on the development of an absorption stripping system for the removal and recovery of xenon and krypton from reactor and fuel processing plant purge gas streams on a continuous basis. Studies of the equilibrium solubilities of xenon, krypton, argon, helium, nitrogen, oxygen, and air in various solvents showed that, in general, the less the polarity of the solvent, the greater the solubility of the noble gas. It has been shown that the solubility of xenon and krypton in a kerosene base decreases at higher temperatures, so that recovery of the noble gases from this solvent is possible. A number of preliminary runs with xenon and krypton were made in absorption columns to determine heights of theoretical units. Radioactive tracer and mass spectrometric methods of analysis were employed.

The basic program of measuring lattice parameters of water moderated, slightly enriched uranium rod fueled reactor cores is nearly completed. Measurements of the critical size and neutron economy for a large number of lattices have provided the experimental data required for theoretical generalizations. During the past year this program has been extended to include measurements with plutonium fuel, and work on a water moderated system employing the thorium-232 uranium-233 cycle has begun. A series of measurements on graphite - natural uranium systems like that in the Brookhaven research reactor have been completed. These measurements together with those on the water lattice system have given a reliable value for the number of fission neutrons per neutron absorbed in natural uranium, namely, 1.309 ± 0.006 .

Measurements of neutron cross sections constitute an example of basic research that is both significant in the testing of various nuclear theories and may at the same time be important in the development and design of reactor systems. For example, the fission cross section of U²³⁵ has been studied extensively. Particular emphasis has been

given to high precision measurements for standardization purposes. Precise values for the capture cross sections of gold and boron have been obtained for 2200-m/sec neutrons. The thermal capture cross sections of these two elements were found to be 98.8 ± 0.3 and 756 ± 6 barns, respectively, based on measurements of the total cross section between 4.0 and 11.5 A neutron wavelength. The total cross section of vanadium has been shown to fit a straight line from 0.10 to 4.0 ev. Neutron transmissions of samples of C, Si, Mg, Y, Nd, Cd, Pb, Be, and Be oxide have also been made. A direct measurement of the absolute fission cross section of U235 has been undertaken by the group from Columbia University for the purpose of removing inconsistencies in values obtained from indirect methods. The new method for this measurement is expected to give an accuracy of about 1%. The measurements will be taken at neutron wave lengths betwen 4.0 and 11.5 A by means of a mica crystal monochromator, neutron filters, and a mechanical neutron velocity selector.

To meet the continually expanding needs of the research programs for computing machinery, the Laboratory has started the construction of a modern high-speed digital computer designed to meet the particular needs of the Brookhaven program. The design of this machine is based upon that of the Maniac II which is in the final stage of assembly at Los Alamos. Modifications are being introduced which will increase the high-speed memory capacity from 12,000 to 24,000 words. The use of diodes and pulse transformer techniques in the circuits of the arithmetic section together with additional registers should result in easier and faster computation. The control section will follow basically the Los Alamos design. Since the Brookhaven computer will have one instruction per word compared to two for the Maniac II, it will be possible to add more instructions. The machine will be housed in a wing of the administration building. The design is well along. The power supply and a considerable amount of other equipment have been ordered, and the assembly of circuits is under way. A summary of the computer specifications is given in the next section of this report.

The radiochemical separation and preparation of radioisotopes has been continued. A successful system for separating the important β -emitting isotope, yttrium-90, from its long-lived strontium

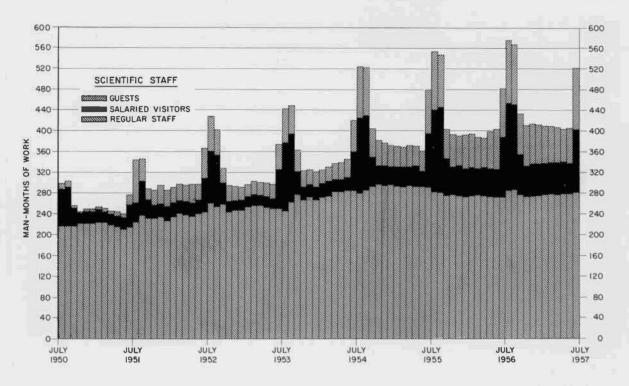


Figure 13.

parent has been devised. The method of obtaining magnesium-28 in sufficient specific activity from magnesium-26 by tritons obtained from neutron interactions with lithium-6 has been improved, and this important isotope is now available for use in medical research. A new separation process has been developed to give high yields of fluorine-18 which extends its useful shipping range. A greatly improved type of generator for iodine-132 has been devised. The product is virtually free of tellurium and other undesirable contamination and is suitable, for example, for direct use in iodinating human serum albumin for medical research.

One of the problems connected with the future use of atomic energy is that of laundering garments contaminated with radioactive substances. Radiation levels and spread of contamination have been studied at the decontamination laundry. Washing of 350 cotton twill coveralls used at the pile and waste disposal areas was done in 10 batches, divided according to degree of contamination. Extensive measurements were made of air and surface contamination levels as well as of the activity in the waste water. Some general observations can be made on the basis of this experiment.

Clothing mildly contaminated with fission products can be processed with essentially no hazard either to the laundry or to other customers. Processing of clothing heavily contaminated either with radioactive materials or with especially toxic isotopes would present a hazard if processed by untrained people in an ordinary laundry; however, a commercial laundry with proper equipment and procedures could do such work safely. Disposal methods for handling contaminated waste water will depend on local conditions, the scale of operation, and the degree of contamination.

PERSONNEL

The total number of people on the Laboratory payroll on June 30, 1957, was 1696 exclusive of temporary appointees, a net increase of 98 staff members during the year. The ratio of nonscientists to scientists rose from 3.8 to 4.0.

The growth of the scientific staff from July 1950 to July 1957 is shown in Figure 13. The actual number of man-months of work performed by the scientific staff is plotted for each month. The graph gives, therefore, an indication of scientific services rendered and also represents the average

number of scientists working at the Laboratory full time each month. Salaried visitors include scientists and engineers on leave from their own institutions, graduate students doing doctoral investigations while on leave from their graduate schools, postdoctoral research associates on one-year appointments, and temporary appointees whose services are in some measure requested by Brookhaven. Guests include scientists and engineers who participate in the Brookhaven program but receive no remuneration from the Laboratory. The services of consultants are not included in the graph. During fiscal year 1957, 17 man-months of service were rendered by these consultants as compared with 21 in the previous year.

The regular scientfic staff has remained almost constant in number for the past two years in spite of the characteristic high turnover promoted by the Laboratory's appointment policy. In contrast, there has been an increase for the tenth successive year in the number of scientific visitors who worked at the Laboratory for one month or more. The number of salaried visitors increased by more than 10%. This increase is traceable to the growing number of postdoctoral research associates. Nonsalaried visitors increased in number by 20%. The continuing increase in the number of visiting staff who do research with Brookhaven's facilities is gratifying.

During the past year 86 scientists and engineers from 24 other countries came to Brookhaven to do research, nearly double the number in the previous year. The presence here of the foreign scientists is not only stimulating; it also plays an important role in integrating the scientists of the free world and promoting mutual understanding.

Arrangements have been made for 100 faculty members from 70 different educational institutions to work at the Laboratory during the summer of 1957. About 20 scientists and engineers from 15 industrial and other organizations are also expected. The formal summer program for students will bring 45 undergraduates and 35 graduate students from 40 different educational institutions. Including 24 Radiological Physics Fellows and 26 additional graduate students, there will be an influx of about 250 additional research workers this summer.

INTER-AMERICAN SYMPOSIUM

An outstanding international event in Brookhaven's history was the Inter-American Symposium on the Peaceful Application of Nuclear Energy, held here May 13 to 17. Ninety-nine eminent Latin American scientists and administrators, representing 19 countries, attended. The purpose of this meeting was to produce an increased realization that a new servant of man nuclear energy - stands ready to improve the health and well-being of all the American peoples. The meeting's specific objectives were to clarify the present and future uses of atomic energy in the Americas, to call attention to the potential efforts necessary to support and accelerate the development of atomic energy, to stimulate and increase these efforts, and to foster cooperation and the interchange of scientific information among the American Republics.

The Symposium was sponsored by the Government of the United States, and conducted by Brookhaven National Laboratory under the



Figure 14. Latin American participants in the Inter-American Symposium on the Peaceful Application of Nuclear Energy.

auspices of the Atomic Energy Commission, the Department of State, and the International Cooperation Administration. Brookhaven undertook the planning of the agenda and the organization of the Symposium. Outstanding U.S. authorities in the fields to be covered in the agenda were invited to present papers, and the Latin American participants were also encouraged to report their own research efforts. In addition, each country was invited to give an outline of its national plans and programs in nuclear energy. After the presentation of each paper, a discussion period was held. There were also panel discussions on such general topics as training and education for the nuclear age.

In addition to the general sessions covering the topics of broad interest, the Symposium agenda included special parallel sessions devoted to four principal fields of interest: management, physical sciences and technology, biology and agriculture, and medicine. The basic policy of the Symposium was to emphasize those phases of nuclear energy more closely within reach of all the American Republics. The Proceedings are to be published in both Spanish and English versions; copies will be made available to all participants and to the major technical libraries in the participating countries.

In addition to the formal sessions there were technical exhibits including the AEC's Atomsfor-Peace panels and conducted visits to Brookhaven's various laboratories and research facilities. An extensive collection of technical books, reports, and pamphlets from U.S. and Latin American sources and appropriate brochures from industrial concerns were available to all visitors.

Following their week at Brookhaven, the participants went on conducted tours to other AEC installations, according to their special interests.

The twenty countries represented at the Symposium were: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, United States, and Venezuela.

SUMMER INSTITUTE IN NUCLEAR SCIENCE AND ENGINEERING

An eight-week Summer Institute in Nuclear Science and Engineering was held by the Laboratory for 30 professors from 22 different engineering

schools in 14 states and Puerto Rico. The Institute was sponsored by the American Society for Engineering Education, the National Science Foundation, and the Atomic Energy Commission. The objective was to present to the faculty members the basic theory and technology essential to reactor development in a form suitable for use in the curricula of engineering schools, in particular for those students preparing to enter the field of nuclear engineering. The laboratory experiments, some 22 in number, were designed to give a basic insight into reactor design and technology problems. The lecture program utilized special qualifications of regular members of the Brookhaven staff. The experimental program made use of such Brookhaven facilities as the standard pile, the research reactor, and the criticality experimental setup. A subcritical graphite assembly and special neutron spectrometer were constructed, and research equipment was modified to permit experimental study of techniques developed at BNL in heat transfer, metallurgy, and liquid metal technology. A reactor symposium to which seven full mornings were devoted at the end of the course served to integrate the material presented earlier. Experts directly engaged in a number of the AEC's demonstration power reactor projects gave the lectures in this symposium, which were open to all Laboratory staff members. Discussion periods for the Institute members followed the lectures. The interest and response of the group from the engineering schools was most heartening, and the Laboratory staff felt more than repaid for their efforts to organize and present the program at short notice.

At the request of the Atomic Energy Commission a Summer Institute will again be given in the summer of 1957. Another group of 30 faculty members from 26 different engineering schools have accepted appointments. This Institute is being sponsored by the American Society for Engineering Education and the Atomic Energy Commission.

CONFERENCES AND PUBLIC INFORMATION

Seven organized conferences were held at the Laboratory during the past year: 1) Dynamics of Proliferating Tissues, Sept. 5-8, attended by 37 individuals; 2) Resonance Absorption of Neutrons in Nuclear Reactors, Sept. 24-25, attended by 43

persons; 3) Molecular Beams, Oct. 5-6, attended by 61 people from 20 institutions; 4) the Fifth Tripartite Instrumentation Conference, Oct. 22-26, attended by 37 persons, 5 from Great Britain, 2 from Canada, and 30 from the United States; 5) an AEC Computer Conference, April 29-30, attended by 36 individuals; 6) Annual Meeting of the Northeastern Section of the American Society of Plant Physiologists, May 3-4, attended by 119 people from 42 institutions; and 7) the Tenth Annual Brookhaven Biology Symposium, on Homeostatic Mechanisms, June 12-14, attended by 82 biologists from 41 institutions.

In addition, the Fifth Annual Naval Reserve Seminar was held at the Laboratory between May 26 and June 8, attended by 62 officers from the Navy, Army, and Air Force Reserves. The subject of the seminar was life sciences and atomic energy.

During the report period the Laboratory was also host to 51 professional groups consisting of 1527 individuals representing organizations in this country.

In addition to the above there was a large increase in the number of foreign visitors both in groups and as individuals. In all more than 1300 professional, governmental, or industrial representatives from foreign countries visited the Laboratory for one or more days during the past year.

The annual Student Visitors' Day, October 12, was attended by 4151 students, and on Visitors' Day, October 13, 3749 persons toured the Laboratory facilities. The attendance at these annual affairs has increased by over 1000 persons in each of the last two years.

Staff members have responded to 40 requests to address organizations of lay and semiprofessional audiences in the vicinity of the Laboratory.

The activities of the Public Information Office increased during the past year because of the heightened general interest in the peaceful applications of atomic energy and the widening areas of unclassified research resulting from the AEC declassification program. A number of television and radio programs featured Brookhaven personnel in interviews. There was also an increase in the volume of requests for general information, in the number of interviews by representatives of news media, and in the use of photographs for publication in the popular press.

ADMINISTRATION

The organization of the Laboratory as of August 1957 is given in Figure 1. The most important changes are as follows.

Dr. Marvin Fox, Chairman of the Reactor Department and a senior member of the scientific staff since 1947, has resigned to accept an industrial position. The Reactor Department will continue as the Reactor Division under Mr. Robert W. Powell. The neutron physics group is being transferred to the Physics Department, and responsibility for the meteorology work is being tranferred to the Instrumentation and Health Physics Department.

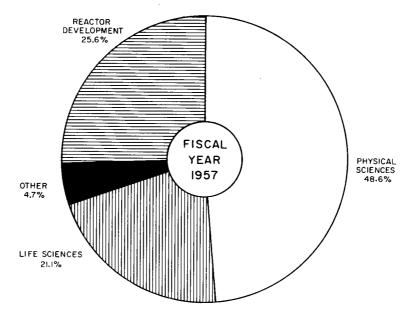
A Division of Applied Mathematics has been established to meet the increasing demand by the Laboratory research program for mathematical and computational assistance and to provide a central research effort for related mathematical studies. Dr. Milton E. Rose, formerly associated with the Office of Naval Research and the Institute of Mathematical Sciences at New York University, was appointed Head and assumed these responsibilities in February.

As of July 1957 the Mechanical Engineering Division will report directly to the Director's Office rather than through the Accelerator Development Department.

FINANCE

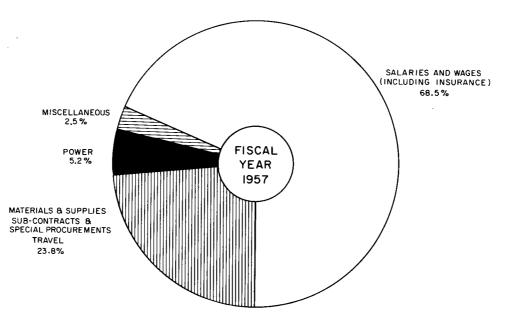
Organizational costs, exclusive of the direct cost of the Alternating Gradient Synchrotron and other fixed assets, totaled \$14,420,937 for fiscal year 1957, an increase over those of the previous year of \$2,556,854 (21.6%). The Laboratory's research programs accounted for \$2,243,859 (87.8%) of the increase. The cost of work for others, largely because the Wright Air Development Center underwrote shielding research for a full 12 months as compared to 3 months in the previous year, increased by \$280,718 (11.0% of the total increase). Organizational unit services for fixed assets increased by \$32,277 (1.2% of the total).

As in the past, the Laboratory research programs were supported by three Divisions of the Atomic Energy Commission, the Reactor Development, Research, and Biology and Medicine Divisions, at a total cost of \$13,687,791, an increase over the pervious year's costs of 19.6%. Of this in-



OPERATING COST DISTRIBUTION BY PROGRAMS

FISCAL YEAR	PHYSICAL SCIENCES	REACTOR DEVELOPMENT	LIFE SCIENCES	OTHER	TOTAL COST
1957	7,004,220	3,686,396	3,046,188	684,133	14,420,937
1956	6,201,158	2,583,294	2,659,480	420,151	11,864,083
1955	5,814,735	1,931,246	2,558,355	399,433	10,703,649



MAJOR CATEGORIES OF OPERATING EXPENDITURES

FISCAL YEAR	SALARIES AND WAGES	MATERIALS, TRAVEL, SUB-CONTRACTS SPECIAL PROCUREMENTS	POWER	MISCELLANEOUS	OPERATING TOTAL
1957	9,885,738	3,428,550	752,879	353,770	14.420.937
1956	8,726,773	2,189,998	711,590	235,722	11,864,083
1955	7,942,253	1,960,395	606,559	194,442	10,703,649

Figure 15.

crease \$1,721,386 (76.7%) occurred in the direct cost of research. Nuclear Engineering activities, the LMFR in particular, accounted for \$1,021,865 (59.4%) of the increase in direct research cost. Of this \$740,682 were expended on subcontracts and special procurements incident mostly to the LMFR Project.

Table 1, which will be found on the reverse of the organization chart, shows in detail the operating expenditures on a broad organizational basis. Labor costs continued to be the largest single item of expense. These usually represent 70 to 75% of total costs, but they fell to 68.5% during fiscal year 1957, largely because of the subcontracts and spe-

Table 2

Capital Equipment Expenditures and Commitments
(Including Charges from Organizational Units, See Table 1)

	FY 1957		FY 1956		FY 1955	
	\$	%	\$	%	\$	%
Scientific & hospital	1,066,359	79.0	582,430	80.5	401,494	75.4
Automotive & heavy mobile	98,725	7.3	40,894	5.6	36,056	6.8
Office machines & furniture	72,956	5.4	35,348	4.9	23,588	4.4
Shop equipment	70,003	5.2	49,843	6.9	39,116	7.4
Miscellaneous	41,630	3.1	15,298	2.1	32,183	6.0
Expenditures & commitments, Total	1,349,673	100.0	723,813	100.0	532,437	100.0
Proceeds from sales	(16,107)		(18,773)		(21,770)	
Expenditures & commitments, Net	1,333,566		705,040		510,667	

Table 3

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

	FY 1957		FY 1956		FY 1955				
	Costs	Ma	Man-years		Man-years			Man-years	
		Sci.	Others	Costs	Sci.	Others	Costs	Sci.	Others
	Alte	rnating	Gradient	Synchrotro	on	·- * <u>-</u> ····			
Direct									
Salaries, wages, insurance Materials, construction, etc.	585,480 3,773,723	26.5	60.5	492,460 1,871,898	23.5	47.5	417,880 610,958	24.5	45.0
Subtotal direct Charges from organizational units	4,359,203 125,031			2,364,358 117,697			1,028,838 138,764		
Total	4,484,234			2,482,055			1,167,602		
0	ther, Includ	ing Me	dical Rese	arch Cente	r React	or			
Direct									
Salaries, wages, insurance Materials, construction, etc.	39,273 1,516,892	2.0	3.0	10,565 937,560	1.0	0.5	657,694		
Subtotal direct	1,556,165			948,125			657,694 63,318		
Charges from organizational units Total	93,618 1,649,783			69,201 1,017,326			721,012		

cial procurements of the LMFR Project. The charts and tables in Figure 15 show a breakdown of costs by the major programs as well as by major categories of expenditures.

The capital equipment expenditures and commitments for the past three fiscal years are given in Table 2. Table 3 is a summary of expenditures for fixed assets (plant and equipment) for the same three-year period. Costs of the Alternating Gra-

dient Synchrotron are separated from those of the other items.

During the past year the upward tendencies in unit costs continued. Salary and wage rates increased an average of about 11%. Although some building materials decreased in cost, most categories of items and services used by the Laboratory showed increases in unit costs ranging from about 5% to 40%, averaging about 10%.

BROOKHAVEN NATIONAL LABORATORY

BALANCE SHEET

	June 30, 1957	June 30, 1956
Assets		
Cash	\$ 777,830	\$ 320,585
Accounts receivable	128,065	95,444
Inventories	372,783	336,646
Advances, deposits, and prepaid items	209,122	223,209
Fixed assets (less reserves of \$23,993,640 at	ŕ	,
June 30, 1957 and \$21,559,812 at June 30, 1956)	34,614,893	36,248,769
Construction in progress	9,201,338	4,554,371
Total assets	\$45,304,031	\$41,779,024
Liabilities		
Accounts payable	\$ 1,499,043	\$ 910,341
Accrued payroll	88,757	78,265
Atomic Energy Commission	43,716,231	40,790,418
Total liabilities	\$45,304,031	\$41,779,024

PHYSICAL SCIENCES AND ENGINEERING

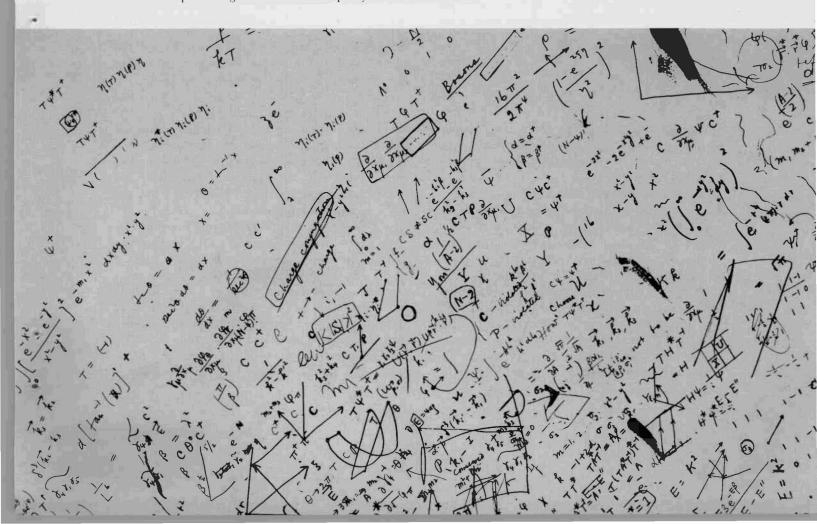
Physics

The research program in physics covers a wide variety of experimental and theoretical studies on the structure and fundamental properties of matter. In most of the researches the basic approach to the problems involves some aspect of the interaction of charged particles, neutral particles, or radiation with atomic nuclei. The energy of the particles used extends from the very low energies corresponding to the thermal motion of atoms in solid matter up to 3 Bev for the protons accelerated in the Cosmotron.

As improvements are made in experimental techniques, the results obtained sometimes bring out details not apparent in older investigations which make it necessary to modify previous interpretations. The theoreticians may also change their approach to a problem or develop new ideas which do not agree with previously accepted

formulations. An outstanding example of such a situation occurred during the past year when two visiting scientists at Brookhaven, T.D. Lee from Columbia University and C.N. Yang from the Institute for Advanced Study at Princeton, became convinced that the accepted principle of conservation of parity may not be true in all types of nuclear interactions. Unlike an experimental attack on a problem, the line of thought of a theoretical development can rarely be illustrated. In this case, however, the doodle pad used by Lee (Figure 1) during his discussions with Yang presents to the initiated a rather artistic arrangement of their principal points. Immediately after the new pronouncement was made, experiments were planned and performed at Brookhaven and elsewhere which showed that the Lee-Yang ideas were indeed correct.

Figure 1. Doodle pad used by T.D. Lee during the discussions with C.N. Yang while both were visiting scientists at Brookhaven during the summer of 1956. These discussions led to their questioning the conservation of parity in weak interactions.



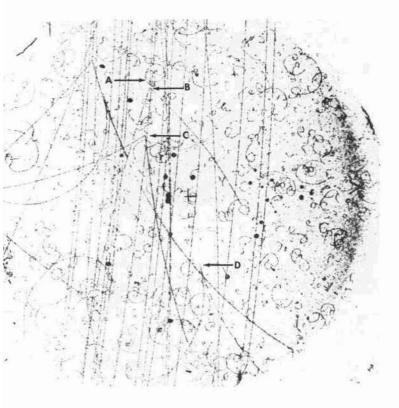


Figure 2. This propane bubble chamber photograph demonstrates the effectiveness of these instruments in resolving complex processes involving short-lived particles: It shows the consequences of a collision of a 1.3-Bev π^- -meson with a proton. At point A the reaction $\pi^-+p\to \Sigma^0+\theta^0$ took place. The θ^0 -meson decayed at point B by the process $\theta^0\to\pi^++\pi^-$, and the Σ^0 decayed very near point A by the process $\Sigma^0\to\Lambda^0+\gamma$. The existence of the Λ^0 is revealed by its decay at point C ($\Lambda^0\to p+\pi^-$), and the existence of the γ -ray is revealed by the electron pair generated at point D.

Most of the researches in high energy physics, nuclear structure, neutron physics, atomic and molecular structure, and solid state physics continue to be centered about one or more of the major facilities available at Brookhaven. The experimental scientists use the Cosmotron, the 60-in. cyclotron, the research Van de Graaff accelerator, the 18-in. cyclotron, or the reactor as the source of particles or radiation necessary for research. The theoretical scientists conduct their investigations in close association with the experimenters and provide stimuli to the search for new results and new approaches to problems. Many visiting and guest physicists from universities and other laboratories, both from this country and abroad, continue to make use of the BNL facilities and to cooperate with BNL scientists in researches dealing with the complex structure of matter.

HIGH ENERGY PHYSICS

The experimental work in high energy physics experienced an unfortunate interruption on January 24 when the Cosmotron had to be shut down for repairs. One of the copper conductor bars of the primary magnet coil failed, apparently because of the repeated stresses to which it had been subjected. While the resulting arc did only minor damage, all experimental equipment, shielding, sections of the vacuum chamber, and conductor bars in the damaged quadrant had to be removed. Resumption of operation for research purposes is only now, six months later, getting under way. Consequently the high energy research reported below is based on experiments performed up to about February 1957.

High Energy Research

One of the most productive experiments was an investigation of the unstable neutral particles produced by negative pions in a propane bubble chamber. This was carried out by a group from Columbia University, with members of the Brookhaven staff collaborating. Analysis of the pictures obtained gave the following information about hyperons and heavy mesons. The existence of the neutral form of the sigma hyperon, Σ^0 , was established with certainty, together with its decay into two neutral particles, a lambda hyperon, Λ^0 , and a gamma-ray. The decay of Λ° into two neutral particles, a neutron and a pion, π^0 , was discovered. Strong evidence was found for the decay of the neutral K-meson, θ^0 , into a pair of neutral pions. The mean lives of both Λ^0 and θ^0 were determined with better precision than heretofore. Finally, this experiment confirmed indirectly the existence of the long-lived neutral K-meson, θ_2^0 , the discovery of which was reported last year. According to the concept of associated production, every neutral hyperon must be accompanied by a neutral heavy meson. Only half as many θ^0 -mesons as neutral hyperons were in fact observed, which suggests that in half the events the θ_2^0 -meson was produced but escaped from the bubble chamber unobserved because of its long lifetime.

The investigation of the characteristics of this neutral K-meson, θ_2^0 , has been continued with

the cloud chamber from Columbia University. The mean life of this particle has now been established as relatively long, of the order of 10^{-7} sec. These θ_2^0 -mesons have been observed to decay into a pion, muon, and neutrino; into a pion, electron, and neutrino; and into three pions.

In nearly all the associated production experiments performed in the past the high energy particles producing the events were negative pions. Recently, however, attention has been directed to the process of associated production by high energy protons, and the results so far obtained are conflicting. A hydrogen diffusion chamber experiment and a counter experiment showed the cross section for the production of neutral hyperons and neutral heavy mesons from proton on proton collisions to be almost zero. Another counter experiment and an emulsion experiment gave results indicating that the cross section for the production of positive K heavy mesons from proton on proton collisions is appreciable. Since there is no known reason why positive K-mesons should be formed much more frequently than their neutral counterpart, an interesting discrepancy remains to be clarified. The Princeton and MIT multiplate cloud chambers have been used to study the production of hyperons and heavy mesons by protons and negative pions in carbon, iron, and lead. A suitable number of cloud chamber photographs have already been taken and are now being analyzed. These studies may help to resolve this discrepancy.

Negative pions with energies between 0.6 and 1.4 Bev have been used to explore the size and opacity of such nuclei as C, Al, Ca, and Pb. Observation of the absorption and scattering of pions by these nuclei gave values for the radii about 6% larger than those obtained by using electrons instead of pions. The experiment also favored a radially diminishing distribution of nucleons rather than one which remained uniform to the edge of the nucleus.

Soon after the breakdown of the law of conservation of parity had been established, a confirming experiment was performed at the Cosmotron with a hydrogen bubble chamber. In this experiment the angular distribution of the decaying electrons was observed directly, and an asymmetry expressed by the relation $(1-0.25\cos\theta)$ was found. Parity cannot be conserved if the angular distribution of electrons emitted from muon decays is asymmetric.

The production and interaction of positive and negative K-mesons were studied by nuclear emulsion techniques. The threshold for the production of negative K-mesons was found to be about 0.7 Bev higher than that of positive K-mesons. This result confirms the production scheme of Gell-Mann and Pais, which states that a negative K-meson must be made together with a positive K-meson, whereas the positive K-meson can be made in association with a hyperon. Observation of the interaction of negative and positive K-mesons in passing through the emulsion showed the interaction cross section for the negative meson to be somewhat greater than geometrical and that for the positive meson to be $\frac{1}{2}$ to $\frac{1}{3}$ geometrical.

The results of studies on the production of nuclides in bombarding complex nuclei with high energy protons are described in the Chemistry section of this report.

Cosmotron Operations — Experience and Plans

The Cosmotron was operated successfully for research purposes on a basis of three shifts per day for the first seven months of this report year. One interruption occurred in October when a bolted connection came open between copper strips in the rotor of the generator. After this was repaired and operation resumed, especially high average intensity circulating beams were produced, which caused high radiation background in the control room in spite of increased shielding. For the first time in the operation of this machine it became necessary to limit the running time of an experiment in order to keep the exposure of the operators below prescribed levels. This highly satisfactory operation of the Cosmotron was interrupted on January 24 when an open circuit occurred in the magnet coil. This is the second accident of this kind. The previous one (November 5, 1954) was due to a water leak in the cooling system. This second failure was traced to a fracture in one of the copper bars at a right-angle bend near the end. These copper bars experience heavy mechanical stress, particularly near their ends, which results in some mechanical motion. This apparently workhardened the copper and eventually caused fracture. All the copper bars and the vacuum chamber had to be removed from the second quadrant. Six months elapsed before operation could be resumed.

In repairing the broken conductor bar steps were taken to prevent a recurrence of this type

of failure. The supporting members of the coil structure were modified to relieve the stresses at the point of failure. Moreover, new supporting members that wedge the coil tightly against the back of the gap were made adjustable from outside the magnet, so that, as the coil becomes compacted during operation, they can be kept tight in order to minimize motion and resulting metal fatigue. These same modifications were applied in the other three quadrants.

Advantage was taken of the enforced shutdown to make other improvements. The sand under the Cosmotron floor was reinforced to support additional heavy shielding. The ion source assembly in the injection Van de Graaff was modified to produce a more intense proton beam. An additional window was provided in the second quadrant vacuum chamber for the emergence of a second external beam that will be used primarily for the production of high energy pion beams. A new pulsing circuit was constructed for the deflecting magnet of these two external beams, which will permit diversion of one portion of a single pulse of the internally circulating protons out of one exit port, and then, after a few revolutions, diversion of another portion out of the other port; thus concurrent experiments with both external beams will be possible.

Interest in high energy physics is increasing, as shown by the number of physicists doing research at the Cosmotron. In July 1957, 26 physicists from BNL, 34 from the Universities, and 29 graduate students were awaiting their turn at the high energy beams. The demand for running time is greater than ever, and it is an exasperating problem to limit the number of experiments so that adequate running time exists to complete an investigation within a reasonable period, once it has been undertaken. Experiments now require much more elaborate apparatus in the form of electromagnets, hydrogen targets, bubble chambers, etc., than they did two years ago. More quantitative objectives require intense external beams and better shielding as well as more running time. The number of people needed to carry out a typical experiment has increased. Some of the efforts and plans made to meet this situation are described below.

The most easily interpreted phenomena involving the production and interactions of mesons and hyperons are those that arise from single nucleons such as protons. For this reason a hydro-

gen bubble chamber is an extremely effective detecting instrument, since the region of interactions contains nothing but protons. Even complicated interactions can be analyzed with accuracy. Because of the great interest in using these instruments, two hydrogen bubble chambers are now under construction. The larger one will have dimensions of $20 \times 10 \times 9$ in. and will operate in a magnetic field of 17,000 gauss; the smaller, an active volume of $14 \times 14 \times 8$ in. in a field of 15,000 gauss. They should be in operation early in 1958.

An extension of the present Cosmotron experimental area has been planned. An addition approximately 100×200 ft, equipped with a heavy crane, will be connected to the present structure in a position such that external beams from the Cosmotron can pass over the new floor area. These beams will be directed in turn to different points on the floor, so that several experimental setups can be independently shielded and operated. This will bring the high energy protons to the experimental equipment in contrast to the more usual method of bringing the experimental equipment to the beams. By switching the proton beam from experiment to experiment it is anticipated that more nearly continuous operation of the Cosmotron will be realized. The addition, when completed, should increase markedly the effective use of the Cosmotron, which is now seriously handicapped by lack of space in which to set up the various complicated equipments.

NUCLEAR STRUCTURE

Research on nuclear structure may be divided into two broad classifications: studies of the characteristics of unstable nuclei produced by nuclear interactions, and the study of the instantaneous products of a nuclear interaction. Observation of the way in which an unstable nucleus is produced and the way in which it decays into a stable nucleus (radioactive decay) gives information about the characteristics of both the original unstable nucleus and the final stable nucleus. Measurements are made which identify the types of particles or radiation emitted by the unstable nucleus, together with their energies, systematics, and characteristic decay time. Analysis of the data yields information as to the structure and properties of nuclei.

Studies of the instantaneous products of a nuclear reaction involve identification of the types

of particles or radiation yielded by the interaction and measurements of their energies and systematics. The term, instantaneous, is used here in a relative sense, and applies to those reaction products which follow the interaction of a particle or radiation with a nucleus in a time too short to be readily resolved with existing techniques. Such measurements again provide information on the energy level structure of nuclei and on the fundamental phenomena of nuclear interactions.

One of the most important recent contributions to the theory of β decay comes from the discovery that the principle of conservation of parity does not hold in certain cases. The nonconservation of parity leads to the conclusion that the electrons emitted in β decay are longitudinally polarized with their spins antiparallel to their direction of emission. This suggested that, if the electrons are polarized, the x-rays produced by these β -rays in matter (bremsstrahlung) should be circularly polarized. This question was investigated in some detail from both experimental and theoretical points of view. It has been demonstrated that x-rays produced by β -rays are circularly polarized to a high degree. The principle of the analysis of the circular polarization of the x-rays is based on the existence of a spin-dependent part of the Compton cross section. The sense and magnitude of the circular polarization of the x-rays was investigated by measuring their transmission in iron magnetized either in the direction of propagation of the x-rays or opposite to it. A definite difference in absorption in the magnetized iron was found (Figure 3), which indicates nearly complete circular polarization of the x-rays.

The nonconservation of parity in weak interactions has stimulated the theoretical investigation of the scattering of polarized fermions. For longitudinally polarized fermions three cases have been worked out: electron-electron, positron-electron, and μ -meson-electron scattering. In addition, the theory of scattering of polarized high energy μ -mesons, which has been given for a point charge by Mott, is being extended to finite charge distributions for application to scattering from heavy nuclei.

New problems have been raised in the theory of β decay by the principle of nonconservation of parity. In an allowed β decay process, the interaction terms can be classified as those obeying either the Fermi or Gamow-Teller selection rules,

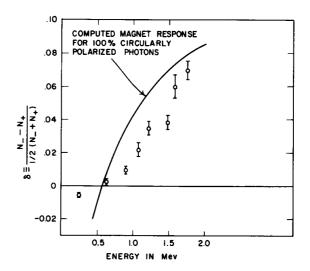


Figure 3. Experimental values for $\delta = (N_- - N_+)/[(1/2)(N_- + N_+)]$ and computed magnet response curve as a function of energy for 100% circularly polarized photons with spin antiparallel to direction of propagation. N_+ = counting rate with magnetic field pointing toward the β source; N_- = counting rate with magnetic field pointing away from the β source.

and it is important that a dependable value be obtained for the ratio of the Fermi to Gamow-Teller coupling constants. The ratio of these coupling constants can be determined from a systematic study of the comparative ft values of two groups of β -active nuclei: the $0 \rightarrow 0$ transitions which obey only Fermi selection rules, and the "doubly closed shell ±1 nucleon" mirror transitions which obey both sets of rules. Of the six existing nuclei comprising the latter group, the decay properties of only three (n, H3, and F17) have been previously measured with any precision. The collection of data for the determination of β decay coupling constants is continuing under a program of research jointly sponsored by Columbia University and Brookhaven. The β spectrum, half-life, and comparative ft value for O15 measured under this program were reported in the last Annual Report. The remaining two nuclei in this "closed shell ±1 nucleon" group are Ca³⁹ and Sc41. These activities have been produced at the BNL 60-in. cyclotron by the reactions $K^{39}(p,n)Ca^{39}$ and $Ca^{40}(d,n)Sc^{41}$. To minimize the neutron induced background in measurements of these short-lived activities, a fast pneumatic shuttle system was constructed. The targets are transported within 1 sec to a low background area lo-

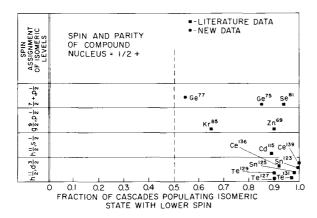


Figure 4. Experimental evidence for rule concerning isomeric ratios.

cated 50 ft from the bombardment position at the end of the external beam pipe of the cyclotron. Preliminary measurements on Ca³⁹ with the BNL thin-lens spectrometer gave a spectrum end point of 5.45 Mev. The half-life of the activity is 0.90 sec, and the decay appears to be a simple superallowed transition, as no γ -rays above 0.6 Mev were detected with a NaI(Tl) scintillation spectrometer. The decay of Sc⁴¹ will be investigated as soon as the measurements on Ca³⁹ are completed.

A number of studies have been made of the systematics in the characteristics of isomeric states in nuclei. One of these dealt with the production of two isomeric states in nuclei by radiative neutron capture. It has been known for some time that the relative cross sections for radiative neutron capture leading to two isomeric states in a given nucleus are such as to favor the formation of the isomeric level with spin closest to that of the compound nucleus. Data published for the nucleus Ge⁷⁷ made this isotope appear to be an outstanding exception to the rule. Its cross sections were therefore remeasured, and the new results agree with the rule as shown in Figure 4.

The existence of groups of even-even nuclei occurring between the magic nuclei and the rotational regions, which have been characterized as "near harmonic," has been pointed out in previous annual reports. It has also been shown that fairly abrupt transitions occur between these and the rotational regions at 88 < N < 90 and at 86 < P < 88. The third transition, occurring between Os¹⁸⁶ and Os¹⁹², was studied experimentally. It was found to be much more gradual than the others, so that

the lowering of the second vibrational (2+) level, with simultaneous increase of the rotational level energies, could be observed. The 4+ level crosses the second vibrational 2+ level at about Os^{190} . In Os^{190} a spin sequence 0, 2, 4, 6, 8, all of even parity, has been established. The energy ratios of these levels, however, differ greatly from the proportionality with I(I+1) which is characteristic of rotational nuclei. The theoretical study of this level scheme should furnish a valuable clue to the nature of the transition nuclei. The isomeric transition discovered in Os^{190m} was shown to be of the rare "K-isomeric" type.

Further investigations on radioactive sources have been carried out with the intermediate-image pair spectrometer by using an electron-electron coincidence facility. In the decay of Y^{90} the half-life of the 1.75-Mev 0+ first excited state of Zr^{90} has been measured as 6×10^{-8} sec. Thin-window counter techniques were developed and used to establish the energies and conversion line intensities of isomeric transitions in Os^{189} and Os^{190} . Other activities studied included O^{15} , Se^{72} , Rb^{84} , Ga^{72} , Hf^{180} , Au^{194} , Au^{196} , and Au^{198} .

The charged particles accelerated in the Van de Graaff accelerator have been used to study nuclear energy levels in a number of interesting nuclear reactions. Among the cases investigated were the low-lying states in N^{16} excited in the reaction $N^{15}(d,p)N^{16}$ and observed by scintillation counter detection of the subsequent gamma radiation. The results were consistent with the positions of levels observed previously by particle detection, but the new information allows the spins and parities of the first three excited states to be assigned. The results are in good accord with the theoretical shell model predictions of J.P. Elliott.

An interesting study has been made of the 2.14-Mev first excited state of B^{11} . Previous measurements of the $B^{10}(d,p)B^{11}$ stripping pattern had suggested that the spin of the 2.14-Mev state should be $3/2 \le J \le 9/2$ according to the usual stripping theory. In the present study the Doppler shift method was used in the $B^{11}(p,p')B^{11}$ reaction to show that the lifetime of the 2.14-Mev state is $<4\times10^{-14}$ sec. This fixes the transition as magnetic dipole and shows that the spin of the level must be $\frac{1}{2}$. Consistency with the stripping result is possible only if the departing proton emitted in the reaction flips its spin so as to transmit an additional unit of angular momentum to the nucleus. This

newly suggested process has been designated "spinflip stripping."

A series of studies has been made on isotopic spin selection rules including investigations of the decays of the 9.58-Mev state in O^{16} , the 8.06-Mev state in N^{14} , and the first excited states of Be^7 and Li^7 . In the O^{16} case the 9.58-Mev level was excited in the $C^{12}(\alpha,\gamma)O^{16}$ reaction. Since the state is 1- and T=0, emission of electric dipole radiation to the 0+ and T=0 ground state should be forbidden by selection rules. However, 9.58-Mev gamma radiation was observed, which shows that either the ground state or the 9.58-Mev state is contaminated with a small T=1 component. Contamination of the 9.58-Mev level could be ascribed to a mixing-in by the Coulomb perturbation of the T=1 state at 13.09 Mev.

An arrangement has been installed in the research Van de Graaff accelerator which produces a pulsed beam of the accelerated particles. The pulse duration is about 5 m μ sec with a repetition period of 125 m μ sec. By use of this pulsed beam facility, the lifetime of the 0.72-Mev first excited state of B¹⁰ has been measured as 1.07 ± 0.1 m μ sec by detection of the delayed gamma radiation.

Also at the research Van de Graaff a measurement of the polarization of protons scattered by He⁴ is being made with a specially constructed scattering chamber. Analysis of the polarization occurring in an initial scattering event is accomplished by measuring the angular asymmetry in a second scattering in He⁴ as recorded on two photographic plates.

Two guest scientists from Columbia University are studying the interactions of deuterons with nuclei by using the focused beam of deuterons accelerated in the 60-in. cyclotron. A careful search has not disclosed any low energy proton group $He^{3}(d,p)He^{4*}$ which would indicate an excited state in He⁴. In the He³(d,p)He⁴ (ground state) reaction a broad distribution of protons was observed at energies corresponding to three-body breakup, but with a spectrum in bad disagreement with that calculated from phase space integrals on the basis of isotropic breakup in the center of mass. This will be investigated further. The angular distribution of the $He^3(d,d)He^3$ reaction has been measured. It has a minimum at $67.5\pm2.5^{\circ}$ (center-of-mass angle) and a maximum at 90° (c.m. angle). These features are reproduced by a curve calculated for optical model scattering of a

spinless, chargeless, mass two particle from a 42-Mev potential well with a radius of 1.99 fermis and no imaginary part. This correspondence is being checked at backward angles.

The (d,α) reactions on nitrogen leading to the ground state and several excited states of C12 have also been studied. Since the Bohr assumption states that true compound nucleus breakup is independent of the mode of compound formation, a comparison of the angular distributions of the decay products from intermediate states formed by different routes should have a bearing on the validity of the assumption. The data obtained on the $C^{12}(\alpha,\alpha')C^{12*}$ reaction exhibit an oscillatory character which differs from published results; therefore, the reaction is believed to proceed by a direct pickup or knockout process. The cross section observed at a deuteron bombarding energy of 20.9 Mev varied between 0.02 and 0.2 mb/st for the ground and third excited state groups, but was 5 times larger for the first excited state and less than 0.01 mb for the 7.6-Mev state of C12. Elastic deuteron scattering from the N14 gas target was also studied.

NEUTRON PHYSICS

Research dealing with the interactions between neutrons and matter continues to be the source of much information pertaining to the characteristics and properties of atomic nuclei. The neutrons used in this research range in energy from millivolt subthermal neutrons available from the reactor to Bev neutrons available from reactions produced by the 3-Bev protons at the Cosmotron. This wide range of energy requires the use of a great variety of techniques. As techniques are improved and new ones are developed, the details of neutron interactions can be studied with higher precision and in greater quantity. As a result, the theories of atomic and nuclear structure can be developed to higher orders of reliability in the interpretations and predictions of the properties of matter.

In a continuing program of research at the reactor, the slow chopper is used for studies with neutrons in the subthermal energy region. This chopper breaks up the beam of neutrons from the reactor into short pulses in order that neutrons of different energies may be separated by time-of-flight techniques. The cold neutron facility at the

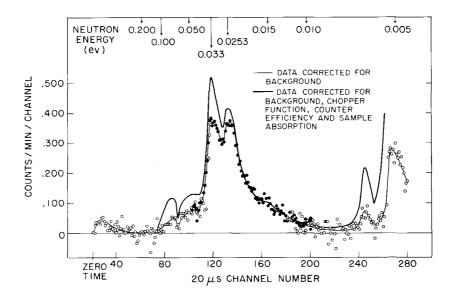


Figure 5. Time-of-flight spectrum of neutrons inelastically scattered from vanadium.

top of the reactor has been completed, and the flux has been increased by a factor of 25 over that of the previous facility. This increased flux has made possible better resolution of the slow chopper in the study of the scattering of long wavelength neutrons by crystalline materials. Since the energies of the neutrons available from the cold neutron facility are very low compared to the energies of atomic vibrations in crystals, the slow chopper and associated equipment provide a means for studying the vibrational modes in crystal lattices.

The spectrum of neutrons inelastically scattered from vanadium has been remeasured with the improved resolution, and two clearly resolved peaks have been observed. Figure 5 shows the time-of-flight neutron spectrum, including the low energy elastic peak at the extreme right. These results are directly related to the frequency distribution of lattice vibrations in vanadium. The details of the spectrum may therefore be of use in determining the nature of interatomic forces.

Several moderator materials have been examined to determine which vibrational modes are important in energy exchange with neutrons. Zirconium hydride, for instance, exhibits a sharp vibrational mode at 0.14 ev, as well as a continuous distribution of modes at lower energies.

Because lattice vibrations play an important role in the theory of semiconductors, a single crystal of germanium was studied. The scattering of neutrons in a given direction from a single crystal with one atom per unit cell produces discrete peaks whose energies vary with the orientation of the crystal. At least one peak has been found in germanium, however, whose energy remains constant, independent of crystal orientation. This peak results from the interaction with an optical mode. This type of vibration, which appears in crystals with more than one atom per unit cell, is a high frequency vibration with frequency relatively independent of neutron wavelength. A systematic study of the scattered neutron spectrum as a function of crystal orientation is now under way.

A fast chopper is used to carry out a continuing program of research with reactor neutrons in the energy range from thermal up to several kilovolts. A 1000-channel analyzer is in routine operation in this program, with a number of minor improvements added to make it more reliable. Accurate graphical methods of data handling have been developed to facilitate analysis of the greater volume of data. The ZnS-B₂O₃ scintillation detector used with this fast chopper has been modified to eliminate the background composed of the beam neutrons which pass through the scintillator, moderate in the phototube bases, and return to the scintillator to be detected with higher efficiency at a later time. This was done by placing ≈ 0.25 -in.-thick transparent discs of B_2O_3 between the phototubes and the scintillator. The discs effectively absorb the delayed and moderated

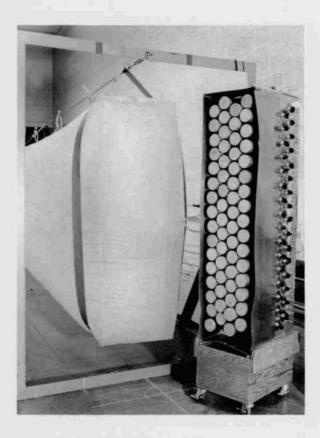


Figure 6. The bank of 64 ZnS-B₂O₃ scintillation detectors used with the fast chopper.

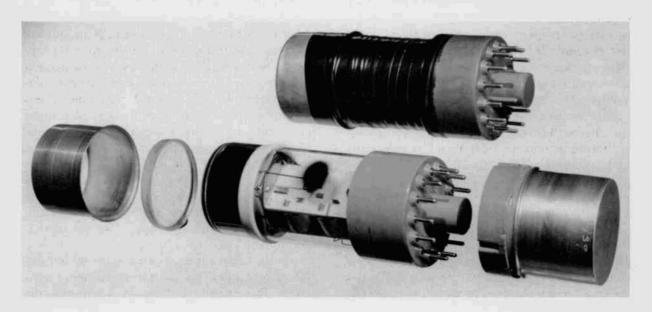
Figure 7. An exploded view of one unit of the ZnS-B₂O₃ scintillation detector.

neutrons and only slightly reduce the light from the scintillator. Figures 6 and 7 show the bank of 64 scintillators used with the fast chopper and an exploded view of one of the scintillators with the transparent $B_2\mathrm{O}_3$ disc.

In the research program with the fast chopper, emphasis is on measurements of particular interest in connection with current theoretical models of the nucleus. One such measurement is the strength function, or the ratio of the average reduced neutron width $\overline{\Gamma}_{n}^{0}$ to the level spacing D. This ratio has been measured for a number of elements and separated isotopes whose atomic weights range between 100 and 240. Some of the measurements were performed by detailed resonance analysis. If enough resonances in a single isotope are analyzed, an average neutron width and level spacing may be obtained, but the statistical accuracy of the results is almost always seriously limited by the number of levels available for such detailed analysis. In order to determine the strength function more accurately, a method was devised in which measurements are made in the kev region, where the instrumental resolution averages over many unresolved resonances. In this case it can be shown that the transmission of a thin sample is given by

$$T = e^{-n\sigma_{\text{pot}}} \left[1 - n \frac{13 \times 10^4}{\sqrt{E}} \frac{\overline{\Gamma}_n^0}{D} \right],$$

where n is the sample thickness in atoms/barn, σ_{pot} is the potential scattering cross section, and E



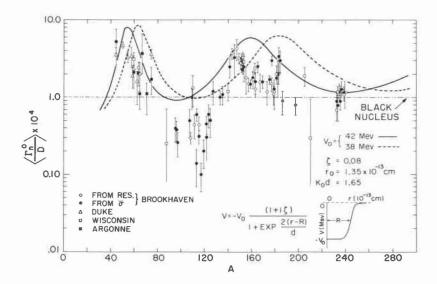


Figure 8. A comparison of the observed strength functions and the predictions of the "cloudy crystal ball" optical model. The dashed line labeled "black nucleus" refers to the value of the strength function that a nucleus would have if it formed a compound state from every neutron that enters it.

is the neutron energy expressed in kev. The simplicity of the measurement is illustrated by the fact that the slope of the transmission plotted against time-of-flight (or $1/\sqrt{E}$) gives the strength function directly. The intercept at zero time- offlight gives the potential scattering cross section, although it is not obtained with great accuracy for thin samples. Figure 8 shows the results of strength function measurements by both methods compared with those of other laboratories and with the predictions of the "cloudy crystal ball" optical model of the nucleus. The data shown in this figure are an extention of those shown in the last Annual Report, together with additional theoretical calculations. The theoretical computations were performed by Feshbach, Porter, and Weisskopf.

A theoretical investigation has been made of the "strength function" for low energy neutron scattering by nonspherical nuclei. A qualitative understanding of spheroidal nuclei was achieved by a perturbation theory calculation, and a numerical computation at the NYU Computing Facility is in progress for "pear-shaped" nuclei.

Another aspect of the research program with the fast chopper has been the measurement of the potential scattering cross section for a number of elements. This was done by carefully correcting the cross section observed between resonances for the effects of nearby resonances, and by an averaging method similar to that outlined above for determining the strength function. Figure 9 shows these results compared with the theoretical prediction of the "cloudy crystal ball" model.

The resonance analysis for the separated isotopes of dysprosium has also been performed. About 55 levels were found and analyzed in Dy¹⁶¹, Dy¹⁶², Dy¹⁶³, and Dy¹⁶⁴. Table 1 shows the results for the first few levels.

Crystal spectrometers are important tools in the studies with reactor neutrons. They are used to produce highly monoenergetic beams of slow neutrons and to analyze in fine detail the energy distributions of slow neutrons in cross section measurements. Because of the high energy resolution attainable with a crystal spectrometer, it is possible to study neutron resonances and neutron cross sections over narrow energy ranges. In one of the research programs in which this technique is used, the fission cross section of U235 has been studied extensively. It has been clearly established that a multi-level formula is required for fitting the fission component of the resonances, while a single-level formula is adequate for the capture component.

A new program has been started which will take advantage of the crystal spectrometer technique. This program is designed to determine the

	rable r					
	Dysprosium					
Isotope	E_0 (ev)	$\Gamma_{\gamma}\left(mv\right)$	Γ_n (mv)			
163	1.71	103±10	1.48 ±0.12			
161	2.72	119 ± 10	0.615 ± 0.02			
161	3.69	124 ± 15	1.62 ± 0.15			
161	4.33		0.96 ± 0.18			
162	5.45	175 ± 45	19.5 ± 3.5			

Table 1

angular momentum associated with neutron resonances. This will be accomplished by measuring the cross section of a target in which the nuclei are partially polarized by using a polarized monochromatic neutron beam. The production of polarized nuclei requires ultralow temperatures (0.01°K) and strong magnetic fields (20,000 oersted). The problem will be approached in two phases. The first phase has been started by designing and constructing a low temperature cryostat for the system which will produce the polarized nuclei. Later this same system will be used for the study of radiations from polarized radioactive nuclei. At the same time plans are being made for the system to produce polarized monochromatic neutron beams. The second phase of the project, which will begin in the coming year, will combine the polarized target and polarized neutron beam on a spectrometer beside the reactor.

A program of neutron spectroscopy is being conducted under the cooperative research program of Columbia University and Brookhaven. A single-crystal neutron spectrometer located at the BNL reactor is used to measure cross sections over the energy range from 0.0005 to 20 ev. Particular emphasis is given to high precision cross section measurements for comparison with various nuclear theories and to specific problems of interest for reactor development and for the standardization of neutron cross section measurements.

In the former category, a new determination of the strength of neutron-electron interaction is being made by measuring the variation in neutron transmission of a highly purified sample of liquid bismuth in the energy range between 0.1 and 4.0 ev. Measurements have been taken at sample temperatures of 300° and 500°C. After correction for the capture cross section of bismuth and the

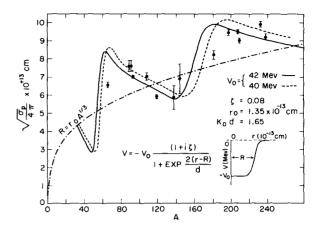


Figure 9. The results of the measurements of potential scattering, displayed as $R' = \sqrt{\sigma_{pot}/4\pi}$, shown together with the theoretical predictions based on the "cloudy crystal ball" nuclear model.

effect of liquid diffraction, an average value of 4.29 ± 0.14 kev was obtained as the depth of a square well potential with radius equal to the classical radius of the electron. The error assignment is the standard deviation arising only from statistical fluctuations. Further measurements are planned to evaluate any small consistent errors which may have affected the results.

The 2200 m/sec capture cross sections of gold and boron have been redetermined. Precise values for these cross sections are important as these elements are often used as reference standards in various neutron experiments. The thermal capture cross sections of gold and boron were found to be 98.8 ± 0.3 b and 756 ± 6 b, respectively, based upon measurements of the total cross section between 4.0 A and 11.5 A neutron wavelength.

The scattering cross section of vanadium is almost completely incoherent and for this reason is also often used as a reference standard for neutron experiments. In the measurements of liquid bismuth for the neutron-electron experiment, a sample of solid vanadium was run parallel with each bismuth transmission measurement. The total cross section of vanadium taken from these data over the energy range from 0.10 to 4.0 ev fits a straight line. The absorption cross section at 2200 m/sec was 4.98 ± 0.02 b, and the bound scattering cross section was $\sigma_{\rm f.a.}[(A+1)/A]^2=5.13 \pm 0.02$ b. The neutron transmissions of samples of C, Si, Mg, Y, Nd, Cd, Pb, Be, and BeO were also measured for various problems.

A direct measurement of the absolute fission cross section of U235 has also been undertaken by the Columbia group, because previous measurements of this quantity for U235 and other fissionable isotopes have not been entirely consistent with values deduced from the ratio of the total cross section and the ratio of fission to absorption. A new method is proposed for the measurement, which, from an analysis of the factors involved, is expected to give the absolute fission cross section to an accuracy of about 1%. The apparatus, which has been constructed for the experiments, consists of two multiple plate ionization chambers, one with plates covered with a very thin evaporated film of B10 and the other with plates electroplated with U235. The intensity of the monochromatic neutron flux in the beam from the crystal spectrometer will be measured with the boron ionization chamber and the quantity of material electroplated in the U235 chamber by a transmission measurement, and the absolute number of fissions produced will be determined by counting the fission fragments in the ionization chamber. The measurements will be taken at neutron wavelengths between 4.0 and 11.5 A with the aid of the recently developed neutron filters and the mechanical neutron velocity selector, which remove second and higher order neutron reflections from the mica crystal monochrometer of the spectrometer.

Studies of nuclear interactions involving neutrons with energies higher than those available at the reactor are being conducted at the 18-in. cyclotron and the 60-in. cyclotron. The energy of the protons accelerated in the 18-in. cyclotron was increased from 2.5 to 3 Mev by correcting the shape of the magnetic field. The energy stability of the cyclotron has been improved by the introduction of an automatic frequency stabilizer, with the result that the fluctuation in energy is reduced to as little as ± 9 kev out of 3 Mev. With the increased proton energy and stability it has been possible to study the neutrons from the $Cu^{65}(p,n)Zn^{65}$ reaction. The energy balance for this reaction is measured to be Q = -2.148 Mev. Three neutron groups are observed which correspond to the ground state and two excited states. States at about 100 and 200 kev above the ground state have been reported in the literature as the result of gamma-ray studies on this reaction. The timeof-flight technique used here gives the energy level

assignment unambiguously, since the neutrons of different energies are observed simultaneously. In addition to the 100 and 200-kev levels, an excited state at 50 kev has been reported by others. Evidence for this state is observed in these experiments, although the energy resolution obtainable is not sufficient to resolve the neutrons from this level. In addition to the ordering of the energy levels, data were obtained on the angular distributions for the neutrons in the three groups.

The exploitation of the beam bunching in the 60-in. cyclotron and the isolation of single bunches by deflector pulsing has continued in connection with the use of the cyclotron beam to produce neutrons in studies involving time-of-flight techniques. The considerable background of gamma radiation from deuteron reactions in the cyclotron has made it difficult to perform good experiments with neutrons in the kev energy region. Resonances in fluorine at 50 and 100 kev were detected, but narrower resonances in heavier elements would present much more difficulty. However, for neutrons in the 3 to 25-Mev region a different detector is used and the background has been reduced to about 4%. Measurements of the cross section of carbon (with pronounced resonance structure), aluminum (with some structure) and bismuth (with little resonance structure) are being made with a resolution of less than 1 m μ sec/m.

ATOMIC AND MOLECULAR PHYSICS

The mass synchrometer, described in previous annual reports, has been used to measure with high precision the doublets C₃D₈-C₄D₂ and CD₄-D₂O and thus to obtain values for the masses of C12 and D. A scheme was devised for obtaining mass defects without using any dissociation ions which eliminates the possibilities of systematic error due to differences in initial kinetic energy between ions formed by dissociation and ions formed by simple ionization. The "best values" for the ten doublets at mass 20 (including CD₄- D_2O) involving the ions A^{40++} , Ne^{20+} , D_2O^+ , ND_3^+ , and CD₄ (all of which are parent ions) were obtained by weighted least squares adjustment of the ten measured values. The following mass defects expressed in μMU were obtained: D= $14,739.974 \pm 0.032$; $C^{12} = 3814.58 \pm 0.10$; $N^{14} =$ 7524.50 ± 0.10 ; $Ne^{20} = -1204.48 \pm 0.13$; $A^{40} =$ $-24,903.56\pm0.33$. Each doublet was measured

between 20 and 100 times under various conditions over a period of several months with half-width resolution of about 20,000. Errors are estimated probable errors of the means.

The techniques of atomic beams and paramagnetic (electron) resonances are being used in the continuing nuclear moments research program. The objectives of this program are to obtain highly precise measurements of the spin, magnetic, and higher moments of atomic nuclei. Particular emphasis is being placed on studies with radioactive nuclei. The paramagnetic resonance spectrum of V^{49} has been studied with a sample in which the concentration of V^{49} was of the order of one part in 100 relative to the stable isotope V^{51} . The measurements appear to give a value of 7/2 for the nuclear spin and a ratio of the magnetic moment of V^{49} to that of V^{51} of 0.867. Work is continuing on this problem.

Modification of the atomic beam apparatus is continuing in order to permit measurements of nuclear magnetic moments to be made to a precision of one part in a thousand. When the modification is completed it will, therefore, be possible to observe hyperfine structure anomalies. The details of magnetic spectra will be measurable to a precision of one part in 10⁷. Most of the parts necessary for the modification have been completed and tested. A few electronic components remain to be completed.

SOLID STATE PHYSICS

Structure of Solids

The neutron diffraction program of the Physics Department is concerned mainly with structural studies on magnetic, ferroelectric, and antiferroelectric crystals. Progress can be reported on specific problems as well as in developing new experimental techniques.

It was pointed out last year that an important advance in experimental technique has been the development of polarized neutron beams for refined structural studies of magnetic materials. Polarized neutron beams of 95% polarization have now become available by use of a cobalt-iron single crystal as the monochromator. The polarization state of neutrons can be reversed by the application of an oscillating magnetic field along the beam direction at the crystal.

The enhancement of the magnetic scattering effects, which results from the use of polarized neu-

trons, has been used to measure the magnetic form factor of nickel out to a value for $4\pi\sin\theta/\lambda$ of around 9.0. The nickel form factor, although it exhibits the typical fall-off with increasing $4\pi\sin\theta/\lambda$, does not appear to decrease as rapidly as the form factor previously measured for iron.

The theory of neutron scattering by a magnetic single crystal predicts a probability of neutron flipping for Bragg scattering from magnetic materials which depends on the relative orientation of the crystal magnetic axis and the polarization direction of the incident beam. This flipping has been observed in Cr_2O_3 and α -Fe₂O₃ and has been used to determine the direction of the moments within these crystals with respect to the crystallographic axes. A further study was made of the effects of a magnetic field on the spin orientation in α -Fe₂O₃ by using this same effect.

Further experimental advances are represented by the installation of a second single-crystal neutron spectrometer and the construction of a low temperature system for separating out the magnetic scattering from the nuclear scattering in neutron diffraction patterns. The new spectrometer is now being used in the initial phase of the structure analysis of orthorhombic α -Pb(N₃)₂. This first phase involves the collection of (hk0) diffraction data which are sufficient to determine the x and y parameters of the constituent atoms. The low temperature system is of use in observing the effects of magnetic fields on substances of low Curie point as well as in the study of the behavior of the magnetic contributions to the diffracted peaks as a function of temperature. An example is the study of the saturation magnetizations of the individual sublattices in ferrimagnetic substances.

The determination of the structure of ferroelectric Rochelle salt, in progress for some time, has been carried to its final stages. Refinement of the structure is based on diffraction data from deuterated samples and the use of reiterative leastsquares machine calculations (IBM-704). In addition, an alternate approach to the problem was initiated in which diffraction data for 230 (hk0) reflections from single-crystal samples of the normal salt were collected and compared with the corresponding deuterated data. Since the scattering lengths of deuterium and hydrogen have opposite signs, difference and sum maps of the two sets of observed data lead to separate representations of the ten replaceable hydrogen positions and of the remainder of the structure. Final refinement of the structure based on the combined data is now in progress.

A third phase of the study of ferroelectric BaTiO₃ has been undertaken, in which several of the structure sensitive reflections have been observed as a function of temperature. These data, in conjunction with a structure analysis of the tetragonal phase at 105 °C, indicate that the atomic displacements resulting from the cubic to tetragonal transition are mutually proportional as a function of temperature.

Combined x-ray and neutron diffraction methods have been utilized for studying the structure of U₄O₉. This work was started by A.F. Andresen at Jener, Kjeller, Norway, and continued at BNL during his stay as a guest. Neutron diffraction diagrams of samples prepared in Norway and at Westinghouse have been found to be identical. They show numerous peaks which cannot be indexed on the simple cubic cell of the UO2 structure. The previous assumption that the extra oxygen is introduced in the center of the UO2 unit cell to form the U₄O₉ cell is, therefore, incorrect. The observed peaks can apparently best be indexed on the basis of a tetragonal unit cell, 16 times the small UO₂ one, derived from this by making the a axis twice the face diagonal and the c axis twice the cell edge. The large cell contains 144 oxygen atoms whose positions have to be determined, a problem which normally would be impossible to solve by powder diffraction data. In this case, however, it is clear that the uranium atoms are retained in the face-centered positions of the small UO2 cell, since the x-ray data show only very weak extra lines at high angles. Only a limited number of positions are, therefore, available for the oxygen atoms. Some progress has been made towards finding an arrangement which will account for the intensities of the observed peaks, but the problem seems too complicated to solve without the building of an elaborate model.

Current experiments on the inelastic scattering of neutrons by ferrites have stimulated interest in the problem of spin waves in ferrimagnetics. A calculation of the wave functions and energy spectrum for spin waves in a normal spinel has been made based on an extension of P. W. Anderson's approach to antiferromagnetism. Only A-B exchange was assumed to exist, and the calculation was carried to second order in the magnitude

of the propagation vector, \mathbf{k} . Five distinct energy surfaces $(E \text{ vs } \mathbf{k})$ were found, two of which are identical, in the classical limit, to the ones previously reported. Although the energy surfaces are all spherically symmetric, the wave functions depend in general on the direction of \mathbf{k} .

Radiation Effects

The other major activity in solid state physics is the study of defects in crystals. Radiation effects and other departures from perfect periodicity are under investigation with many diverse techniques.

Displaced atoms, and particularly the associated structural changes, can be studied in considerable detail by x-ray techniques. A careful investigation of irradiated diamond and sodium azide has progressed far enough to propose rather specific models. The x-ray diffraction pattern of a heavily irradiated diamond sample (6.65×10^{20}) fast nvt) is characteristic of an amorphous material in which the general features of the diamond structure are retained. The integral Fourier inversion of the pattern yielded a radial distribution curve (number of carbon atoms between the distances r and r+dr) strongly characteristic of the diamond structure. A detailed analysis of the radial distribution curve dictates a model for the irradiated structure of diamond which contains interstitials and vacancies. The normal diamond structure contains an equal number of occupied and unoccupied lattice sites. Fast neutrons, through collision processes, displace atoms from the occupied sites to fill the unoccupied sites. For this particular sample 18% of the unoccupied sites were populated with interstitial carbons. The fraction of atoms displaced (some atoms are displaced more than once and not all displaced atoms become interstitials) was 30%. Two theoretical calculations for the fraction of atoms displaced, an average neutron energy of 1 Mev and an integrated fast flux of 6×10^{20} nvt being assumed, gave 10% and 40% respectively, in good agreement with the value obtained from the x-ray study. The irradiated structure is highly strained. A root mean square strain, independent of distance, of 5.4% was found, while a strain falling off as 1/r with a strength of 3% was evident. These large strains so weaken the interference effects that the x-ray pattern takes on an amorphous appearance.

Sodium azide decomposes under gamma-ray and reactor (neutrons and gamma-rays) ir-

radiation. The crystal has a layer structure with the cubic close-packed stacking sequence. X-ray studies have shown that gamma-rays, reactor irradiation, and mechanical deformation (grinding) produce mistakes, i.e., "stacking faults" in the normal stacking sequence. This is an unusual manifestation of radiation damage, since a stacking fault involves cooperative action of atoms in order to shear layers with respect to each other. In the ground samples the number of faults and strain parallel to the slip or basal planes increases with grinding. There is a tendency for both to saturate, and there is no evidence of decomposition. The stacking faults produced are sharply divided into stable and metastable categories. The metastable faults are removed at temperatures of 100°C, while the remaining faults are stable for all reasonable times and temperatures up to the ignition point. From the isothermal studies of the metastable faults it appears that their removal does not proceed by a diffusion process and that a slipping process is more likely. The generation of stacking faults may proceed directly from the slip of the basal planes over one another, but more likely by the motion of a Shockley partial dislocation across the slip plane. A partial dislocation necessarily is associated with the strain where registry is regained. Stacking faults may also terminate in sessile dislocations, which have associated strains. A sessile dislocation cannot move by slipping but only by diffusion. It seems reasonable to associate the metastable faults with the glissel Shockley partial dislocations and the stable faults with the sessile dislocations.

In the gamma and reactor irradiated sodium azide the number of faults, strain, and lattice contraction (not exhibited in the ground specimens) perpendicular to the basal planes increase with dosage. The samples color, and strains run higher for the same number of stacking faults than after grinding. The long dimension of the azide molecule is perpendicular to the basal planes, and the decomposition of the molecule by ionization causes a shrinkage perpendicular to the basal planes. The observed shrinkage, coloration, and lowering of the ignition temperature indicate decomposition. The local stresses produce the dislocations and associated stacking faults. The high strain in these cases is probably due to a large number of dislocations associated with a faulted region and other imperfections such as interstitial nitrogen (in the neutron irradiated case it is likely that all known crystal imperfections are produced to some degree). Annealing studies reveal again stable and metastable faults, the metastable faults being removed at higher temperatures (≈175°C) than in the case of ground crystals. The lattice contraction recovers, which indicates a diffusion process that restores stoichiometry. There is evidence that sodium eventually diffuses to the surface of the crystallites, since, after sufficient annealing, sodium carbonate and monohydrate are formed. However, isothermal anneals show that the contraction recovers only during the period in which the stacking faults are removed. The isochronal plot shows that the lattice contraction recovers completely. A complex cooperative process is involved. In general the neutron and gamma irradiated sodium azides are similar but differ in some fine details. The neutron irradiated azide shows the highest strain for a given number of faults.

During the past year the major effort on phase transformations has been concerned with radiation enhanced diffusion. This effect is conveniently studied in the α -brass system where enhanced diffusion leads to increased short-range order. It has been shown that at 50°C the ordering rate (which is thermally very slow) can be increased by a factor of about 107 by suitable reactor or 2-Mev electron irradiation. The electron irradiation, at a theoretically equivalent flux, is less efficient than the reactor irradiation by about a factor of 14, probably because of the production of a higher fraction of close vacancy-interstitial pairs which can recombine without appreciable diffusion. This general technique is to be studied in further detail and will be applied to other systems as a means of driving very sluggish solid state systems toward equilibrium. An experimental program has also been started on the effect of neutron irradiation on a shear type of transformation, the martensite transformation in iron-nickel alloys, with electrical resistivity as the index of the transformation. It has been found that irradiated specimens have a consistently lower M_s (martensite start) temperature than unirradiated specimens. A flux of 2.5×10^{17} epi-U²³⁸ neutrons/cm² lowers M, temperature approximately 6°C. Moreover, it appears that as much as 0.27% additional martensite has formed during irradiation in specimens which are partially transformed before irradiation. Further studies of

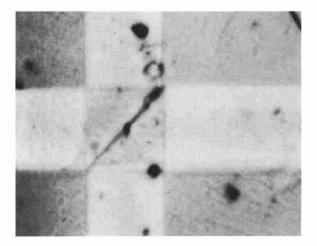


Figure 10. A picture taken with a polarizing microscope of the intersection of two birefringent bands in potassium azide (KN_3). The birefringence is indicated by the fact that the normal crystal is colorless and the bands are brightly colored. The bands are due to slip or twinning on the (112) planes of the crystal and are about 0.1 mm wide.

these effects are expected to result in a better understanding of the mechanism of the radiation effect as well as of the nature of the martensite transformation.

The program designed to use optical effects, particularly color centers, for measuring radiation effects has made several advances during the last year. Al₂O₃ is one of the crystals being studied intensively. As described previously, reactor radiation produces absorption bands in this material which differ in energy from those formed by ionizing radiation. It is suspected that some of the observed bands must arise from Al or O vacancies in the lattice, and this supposition is supported by recent experiments in which the level of gammaray coloring is altered by quenching the crystal from temperatures near the melting point, a procedure which increases the concentration of vacancies in the crystal. It appears that the intensity of one of the bands produced only by reactor radiation and of one of the bands produced by coloring with gamma-rays are enhanced by the quenching procedure. It is necessary to heat the crystals to a temperature from 1700°C to just under the melting point (2050°C) and rapidly cool or quench the sample in order to change the vacancy concentration. This is accomplished by using an induction heater to heat the crystal in a tungsten

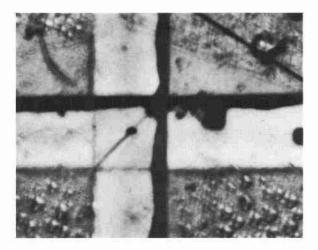


Figure 11. The same area as shown in Figure 10 after the crystal was exposed to 10⁷ r of Co⁶⁰ gamma-rays. The heavy black lines show the extent of decomposition at the intersection of the (112) twin or slip planes and the upper surface of the crystal. Similar decomposition occurs on the bottom of the crystal, except that the decomposition areas are at the other side of the colored bands. There is additional decomposition forming well-defined pyramidal etch pits.

or tantalum crucible in a high vacuum. The heated system is purposely made with small heat capacity so that rapid temperature fall is accomplished by shutting off the induction field. Additional quenching is obtained by introducing an inert gas at the precise moment the field is turned off.

The coloring of very pure fused silica has been of interest, since it originally appeared that only a few color centers were present. Recent work indicates that the temperature at which this material is irradiated controls the intensity of some of the absorption bands. The intensity of a band at 2420 A is increased by a factor of two, relative to a standard, by irradiating at liquid nitrogen temperature instead of at 70°C. Also, irradiation of the fused silica first in the reactor and later with gamma-rays indicates that several absorption bands result from "sensitizing" this material in the reactor which do not appear with gamma-ray irradiation alone. The spectra are by no means simple, as resolution of the spectrum into its components indicates the presence of six new bands in this sample of fused silica.

The study of the room temperature gamma-ray coloring of KN_3 , which is part of the cooperative

program with Picatinny Arsenal, is largely completed. The observed spectra have been resolved into Gaussian bands, and the growth and decay of each of the observed bands determined. Surprisingly, the gamma-ray induced coloring decays with a fast and slow component exactly as previously found in the alkali halides. Future work may indicate which of the observed bands are colloidal, i.e., result from the radiation induced decomposition. It was shown some time ago that, when KN₃ is thermally shocked, brightly colored birefrigent bands (Figure 10) are formed which are associated with certain planes that pass diagonally through the crystal. When KN₃ (and NaN₃) are decomposed by gamma-ray irradiation, the major portion of the decomposition occurs at the intersection of these diagonal bands and the surface, as is shown in Figure 11. It was also shown that in some instances these bands are caused by lamellar twinning. Since these bands are also formed by mechanical means, this work constitutes a clear-cut demonstration (perhaps the first) of why grinding some crystals increases their ease of decomposition much more than expected from particle size considerations only.

The cooperative program with R. Truell's group at Brown University is continuing. The detection of directional neutron damage was described last year, i.e., the correlation of radiation damage with the direction of the damaging particle to produce an anisotropic elastic constant change. The only material studied so far is silicon, but similar experiments on germanium and diamond are under way. In the original detection of the directional effect, an ultrasonic double refraction technique was used. A separate and independent determination of this effect has been made by measuring the elastic constants (actually the ultrasonic velocity). The results obtained are in complete accord with the double refraction measurements. The decrease in ultrasonic attenuation observed when alkali halides are exposed to gamma-rays has been investigated in considerable detail. A group of NaCl crystals, both annealed and plastically deformed to various degrees, was irradiated at different temperatures at relatively low irradiation levels. The results to date are consistent with the idea that radiation causes dislocation pinning. In fact it is possible to obtain an expression for the concentration of pinning points as a function of time for low irradiation levels.

Chemical effects of irradiation in solids are under investigation in various systems. As part of the cooperative work with Picatinny Arsenal the thermal decomposition kinetics of explosives and related materials are being studied, both before and after gamma-ray and reactor irradiations. At the moment results are available only for a primary explosive, normal lead styphnate monohydrate. The activation energy for the acceleratory portion of the decomposition curve of the unirradiated material is a few kcal/mole higher than reported in the literature. Gamma-ray irradiations up to 1.8 × 108 r have only a slight effect on the decomposition curve. Reactor irradiations produce a marked accelerating effect and virtually eliminate the induction period, even though negligible gas evolves from the sample during irradiation.

Study of the effects of radiation on the oxidation rate of graphite has continued during the past year. The oxidation rate, as reported last year, increased whenever any radiation was present, and also increased with increasing temperature. Results obtained since that time are generally consistent with this pattern. During the past year results have been obtained on graphite oxidation rates in the presence of BNL reactor radiation (in-pile oxidation). The in-pile oxidation rates at 250° and 300°C at two different fluxes are consistent with previous data. However, the in-pile oxidation rates at 350° and 400°C in the high flux are lower than at 300°C. This differs sharply from the previous pattern of results. A further complication is present because the in-pile oxidation rates at 400°C at the high flux are lower by about a factor of 6 than the rates for virgin graphite in the absence of any radiation. The in-pile oxidation rates at 350° and 400°C in the low flux hole are higher than at 250° and 300°C, but are lower than those of virgin graphite in the absence of any radiation. At present there is no explanation for this discrepancy. The experiments are being repeated, and the effects thus far are reproduced. These findings appear to be valid, and have very significant solid state and practical implications.

Limited work has been done on the effect of reactor radiation on the surface area of γ -Al₂O₃. There is an increase in surface area due to reactor irradiation. Upon annealing, the surface area of the γ -Al₂O₃ is about the same as that of the unirradiated γ -Al₂O₃. Recently the surface area work has been concentrated on aluminum oxide – mo-

lybdenum oxide catalyst, commonly known as hydroforming catalyst. Preliminary results show that a 10-day reactor irradiation of this catalyst results in a decrease of surface area from about 250 $\rm m^2/g$ to about 160 $\rm m^2/g$, but further substantiation is required. Reactor irradiation appears to increase the catalytic activity of the hydroforming catalyst for the cyclohexane to benzene reaction by about 30%. Here also further studies are needed to substantiate this effect.

Breakdown of the low temperature irradiation facility has slowed down several projects, particularly the determination of displaced atom concentration by neutron transmission and by optical techniques. Research with long wavelength neutrons for lattice vibration studies has been performed by the group using the slow chopper and is reported above in the section on neutron physics.

Theoretical work has continued on several problems with good progress. The absolute rate theory of the movement of defects in solids has been generalized to take proper account of the many-body features of the process. The effective frequency which determines the jump rate for defects has been shown to depend on all normal frequencies of the defect lattice and the frequencies of a similar lattice subjected to certain constraints. The influence of atomic masses on this effective frequency and consequent isotope effects in diffusion have been treated.

A general survey of the theory of defect production in solids by nuclear radiation has been under way. The theory of replacement and displacement collisions, with the model of Kinchin and Pease, has been extended, and the calculation of replacement collisions on this model has been carried out rigorously for the first time. The effect of inelastic and anisotropic scattering of fast neutrons on the production of displacements has been calculated in a number of substances. A theory of the production of displacements by gammarays by means of Compton electrons has been formulated and applied to representative materials. An extended treatment of the effect of thermal spikes on rate processes has been given, and a new theory of the induction of diffusion by displacement spikes has been developed. The problem of the kinetics of the annealing of radiation damage has also been under study, and a unified and rather general approach has been worked out. An attempt is now being made to employ machine computations to determine threshold energies for displacement of atoms in a lattice and the distribution of the resulting interstitials.

The kinetic theory of the distribution of positions, velocities, etc., of molecules in a fluid has been generalized. Previous developments applied to a single time; the present treatment concerns distributions containing two different time parameters. A certain family of two-time distribution functions is shown to obey a system of differentiointegral equations similar to the Born-Green equations. The time-displaced correlation function introduced by van Hove, which is of use in theories of scattering, is determined by one of these distribution functions. Superposition techniques applied to the general equations offer hope of finding approximate solutions.

The localization of Wannier functions, a technique of considerable promise in band theory calculations, is under study. The Wannier functions are Fourier transforms of Bloch functions in k space; therefore, analytic continuation of Bloch functions in k space is of importance. The location of branch surfaces and the discontinuity in the Bloch function across such branch surfaces were investigated. A method was devised to construct a phase function to eliminate these discontinuities. If a phase function is required, the symmetry of the resulting Wannier function is reduced, and in many cases the extreme localization of Wannier functions lowers their symmetry. A simple relationship was discovered between the asymptotic form of Wannier functions and the dimension of the discontinuity of the Bloch function. If there are no discontinuities in the Bloch function, Wannier functions fall off exponentially at large distances from the origin; if discontinuities are at points, inversely as distance cubed; and if discontinuities are on lines, inversely as distance squared.

The relation between lattice parameter, composition, and short-range order has been investigated theoretically in binary alloys, based on nearest-neighbor interactions, additivity of bond energies, and sufficiency of a quadratic expansion of energy as a function of distance. The theoretical relation describes accurately the lattice parameter – composition data for random alloys of Cu-Au and Ag-Au. For AuCu₃ about the right change in lattice parameter is predicted upon ordering. In this particular case a linear approximation is obeyed quite accurately.

Instrumentation

Instrumentation Division personnel design, construct, calibrate, and repair the instruments needed by other Laboratory groups for research and engineering. The major effort this year has been directed toward design of a high-speed digital computer. A small analogue computer has been used by the Division to solve problems for several other departments. Other new projects relate to the measurement of very short times, to data processing, and to a variety of counting circuits.

Last summer (1956) the Division gave lectures and set up experiments on nuclear instrumentation for the AEC-ASEE Nuclear Engineering Institute. Brookhaven was host to the Tripartite Instrumentation Conference in October, and the program and report of the meeting were prepared by this Division in cooperation with the Radiation Instruments Branch of the U.S. Atomic Energy Commission in Washington. W.A. Higinbotham, Division Head, and C.J. Borkowski, Head of the Oak Ridge Instrumentation Division, arranged the program for a symposium on pulse height analyzers sponsored by the National Research Council last fall (Multichannel Pulse Height Analyzers, NAS-NRC 467).

DIGITAL COMPUTER

Last year the decision was made to build a modern high-speed digital computer at Brookhaven, because it was found cheaper to build a computer than to buy one with the required capabilities. A custom built computer can be tailored to meet the Laboratory's particular needs. In addition it was felt that the development of new techniques for information gating and storage would be a useful contribution to the field. The experience gained should also be useful to this Division, which is more and more concerned with data processing and with the use of digital computer techniques.

It was decided to pattern this computer after the Maniac II, which was then nearing completion at Los Alamos. Last summer two of our engineers visited Los Alamos to learn about their computer and to discuss our plan with their designers. Our engineers helped with the design of the Maniac II control section.

A digital computer consists of three parts: an arithmetic section, which is a high-speed electronic calculator with floating point; an electronic "memory" to store numbers and instructions; and a control section which takes instructions from the memory and tells the arithmetic section what operations to perform with the stored numbers. The speed of operation, the size of the memory, and the set of instructions determine the performance of the machine.

Today's best commercial computers have high-speed memories with a capacity of 4000 to 8000 "words," the word being a number or an instruction. The Maniac II computer has a 12,000-word memory, and the BNL computer will have a 24,000-word memory. As in commercial computers, this high-speed memory will be supplemented by a much larger slow memory on magnetic tapes.

The Los Alamos arithmetic section consists of three "registers" for storing numbers and an adding circuit (multiplication and division are achieved by repetitive addition or subtraction). The BNL circuits have been modified by use of diodes and pulse transformer techniques to reduce the number of tubes and to increase the speed. Two additional "registers" have been provided (total 5) which will make computation easier and faster. Design of the arithmetic section has been completed, and construction has begun.

Most current computers employ magnetic cores to store numbers in the memory. The Los Alamos and BNL computers use charge storage on special cathode-ray tubes (barrier grid tubes) which are considerably cheaper if they can be made reliable. The Los Alamos memory is now operating. We hope to obtain more reliable operation by employing a technique developed at the Bell Laboratories and by recording both "ones" and "zeros." The development test phases have been completed; final design is under way.



Figure 1. Testing of BNL memory tube, a radechon (barrier grid storage) tube of the type that will be used in the memory section of the BNL computer. The test rack, designed and built by BNL to insure the highest quality of tube construction, will automatically write and read 1's or zeros on the face of the barrier grid tube and provide a visual display on a cathode-ray tube; this provides means for a fast and accurate operational check on the radechon tube.

The control section must be developed jointly by the mathematician programmers and the electronic engineers. Basically this will follow the Los Alamos design. The BNL Applied Mathematics Division has been studying the logic of the Los Alamos computer and working with this Division on the design. All Los Alamos instructions will be duplicated. Since the BNL computer

will have one instruction per word (compared to two for Maniac II), it will be possible to add more instructions and to increase the flexibility in other ways.

A wing of the administration building has been modified to house the computer. Cooling machinery is installed. Part of the power supply, the auxiliary magnetic tape memory, and a considerable amount of input-output equipment (paper tape punches, readers, electric typewriters, high-speed printer) has been ordered.

A summary of the computer's specifications follows:

Word = 48 bits = number and exponent *or* instruction, plus 2 "tag" bits.

Number = 40 binary bits and sign.

Exponents = 4 binary bits and sign.

Memory capacity = 24,000 (possibly 32,000) words.

Memory access time = $< 10 \mu sec.$

Shift time = $1.5 \,\mu\text{sec.}$

Add time = $4 \mu sec$ (fixed point).

Multiplication time = $120 \mu sec$ average.

Accessory memory = up to 16 magnetic tape units.

Input-output = punched paper tape.

ANALOGUE COMPUTER

A small analogue computer facility was set up last year as a service to the Laboratory. It was first used to determine the set of equations which describe the effect of insulin on the circulatory system of a dog. It was next used by the Cosmotron group, which has since purchased a similar computer. It is currently being used to simulate the damage produced by neutron irradiation of solids. Another simple analogue circuit was built for the Medical Department to help interpret the flow of radioactive tracers between biological systems.

HIGH-SPEED CIRCUITS

For several years physicists have been interested in very fast measurements – in detectors and circuits which can respond in ≈ 1 mµsec (one billionth of a sec). The fastest detectors employ a scintillating crystal (or Cerenkov radiator) and a photomultiplier tube. At present the speed is limited by the available photomultiplier tubes. Last year the development was reported of a type

of high-speed oscilloscope which was able to display pulses in this speed range. Additional equipment has been assembled so that this "sampling oscilloscope" may be used to measure the speed characteristics of experimental and production photomultiplier tubes. The tubes may be excited by a fast phosphor, a pulsed cathode-ray tube, or a pulsed mercury arc. These measurements permit determination of the optimum operating conditions for these tubes, selection of tubes for critical experiments, and evaluation of modifications in the tube structure made by the manufacturers.

A pulsed x-ray generator has also been built which may be used for testing the speed of detectors. It is patterned after an instrument developed at the University of California Radiation Laboratory. The pulses of 100-kv x-rays have a duration of 1 mµsec. This pulser has been found especially useful at the Cosmotron, where it can be used to adjust accurately the timing of a complicated experimental setup and thus avoid wasting pulses from that expensive accelerator.

Light travels about 1 ft/musec. It is possible to measure the speed of very fast particles over a similar distance with these high-speed detectors and circuits. The BNL 18-in. cyclotron produces very short bursts of protons at a frequency of 20 million cycles. A 100-channel time delay analyzer has been built for use with it. By measuring the time it takes particles to travel from the cyclotron target, this instrument is able to sort the particles by velocity into 100 groups. The final circuit makes use of a technique suggested by Emilio Gatti of Italy, which stretches the time scale out to a longer one which permits analysis by conventional circuit techniques. The output of this circuit is fed to a 100-channel pulse height analyzer.

DATA HANDLING

A 1024-channel neutron time-of-flight analyzer and a 100-channel pulse height analyzer were designed a year ago. Both of them have cathoderay tube displays of the data, and provisions for typing out the data at the end of the run by electrically operated printers. They have now been fitted with plotters which automatically draw a curve while the printer is operating. The curve plotter for use with the pulse height analyzers will make a linear plot with a variety of ranges, or it

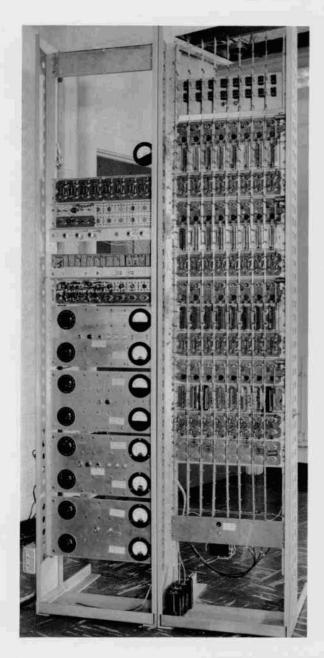


Figure 2. Model of power supply and arithmetical unit of BNL computer. The rack on the right is the arithmetical unit, which consists of three registers and an adder. Each register is composed of three chassis: a driver unit, a diode input gating unit, and a flip-flop unit having two cathode followers for its output. One such rack can handle eight bits of information, and six such racks will be required. The vertical buses are for the transfer of information between registers and the adder within the individual racks. On the other side of the arithmetical unit are mounted the tubes, and the horizontal busing used to provide power and the control gating pulses. The actual computer will be built along the same lines, but two additional fast storage registers per rack will be included.

will plot the logarithm of the number of counts as a function of pulse height.

A number of counters have been built which use glow discharge counter tubes, for specialized applications. These include: 1) a set of 18 scalers with timing and switching circuits for measuring the rate of change (period) of reactivity in a critical fission assembly; 2) timing circuits for control of

a bubble chamber; 3) scalers to store the counts detected in a scanning neutron crystal spectrometer, with control circuits to print out the data automatically at regular intervals; and 4) sets of scalers for use at the Cosmotron and in a low background detector arrangement in the Chemistry Department.

Accelerator Development

In November 1956 the Accelerator Development Department moved into the newly constructed AGS service building. This structure provides, under one roof, the required office space, electronics shop, machine shop, laboratories, AGS control and service center, and a large experimental assembly area.

Experimental studies of the various magnet models and types of magnet steels progressed sufficiently so that the final design of the main magnet coils and cores could be completed. Contracts for the fabrication of these two major items of procurement have been prepared and are awaiting AEC approval. A contract has been awarded to the Westinghouse Electric Corporation for the design and manufacture of the main magnet power supply.

The vigorous modeling program followed by the linac group has given impetus to the completion of the detailed design phase of this component. The Cockcroft-Walton injector for the linac has been delivered and is being assembled so that its performance characteristics may be studied. Final drawings for the linac tanks have been prepared and are being reviewed for inclusion in the solicitation for bids which will be forwarded to prospective fabricators. Various techniques of beam focusing and inflection are under investigation.

The major effort of the control group has been devoted to the design of a centralized AGS water system. This group is also making a study of, and preparing a proposal for, the intercommunication and public address systems for the machine complex.

The design of the radio-frequency accelerating system is progressing satisfactorily. Proposals for the fabrication of the ferrite rings to be used in the accelerating cavities have been returned, and a contract has been prepared and submitted for AEC approval.*

Tests on the Evapor-ion pumps have established both the excellent performance and the reliability of these units. The design of the vacuum chamber and special sections have been modified to accommodate the latest machine requirements.

During the past year the staff of the Accelerator Development Department increased by about 10%. Members of the staff have presented papers at meetings of the American Physical Society, the American Institute of Electrical Engineers, the Institute of Radio Engineers, the Committee on Vacuum Techniques, the Midwest Universities Research Association, the U.S. Naval Reserve, and the AEC Shielding Conference. A total of 36 visiting engineers and scientists came to the Department from Australia, India, England, France, West Germany, Poland, Italy, Switzerland, Sweden, and Holland to discuss accelerator design with Department members.

Details of design and construction are described in the following paragraphs under the appropriate component headings.

MAGNET

The extensive analysis and measurements program of the magnet design group culminated, during the winter, in writing the final specifications and soliciting bids for the magnet cores and coils. Late in April proposals for the fabrication of the cores were received from four companies (five declined) and of the coils from five companies (two declined). After many conferences with engineering representatives from the various firms, contracts for each of these components have been prepared and submitted to the AEC for approval.* They call for delivery of pilot models within seven months for test at the Laboratory before final production starts. Delivery of all the cores and coils is expected to be complete early in 1959.

The magnet cores will be made of thin (of the order of 0.035-in.-thick) laminations, but with 1-in.-thick end plates, assembled under pressure and held by welded straps on all sides. Although a model magnet bonded together with a vinyl

^{*}This contract has since been approved and executed.

^{*}These contracts have since been approved and executed.

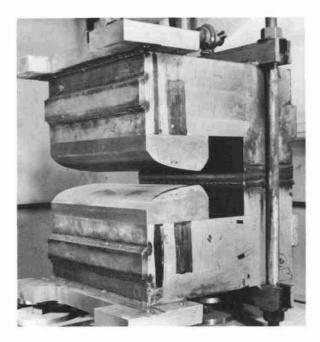


Figure 1. Magnet Model No. 5, configuration 2 (one-half scale).

resin appeared to be quite satisfactory mechanically, it was felt that the control of the temperatures during the bonding cycle was not sufficient to ensure the high degree of uniformity necessary between magnets. The final choice of steel will be made by the fabricator (subject to approval by this Department), since the mechanical properties of the laminations, e.g., flatness, gauge variation, etc., have an important influence on the achievement of the final mechanical tolerances. The steel sheets will be thoroughly shuffled before assembly so that variations in magnetic properties will be distributed uniformly throughout the magnet units.

Further analysis of the saturation behavior in these magnets, coupled with measurements made on the various models, resulted in a small reduction in the radial magnetic aperture to 6 in.; the vertical gap height at the equilibrium orbit is still 3.5 in. The corresponding profile for the magnet gap was computed and tested on Magnet Model No. 5, a half-scale dc magnet. The outside dimensions of the magnet cross section remain at 33×39 in., and the pole width is 12.5 in. The effective n value is 357. There are 240 magnet units, four units comprising a full focusing-defocusing lens system, and the total weight of steel is almost 4000 tons.

The magnet exciting coils will be made of copper bars, 1^{19} ₃₂ \times % in. in cross section, with a %-in.diameter hole in the center for water cooling. The 32 turns of the winding will be made in four twolayer pancakes, two located above the pole gap and two below. These two halves of the coil are connected in series-parallel with alternate transposition from top to bottom location in going from one magnet to the next around the ring. Each pancake will be formed into a bonded monolithic structure capable of withstanding tensile forces of 500 psi and shear forces of 1000 psi between turns or layers. The turn-to-turn and layer insulation is required to withstand a 1500-v peak highfrequency or 5000-v peak impulse test, and the ground insulation must withstand 20,000 v, rms, at 60 cycles. All firms solicited were requested to submit samples of their proposed construction for these electrical and mechanical tests.

During the past year the magnetic measuring equipment has continued to be modified, improved, and enlarged. Search coils for measuring magnetic fields, integrated with respect to the azimuthal direction, have been built and calibrated for lengths of 15 in. and 5 ft. A 10-ft-long search coil has been designed and is now under construction. An accurate current marker, with a peaking strip in a bias field, has been constructed to read currents up to 1000 amp, and another is under design for use up to 7000 amp.

When the pulsed current in the magnets is reduced to zero, the remanent field left in the gap is a sizable fraction of the injection field (somewhat over 20 gauss for a coercive force of the steel of about 1). Its shape may be sufficiently different from that of the dynamic field so that the total gradient at injection may need correction. Experience has shown that coercive force may have the greatest variation of all the magnetic parameters of the steel; therefore, a series of experiments was carried out with small reverse pulses in the magnet winding in an effort to reduce these deleterious effects. Tests on Magnet Model No. 4, which had a large remanent field (about 70 gauss) with large azimuthal variations in value, showed that a single reverse current pulse of about 1/20 or 1/15 of the peak forward current not only reduced the remanent field nearly to zero but also reduced its azimuthal variations in relative magnitude. There was also a reduction in the gradient of the remanent field and in its variations. At the same time

dynamic field measurements taken after such a demagnetization pulse showed that the effective permeability at inductions of the order of 100 to 200 gauss was considerably higher than when the magnet was pulsed under normal remanent conditions. Whether these advantages are still present with other types of steel will be tested on further models. The decision as to whether such a demagnetization cycle will be incorporated into the magnet will depend on the behavior of the steel chosen by the fabricator.

Serious consideration is being given to the use of a series reactor in the magnet circuit in order to reduce the initial rate of rise of the magnetic field. One important reason for this is to reduce the influence of eddy currents in the proposed Inconel vacuum chamber. A model reactor was built and tested with Magnet Model No. 4; a further model is now under construction, and preliminary designs for use with the final magnet are now being studied.

The chief parameters of the magnet power supply were given in last year's report. Final specifications were drawn up and bids solicited in the fall of 1956. In March 1957 a contract for the complete system of alternator, motor generator, ignitron rectifier-inverters, and associated auxiliary equipment was placed with the Westinghouse Electric Corporation. Delivery of the component parts is expected to be complete by the summer of 1958.

LINEAR ACCELERATOR

The design phase of the 50-Mev linear accelerator injector was virtually completed during the past year, and construction is in progress, or about to begin, on all components. Computation of dimensions and shapes of important machine elements has been completed and checked by model studies. The basic features of the injection system which carries the 50-Mev proton beam from the linear accelerator into the synchrotron have been established, and detailed design of injection components is in progress. The status of the various machine elements from ion source to inflector is discussed in that order in the paragraphs which follow.

The 750-kv Cockcroft-Walton set which provides the initial proton acceleration has been delivered. A staff member witnessed tests of this unit

up to 800 kv in the manufacturer's plant at Eindhoven, Holland. The set was then dismantled and shipped to Brookhaven, where it has been reassembled for studies of possible minor mechanical modifications. The high voltage terminal to house the ion source and ancillary equipment has been designed and ordered from a local fabricator. No ion source studies have yet been undertaken, since designs adequate for initial operation of the machine are available at Brookhaven.

The accelerating column in which the protons are led from the high voltage terminal to ground and so into the linear accelerator has been designed. It will have an aperture of 5.5 in. and will be 72 in. long. Ceramic ring sections for this column are on order.

The inside diameter of the linear accelerator tank has been frozen at 95 cm. It will be fabricated from copper-clad steel 1 in. thick over-all; the copper thickness will be 0.15 in. An all steel mechanical model of a 10-ft tank element has been tested for mechanical rigidity and for evaluation of the proposed methods of drift tube support and alignment. The tests were successful on all counts; drift tubes were aligned to 0.003 in. and moved less than 0.002 in. when the tank was evacuated. Only very minor modifications in the drift tube support mechanism were made as a result of the tests. Drawings of all 11 tanks are complete and will be sent out for bids shortly. Preliminary drawings are already in the hands of prospective bidders.

Computation of drift tube shapes on the Univac was completed in January. The diameter of the first drift tube is about 21 cm. This diameter increases to a maximum of 25 cm at about the 6.5-Mev point and then decreases slowly to about 15 cm at the last drift tube. The computations have been spot checked at several points by a precision unit cell model. All drift tubes are roughly elliptical in shape.

Design of the pulsed quadrupoles to be imbedded in the drift tubes for focusing the proton beam has been completed, and the quadrupoles are on order. Harmonic analysis of the magnetic fields of model quadrupoles made possible a simple pole shape to eliminate effectively all spurious multipole fields up to fields corresponding to 20 poles. Higher order fields than this will have no appreciable effects on the proton beam. Fabrication of the quadrupoles was simplified by using only four groups of quadrupoles; in each group

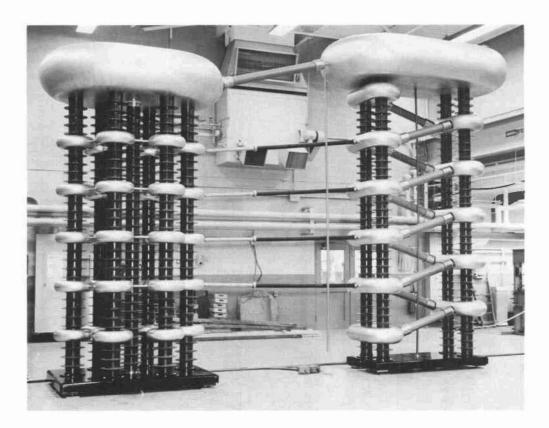


Figure 2. Cockcroft-Walton injector for linear accelerator.

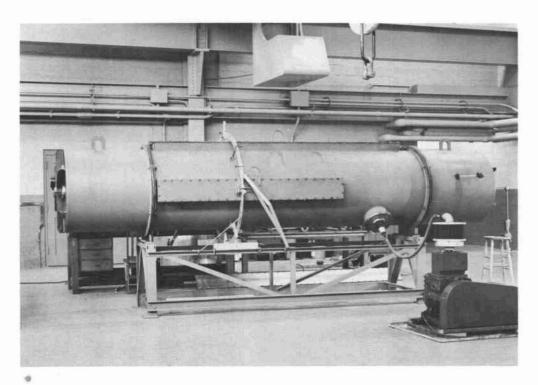


Figure 3. Linac mechanical model.

all quadrupoles will be identical in length and shape. The four groups correspond to the gradual increase in aperture from 0.5 in. at injection to 1.25 in. at 50 Mev.

The mechanical problems involved in assembly of the drift tube with its included quadrupole have been checked in a test fabrication. All joints exposed to electric fields will be either hydrogen brazed or heliarc welded.

Performance of the linear accelerator at the operating field level has been checked in a "high power model." This model, about 4 ft long, is a full-scale model of a section of the linear accelerator around the 35-Mev point. Enough power is available from a 200-Mc triode amplifier to generate fields in the model up to 50% above the operating level. Designs of tuners, probes, and rf connections have been evolved for this model and have been tested for satisfactory performance and freedom from electrical breakdown. A slow buildup of x-ray output to troublesome levels has been traced to hydrocarbon or other contamination of drift tube surfaces and has emphasized the necessity for extreme cleanliness in the vacuum system. Much experience has been gained by evacuating the model with an Evapor-ion pump; several improvements in pump design have resulted from this operation.

Radio-frequency power for the linear accelerator will be supplied by a 5-Mw klystron now under development at the Eitel-McCullough Company. Construction of this tube is behind schedule, although there seems to be no doubt of its eventual success. The tube design is complete, and similar tubes are now under test. The klystron power supply has been designed at Brookhaven, and parts have been tested. The Brookhaven group is also investigating various possible systems for transferring power from klystron to linear accelerator.

A tentative arrangement of quadrupole focusing elements to guide the beam from linear accelerator to synchrotron has been computed. A preliminary design is available also for the debuncher which reduces the energy spread in the 50-Mev beam by a factor of the order of three. Design of the pulsed inflector is in progress, and model tests of the pulsing circuit have resulted in a final design which appears to be satisfactory.

Analysis and computation are completed or in progress on several field problems – for example

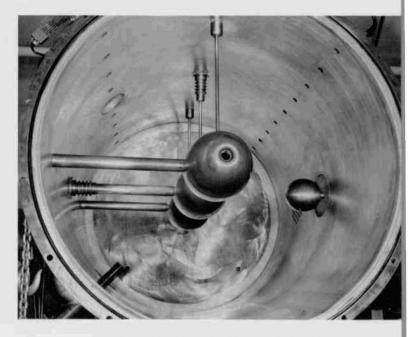
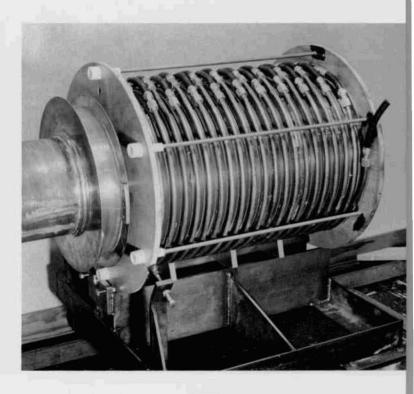


Figure 4. Linac power model showing drift tubes and ball tuners.

Figure 5. One-quarter section of the rf cavity showing ferrite rings, cooling coils, and accelerating gap.



the problem of maintaining field uniformity along the linear accelerator – and on the multipactor effect; the latter is a cumulative loading effect which, for particular fields and separations, may result in an electron discharge between electrodes in radio-frequency fields.

RADIO-FREQUENCY

During the past year some of the original concepts of the AGS rf system have been revised and modified. The effort of the rf group has been in the direction of a parallel development of the five basic components.

The design of the low level system has been based on beam feedback and double mixing circuits. In principle, the double mixing of the signal frequencies makes it possible to accomplish all phase control at a constant frequency. Any differential phase shifts which occur in cables and amplifiers can be effectively cancelled by using a cable of the proper length at an appropriate point in the loop. Circuit details of the various filters, mixers, and amplifiers are being developed.

The model test power amplifier which was designed and built to drive the model ferrite cavity has performed adequately. This unit is being modified so that it can be used as a predriver stage for the newly conceived power amplifier scheme. As visualized at present, the rf power amplifiers will have only the final stages located in the magnet enclosure. The low level, driver, and cathode follower stages will be located at some convenient position remote from the ring. Radiofrequency will be fed from the cathode follower stage to the 12 final stages at the ring over 24 coaxial cables.

The full-scale model ferrite-loaded cavity has been designed, built, and fully tested. The properties of this cavity approximate very closely the predicted performance.

Proposals have been received for the fabrication of all the ferrite rings required for use in the cavities. A contract has been prepared and submitted to the AEC for approval.* The present ferrite saturating supply, which is adequate for use with the model work, has a number of performance defects. Consequently, a completely transistorized dc amplifier with one hundred 12-

amp transistors in parallel has been designed and is under construction. This unit should be able to drive the cavity directly and should be relatively free of any unwanted frequencies.

When the vacuum chamber size was reduced, a re-evaluation of the performance of the already designed beam monitoring pickup electrode structures was undertaken. Direct scaling of the electrodes was found to be impossible, and the units were therefore completely redesigned. The new structures yield good sensitivity and linearity over the region of expected beam excursions.

VACUUM

During the past year two commercial models of the Evapor-ion pump have undergone an intensive engineering evaluation. A number of modifications and improvements in these units have resulted in increased reliability, longer operating periods between maintenance, and easier starting procedure. One of these pumps has been installed to operate in conjunction with the linac power model. Except during the initial outgassing period, it has consistently maintained a pressure of about 1 to 2×10^{-6} mm Hg. The modifications and improvements will be incorporated in the specifications for the balance of the pumps to be ordered for use on the AGS.

Several vacuum chamber sections with rib supports have been built and tested. The thinnest wall material that could meet the requirements was 0.050-in. Inconel X. However, when the vacuum chamber was reduced in size from 8 to 7 in., a chamber of 0.78-in. wall thickness with no rib supports was found to be feasible and was adopted.

By combining a beam viewing station and a pump-out port into one aluminum casting, significant cost and space savings were effected. A prototype vacuum pumping station has been built and will be used in the evaluation of various types of valves and other auxiliary equipment.

STRUCTURES

The construction of the AGS building complex has been proceeding on schedule. Late in 1956 the White Construction Company completed the service building, and shortly thereafter the Department moved most of its activities from the temporary barracks to this center. The same firm was award-

^{*}This contract has since been approved and executed.



ed the contract for the construction of the magnet enclosure shell and linac tunnel and the various tunnel conjunction sections. During this phase of the program, bids were solicited for the completion of the balance of the complex, including magnet enclosure floor and target and linac buildings. The successful contractor was the Malan Construction Corporation, which started full-scale operation in April 1957 and has already completed about 30% of the work.

Figure 6. Aerial view of the AGS complex.

The high-density concrete blocks for shielding in the target building have been designed, and a contract has been prepared for AEC approval.* Most of the appurtenances to the buildings, such as cooling wells, discharge basins, and magnet girders are either completed or under contract.

^{*}This contract has since been approved and executed.

Chemistry

The research activities of the Chemistry Department during the current report period have followed, in broad outline, the program developed over the past few years. In nuclear chemistry considerable effort has been devoted to the study of high energy nuclear reactions. On the experimental side, new techniques for the measurement of relative yields of high energy reaction products, involving the use of mass-spectrometric as well as photographic emulsion methods, have been explored and developed. Extensive Monte Carlo calculations of high energy cascade processes have been carried out in collaboration with groups at Los Alamos, the University of Chicago, and Columbia University. Theoretical and experimental investigations of K capture and positron emission have continued and are discussed in relation to the fundamental beta decay interactions. Continued interest in decay schemes is evidenced by a report on Se⁷². Improved sensitivity of detection has been achieved in the most recent attempts to observe the nuclear capture of neutrinos. This experiment has involved the use of facilities at one of the Savannah River production reactors.

Interest in the chemistry of isotopic molecules as well as in the application of isotopes to the solution of varied chemical problems has continued at a high level. The general problem of calculating the free energy differences of pairs of isotopic molecules has been attacked by approximation methods. In another project, the vibrational frequencies and intensities of deuteriumsubstituted benzenes have been obtained by machine computation and compared with experiment. Computations were carried out with the Univac at the New York University Computing Facility. It is perhaps worth noting that these calculations, in conjunction with the above-mentioned Monte Carlo calculations, represent a significant increase in the use of machine methods for the solution of problems of interest to the Department. The theory of reaction rates, and in particular the isotope effect on rate, is considered in the light of some new theoretical ideas. Isotopes have been used to investigate the role of solvent

in electron exchange reactions and in the study of thallium complex ion formation. A program of characterization of ancient ceramic objects through observation of the gamma activity induced by neutron activation has been carried forward. This work is being done in collaboration with archaeologists associated with the Institute for Advanced Study at Princeton University.

In the field of mass spectrometry several advances in instrumentation have opened up new avenues of approach to nuclear and geochemical problems. High sensitivity techniques have been successfully employed to determine approximate yields of certain nuclides produced by Cosmotron irradiation and to measure the cesium concentration in stony meteorites.

Chemical effects of radiation have been studied in both organic and inorganic systems. A preliminary investigation of the radiation chemistry of hydrocarbons absorbed on solids is described, and results are discussed in relation to the possible origin of natural gas. Work involving homogeneous organic systems is also reported. In aqueous systems, the main interest has been the investigation of the variation in product yields with changes in ionization density.

A theoretical approach to the understanding of the chemical effects produced by nuclear transformations has been developed, based upon the Seitz and Koehler model of the slowing-down of energetic atoms in solids. Reports of experimental work cover some isotope effects in Szilard-Chalmers reactions as well as reactions of recoil tritons with gaseous methane.

As in past years, tracer techniques have played a major role in the elucidation of organic reaction mechanisms. The mechanism of carbinol-olefin interconversion has been studied with O¹⁸. Tritium and deuterium labeled compounds have been used to study the biosynthesis of nicotine in tobacco root cultures. This work has been performed in collaboration with the Botany Department of Columbia University. Continued interest in the study of the mechanism and applications of recoil labeling has

led to new and significant results in certain aromatic systems.

Activities in the field of structural chemistry are quite varied and include molecular orbital calculations, spectroscopy, neutron and x-ray diffraction, and magnetic measurements. During the past year a molecular orbital calculation of the quadrupole moment in carbon dioxide has been carried out. The infrared spectrum of the nitrite ion has been investigated with N15-labeled compounds, and the force constants have been obtained. As part of a continuing program of investigation of magnetic materials by means of neutron diffraction, the antiferromagnetic structures of a series of manganese chalcogenides have been determined. These are discussed in the light of current theories of magnetism. Theoretical studies have been made of extinction effects in the diffraction of neutrons by both magnetic and nonmagnetic crystals. Fluorescence and phosphorescence spectra of certain indole derivatives have been examined at low temperatures. Spectra of such substances have also been used as a tool for investigating the degree of homogeneity of solutions at low temperature. In another series of experiments the symmetries of fields about ions in solution have ben studied spectroscopically.

The work of the Department has been materially aided by a number of visiting scientists from academic, governmental, and industrial institutions in this country as well as from institutions abroad.

NUCLEAR CHEMISTRY

High Energy Nuclear Reactions

Chemists continue to use the Cosmotron for the study of reactions between complex nuclei and protons with energies in the Bev region. In most such investigations, the radioactive products of the reactions are detected and measured by virtue of the characteristic radiations they emit. However, during the past year it has also become possible, at least in special cases, to measure the relative yields of reaction products mass-spectrometrically. This technique is applicable to products with half-lives in excess of ≈ 1 hr and is particularly important for the measurement of very long-lived and stable nuclides, which cannot be detected radiochemically. Specifically, the yields of cesium and rubidium isotopes from the bombard-

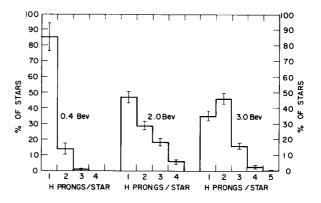


Figure 1. Multiplicity of heavy prongs (Z>2) per star observed in the irradiation of D-1 emulsions by protons of various energies. (Only stars with prongs totaling 8 or more units of charge are included.)

ment of gold with 3-Bev protons have been determined mass-spectrometrically, and upper limits of 0.002 mb could thus be placed on the cross section for formation of the long-lived isotopes Cs¹³⁵ and Cs¹³⁷ from gold. The technique used is discussed in the section on mass spectrometry. Work is continuing on the extension of the surface ionization technique used in this research to other elements produced in Cosmotron targets.

Another technique successfully employed during the past year to supplement radiochemical data is the detection of nuclear reaction products in photographic emulsions. The emission of fragments heavier than alpha-particles in interactions between the AgBr of Ilford D-1 emulsions and protons of 0.4, 2.0, and 3.0 Bev was investigated. In a preliminary study, the average number of such fragments per interaction (including the recoil nucleus) was found to increase from approximately 1.01 at 0.4 Bev to about 1.8 at 2 and 3 Bev. Figure 1 shows preliminary data on the frequency of events with 1, 2, 3, and 4 heavy fragments per star. Measurements of track lengths and angular distributions of such fragments are in progress, and work is continuing with improved emulsions and track-measuring techniques which will make it possible to determine the nuclear charges of some of the fragments.

Eventually it is hoped that it will be possible to correlate these emulsion studies with the results of radiochemical investigations on the emission of light fragments from heavy nuclei. Along this line, the formation of C¹¹ (half-life 20.5 min) from

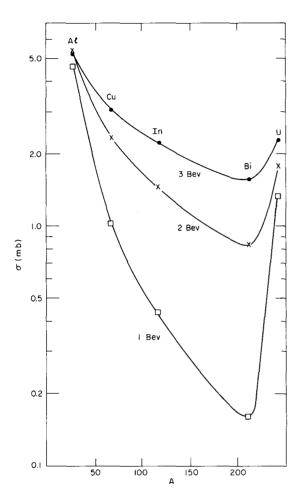


Figure 2. Cross section for formation of C^{11} at 1, 2, and 3 Bev as a function of target mass number.

a variety of target elements of 1, 2, and 3-Bev protons has been investigated in the past year. The results shown in Figure 2 are qualitatively similar to those obtained earlier on the production of F18 and Na²⁴ and described in last year's report. In all these cases the minima in the σ vs A curves indicate strongly that different mechanisms are responsible for the formation of these fragments from light and heavy target elements. It is not yet clear whether the production of light fragments such as C11 from the heaviest elements can be ascribed to a very asymmetric fission process following distribution of excitation energy throughout the nucleus, or whether it results from a rapid breakup process (termed fragmentation to distinguish it from fission).

Other experiments on the interaction of 3-Bev protons with the heaviest elements have been

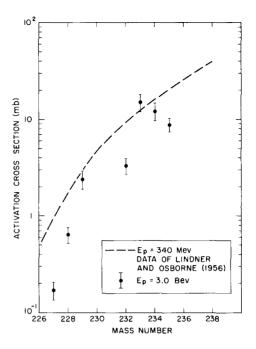


Figure 3. Cross sections for the formation of Pa isotopes from uranium.

undertaken to gain further insight into the various mechanisms operative in these reactions. Because of the Cosmotron breakdown in February 1957, only fragmentary results are available. The cross sections for the formation of several protactinium isotopes in 3-Bev proton bombardments of uranium are shown in Figure 3. The yields are lower than those reported for 340-Mev proton bombardments. This observation confirms the conclusion, previously reached in experiments with copper and bismuth, that the cross sections of relatively simple reactions, i.e., reactions involving mass changes of only a few units, decrease as the bombarding energy is increased above about 300 Mev. The probability of small energy transfers to the bombarded nucleus apparently decreases with increasing bombarding energy. The shape of the yield vs mass curve for the Pa isotopes is similar for the two bombarding energies; the drop in cross section with decreasing product mass may be ascribed to the competition of fission with nucleon evaporation at each step in the de-excitation of the excited intermediate nucleus formed during the initial interaction.

The yields of some nuclides in the fission product region resulting from heavy-element bombardments have also been investigated. The cross sec-

Table 1

Cross Sections (in mb) for Production of Ba and Mo Isotopes in 3-Bev Proton Bombardments of Heavy Elements

		ı	Target	
Product	$\overline{\mathrm{U}^{\scriptscriptstyle{238}}}$	U^{235}	$Th^{\scriptscriptstyle 232}$	Bi ²⁰⁹
Ba140	9	10	8	€0.008
Ba ¹³¹	7	8	4	· 5
$\mathbf{B}\mathbf{a}^{129}$	10	13	7	11
Ba^{128}	9	11	8	7
Mo^{99}	31	37	21	2.9
Mo^{93}		1.1	0.5	1.1

tions for formation of several barium and molybdenum isotopes in the bombardment of U^{238} , U^{235} , Th^{232} , and Bi^{209} by 3-Bev protons are listed in Table 1. Separate experiments, in which U^{235} and U^{238} foils were irradiated simultaneously, have shown the cross sections to be significantly different for the two target isotopes, with $\sigma_{235}/\sigma_{238}$ 1.3 to 1.4 for the neutron deficient Ba products and 1.15 for Mo^{99} and Ba^{140} .

Monte Carlo Calculations of High Energy Reactions

Practically all attempts at interpretation of high energy reactions have been based on a model originally suggested by Serber. In this model the incident particle initially interacts with an individual nucleon in the target nucleus. The collision partners may escape from the nucleus or undergo further interactions with other nucleons; this so-called nuclear cascade continues until every particle involved has either escaped or been so degraded in energy that on reaching the nuclear surface it cannot leave the potential well. The highly excited nucleus resulting from this fast cascade ($\approx 10^{-21}$ sec) is then thought to de-excite on a much slower time scale ($\approx 10^{-15}$ sec) by "evaporation" of successive nucleons or aggregates of nucleons; fission into large fragments may compete with evaporation.

Extensive calculations of high energy cascade processes have been carried out by the Monte Carlo method in a joint program with groups at Los Alamos, the University of Chicago, and Columbia University. The use of the fast electronic computer at Los Alamos (Maniac I) made it

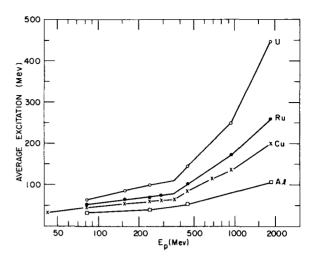


Figure 4. Average excitation energy after nuclear cascade as a function of bombarding energy, as computed by Monte Carlo calculation.

possible to make important improvements over previous calculations in terms of greater statistical accuracy, the use of three-dimensional rather than two-dimensional geometry, and extension to energies up to 2 Bev with the inclusion of pion production and pion interaction processes. The target nuclei investigated were Al, Cu, Ru, Ce, Bi, and U, and a series of incident proton energies from about 80 Mev to 1.8 Bev was used for each. A typical run for a given target and bombarding energy involved 500 to 1000 incident particles. The number, kind, energy, and direction of the particles emitted in each cascade, and the charge, mass, and excitation energy of the residual nucleus were tabulated. The results of the calculation are much too extensive to be even summarized here. One striking feature of the data, the rapid increase in residual excitation with increasing bombarding energy above the pion production threshold, is illustrated in Figure 4. This confirms quantitatively the qualitative suggestion made earlier that pion production and reabsorption provide an important mechanism of energy transfer to the bombarded nucleus.

Comparisons of the Monte Carlo cascade calculations with nuclear emulsion data on numbers, angular distributions, and energy spectra of emitted nucleons, and with radiochemical data on residual nuclei, show encouragingly good agreement. Some systematic discrepancies have appeared, however, and these have led to refinements in the model used. For example, the calculations predict cross sections for p,pn reactions which are too small by a factor of 2 or 3. Since such reactions presumably involve mostly the simple knocking out of a neutron and therefore take place largely near the periphery of the nucleus, it is thought that the introduction of a tapering nucleon density distribution instead of the uniform density model used so far will improve the agreement with experiment. Calculations with such a tapered-edge model are now in progress.

For detailed comparisons with radiochemical data, the cascade calculation needs to be supplemented with calculations of the de-excitation processes. A Monte Carlo calculation of the evaporation phase has therefore been set up, again with the cooperation of the Los Alamos computer group. So far the emphasis has been on making the proper choice of a number of parameters; but this phase of the calculation has been essentially completed, and enough useful results have been obtained to make it appear profitable to pursue the calculations further on the basis of the model adopted. Refinements will have to be added, one of the important ones being the inclusion of fission among the possible competitive processes at each step in the de-excitation. Even then, it is felt that some reactions in the Bev energy range will not be explainable in terms of the model used, but will require additional mechanisms, such as the fast fragmentation process previously postulated.

K Capture and Positron Emission

During the past year studies on the relative probabilities of K-electron capture and positron emission in effecting transitions between characterized nuclear states have been directed towards the derivation of information on the fundamental beta decay interactions. In the course of this work the effects of screening of the nuclear potential by the atomic electrons were found in part to have been incorrectly evaluated in the published literature. Corrected screening and finite nuclear size effects were taken into account in the calculation of theoretical K-capture/ β ⁺ ratios which have been correlated with the experimental values. Furthermore, approximation formulas have been derived to make possible the simple and quick calculation of K-capture/ β ⁺ ratios for the several nuclear matrix elements of interest, relative to the ratio for allowed transitions.

A comparison of theoretical and experimental ratios for the first-forbidden unique transitions in I¹²⁶ and Sb¹²² has shown that the ratio of the beta interaction coupling constants G_A/G_T is 0.01 ± 0.06 in I¹²⁶ and 0.03 ± 0.12 in Sb¹²². Similar conclusions, derived from studies of allowed transitions, are to be found in the literature. In the case of the unique transition in Rb⁸⁴ decay, a discrepancy exists; it is hoped that results of experiments now in progress with this nuclide will be amenable to reasonable interpretation.

The correlation with theory of measured Kcapture/positron ratios for first-forbidden transitions with zero spin change offers additional possibilities for obtaining information about the beta decay interactions. The results of measurements made here and elsewhere are available for three such transitions, which occur in the decay of As74, Rb84, and I126. In the first two cases the observed ratios K-capture/ β ⁺ are about 1.5 times those expected for allowed transitions. The result for I¹²⁶, judged to be less reliable, is qualitatively different; and new measurements by a relatively direct method are being made. Assuming that the observations for the transitions with zero spin change in As74 and Rb84 are correct, it is possible to arrive at certain conclusions. The observed ratio, which is made up of contributions to both capture and positron emission by each of several nuclear matrix elements, may be compared with the ratio which would be obtained if each matrix element alone were operating to produce the transition. In this way it is possible to get some idea of their relative contributions. Capture-positron ratios larger than allowed ratios were found to be associated with two matrix elements of the tensor interaction and with the pseudoscalar interaction. In comparison with allowed ratios, as the transition energy increases, the tensor ratios increase less rapidly than the pseudoscalar ratio, other factors being equal. Thus a comparison of transitions having different energies but the same Z values may make it possible to determine which of these matrix elements are responsible for the high ratios observed in transitions of the type occurring here.

Decay Scheme of Se^{72}

Interest in the determination of the yields of Se⁷² produced in Cosmotron targets has led to an investigation of the decay scheme of this nuclide. The Se⁷² was made by alpha-particle irradiation

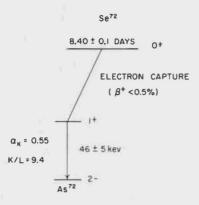


Figure 5. Decay scheme of Se72.

of germanium enriched in Ge70. Results are summarized in the scheme shown in Figure 5. Comparison of the X-X and $X-\gamma$ coincidence rates, measured with a 100-channel coincidence analyzer, was used to derive the value for α_K ; and comparison of the intensities of the K and L conversion lines in the intermediate-image beta spectrometer determined the K/L conversion ratio. These two quantities, the gamma-ray energy, and the Z value establish that the 46-kev transition is electric dipole; and the spin of the 46-kev state is fixed by this fact together with the knowledge that the transition is very probably allowed. The ratio of the intensity of the x-rays to that of the gamma-rays shows that substantially all Se72 transitions are to the excited state of As72.

Neutrino Detection

The experiment to observe the nuclear capture of neutrinos has been continued during the last year in an effort to improve the sensitivity of detection. One thousand gallons of carbon tetrachloride were irradiated with a high flux of neutrinos by placing tanks of the liquid adjacent to one of the production reactors at the Savannah River plant (Figure 6). The reaction looked for was the following:

$$\nu + Cl^{37} \rightarrow A^{37} + e^{-}$$

where ν represents the neutrino. The neutrinos emitted from a reactor arise from the negative beta decay of fission products. The product, argon-37, is radioactive and decays by electron capture (34-day half-life) in a reaction which is the inverse of that written above. Argon-37 was removed from the liquid by sweeping with helium gas, and then

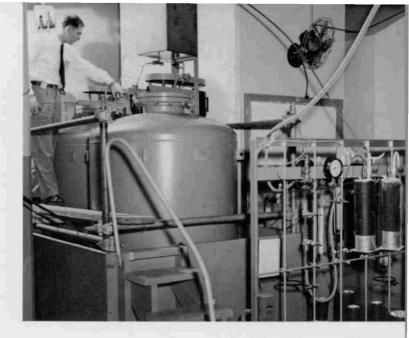


Figure 6. Two 500-gal tanks of carbon tetrachloride and associated helium sweeping equipment used in the Brookhaven neutrino experiment.

isolated from the helium gas, purified, and placed in a low-level counter for measurement. The most recent results show that the cross section for the above reaction is $(1.1\pm0.2)\times10^{-45}$ cm² for fission product neutrinos. The activity observed was found to decay with the proper half-life for argon-37 within the statistical uncertainty of the observations. It is possible for argon-37 to be produced in the carbon tetrachloride by cosmic radiation and fast neutrons. A number of auxiliary experiments designed to study these background effects have been performed. However, at the location near the Savannah River reactor where the tanks were irradiated, the background argon-37 produced by these effects should be lower than the amount observed by at least a factor of 10. It is therefore tentatively concluded that the argon-37 observed arose from neutrino capture. Further experiments will be carried out to check this point.

The theoretically calculated cross section of the above reaction depends upon the nature of the neutrinos emitted by the reactor. If chlorine-37 is irradiated with the identical kind of neutrinos emitted in the radioactive decay of argon-37, then the cross section for the above reaction should be 5.2×10^{-45} cm². However, fission product neutrinos arise from negative beta decay and are not necessarily identical with those emitted in the decay of argon-37. Recent experiments directed toward a study of parity nonconservation have demonstrated that neutrinos emitted by beta decay

processes are polarized, and it is possible that only the neutrinos from the reactor with the correct spin orientation will be capable of inducing the reaction written above. Recent theories, for example, propose that there can be neutrinos (ν) and antineutrinos $(\overline{\nu})$, each capable of existing in two spin states, that is, with the spin directed either along or opposed to the direction of motion (righthanded and left-handed helicity). If, however, neutrinos and antineutrinos are identical, then, of the neutrinos emitted by the reactor, only those with the correct spin orientation should be capable of carrying out the reaction. On this basis the observed cross section would be expected to be below the value of 5.2×10^{-45} cm², and possibly even zero, if neutrinos and antineutrinos are not identical.

Further experiments will be performed with the 1000-gal tanks to check these results and to study background effects. Plans are also being made to improve the sensitivity of the experiment by the use of larger volumes of carbon tetrachloride.

CHEMISTRY OF ISOTOPES

Statistical Mechanics of Isotopic Molecules

The exact calculation of the difference in free energies of a pair of isotopic molecules in the gaseous state requires a knowledge of the zeroorder vibrational frequencies and anharmonicities of the isotopic molecules. For most polyatomic molecules such detailed information is not available. It has been known for several years that significant results can be obtained by the simple first quantum correction approximation, $(\frac{1}{24})(h/kT)^2\sum(\omega_i^2-\omega_i^2)$, where ω' and ω are the vibrational frequencies of the two isotopic molecules. The sum rule in ω_i^2 , which expresses the invariance of $\sum_{i}\omega_{i}^{2}$ for isotopic isomers and similar systems, follows directly from the theory of harmonic vibrations. This theorem permits expression of the difference in free energies of a pair of isotopic molecules directly in terms of force constants and atomic masses without detailed solution of the molecular dynamics. One obtains directly the rule of the geometric mean, the theorem that isotopic isomers have identical chemical properties, and the theorem that the difference in free energies of a pair of isotopic molecules is independent of the isotopic composition of the other atoms in the molecule. Comparison of the results obtained by the method of the first quantum correction with experiment and with exact calculations, where these can be made, shows that the results of the approximate method are valid over a much wider temperature range than would be anticipated a priori from the nature of the first quantum approximation.

This agreement suggests that the contributions to the free energy differences of such isotopic systems from the higher quantum corrections are small. This has been investigated in detail by means of a complete series expansion of the difference in free energies of isotopic molecules in powers of $\alpha \omega^2$, where $\alpha = (h/kT)^2$, and through the higher-order sum rules in $\sum (\omega_{i_1}^{2n} - \omega_{i_2}^{2n})$. The series expansion is valid for $h\omega_i/kT < 2\pi$ and thus includes the isotopes of hydrogen above 1000° K. By using this power series expansion it can be shown that the difference in chemical properties of isotopic isomers arises from interactions in the molecule between nonbonded equivalent atomic positions. Since such interactions are small compared with the valence forces, the deviations from the results of the first quantum correction are small. In the case of the three isomeric dideutero-ethylenes the nonbonded interactions give rise to the bending vibrations, and thus these vibrations will contribute directly to the differences in free energies of these isotopic isomers. Other types of interactions contribute to the higher terms which result in deviations from the rule of the geometric mean. These are associated with the simultaneous motion of the isotopic atom and other atoms bound directly to it in the molecule.

The method also facilitates the evaluation of the isotopic exchange equilibrium constants for complex molecules and simple systems for which there is insufficient spectroscopic data from which to make exact calculations. Thus the temperature coefficient of the O^{18} paleothermometer, CO_3 =- H_2O , PO_4 =- H_2O , etc., exchange is readily evaluated in good agreement with experiment.

Frequencies and Intensities in the Vibrational Spectra of Deuterium-Substituted Benzenes

The vibrational spectrum of benzene has been a subject of continuing interest for many years, since it yields valuable information about the structure, intramolecular forces, and bond moments and polarizabilities of this important molecule. Both frequency and intensity measurements have been made for benzene and some of its deuterium derivatives, notably by Ingold et al., Langseth and Lord, and Whiffen et al. The development of high-speed digital computers has made feasible normal coordinate treatments of molecules previously intractable because of their size and lack of symmetry. This is the case for some of the less symmetrical deuterium-substituted benzenes, and this molecule presents an excellent example for such machine computation. For example, the symmetry of benzene makes it possible to factor the vibrational secular determinant into blocks, the largest of which is 4 rows by 4 columns. But for 1,2,4-benzene- d_3 the symmetry is so low that the secular determinant contains a block 21×21 in size. The evaluation of this determinant with a desk calculator would require man-years of work. The digital computer used for this work was the Univac at the New York University Computing Facility. The general machine procedure and coding used in this problem had been developed previously, and were carried out by the personnel of the Computing Facility.

The coordinate system generally used in setting up the secular equation of motion in such a problem is a set of symmetry coordinates. Each of these is expressed as a function of internal coordinates such as bond stretches, and changes in interbond angles. Unfortunately, the machine code is such that this type of coordinate does not lead to a secular equation of the correct form for solution. Instead, a transformation is required which leads to a secular equation in terms of mass-weighted Cartesian coordinates. This transformation, together with internal force constants previously obtained, and suitable molecular parameters, permits the machine calculation of the desired vibrational frequencies. Simultaneously, the calculation yields data which describe the motion of each atom in each fundamental vibration. This information is used for the intensity calculations.

The results of the machine computation may be summarized as follows. From the observed frequencies and intensities obtained from a few of the most symmetric molecules, frequencies and intensities may be calculated for all the isotopic species. Where a comparison is possible, the calculated results are in good agreement with observations. In some cases there are indications that new spectroscopic investigations are in order.

The calculated frequencies may be examined in light of the isotopic sum rule discussed in the preceding section. In the present case this may be stated in the form

$$6\sum_{k}\omega_{k}^{n}(C_{6}H_{x}D_{y})=x\sum_{k}\omega_{k}^{n}(C_{6}H_{6})+y\sum_{k}\omega_{k}^{n}(C_{6}D_{6}).$$

A general relationship of this type with n=2 can be derived from the theory of small harmonic vibrations. Empirically the rule with n=1 has been found applicable to all molecules for which there are enough spectroscopic data to test it; however, no general proof has been found. In the case of the deuterated benzenes, where for many of the compounds the sum rule cannot be tested empirically, the linear rule, based on calculated frequencies obtained from an experimentally determined potential function, has been found to be accurate to 1 part in 10,000. Even more striking is the agreement to about 1 part in 100,000 for the sums of frequencies for isotopic isomers; e.g., ortho-, meta-, and para-benzene- d_2 , despite the fact that the differences in individual frequencies are orders of magnitude larger. While the reason for this agreement is not clear, it seems that it may be influenced by the choice of force constants and particularly by the neglect of interactions between nonbonded atoms.

From the calculated frequencies, partition functions, Q, may be computed for the various isotopic species. These are found to obey the rule of the geometric mean, e.g.,

$$Q(C_6H_5D)/Q(C_6H_6) = Q(C_6H_4D_2)/Q(C_6H_5D).$$

Also, the ratio of partition functions for C_6H_5D and C_6H_6 may be obtained from experimental data for isotope exchange constants which are available in the literature. These give an experimental value of the partition function ratio, $(s/s')f=10.9_6$ at 25 °C, in good agreement with the spectroscopic value of 11.25.

Isotopic Effects in Reaction Rates

There are two important factors that contribute to the discrimination of isotopes in the rates of chemical reaction. They are the isotopic fractionation, due to zero-point energy effects, between the substrate and the activated intermediate, often called the transition state or activated complex,

and the relative frequencies with which two isotopic activated complexes vibrate in the appropriate mode to lead to the reaction products. The latter factor has in the past been estimated in many cases by the assumption that it is equal to the ratio of frequencies with which a critical coordinate between two atoms is exceeded in the two isotopic molecules. This procedure represents the admixture of the N.B. Slater theory of unimolecular reactions with the transition state theory. A recent analysis of this process indicates that it would seem preferable to define the critical coordinate as the distance between the centers of gravity of the two fragments in the transition state which become the reaction products. To describe the decomposition of the transition state into the reaction products, a further restriction must then be added, i.e., that the internal coordinates within each fragment must remain essentially constant. The molecular fragment treatment leads, in general, to a much smaller contribution to the isotope effect from the rate of crossing the potential barrier than the Slater coordinate.

In the case of intramolecular isotope effects, comparison of theory and experiment shows that the use of the Slater coordinate to evaluate the frequency ratio factor is almost sufficient to explain the observed results. One would therefore conclude that the zero-point energy effect in the transition state from two nonequivalent isotopic isomers is rather small. The latter factor can now be estimated through a more reliable method based on the extensions of the method of the first quantum correction recently developed. A significant contribution is anticipated from the zeropoint energy difference in the transition state. The over-all intramolecular isotope effect estimated by use of the molecular fragment coordinate and the modified first quantum correction to the zeropoint energy of the transition state is in good agreement with experiment. Essential agreement in magnitude is also obtained with the results based on the use of the Slater coordinate. However, the molecular fragment treatment predicts a small but significant temperature coefficient for intramolecular isotope effects. This suggests that experiments designed to measure the temperature coefficient of intramolecular isotope effects may be valuable in sharpening the distinction between the Slater and transition state theories of reaction rates.

APPLICATIONS OF ISOTOPES TO INORGANIC SYSTEMS

Electron Exchange Reactions in Heavy Water

The electron transfer reaction between ferrous and ferric ions in solutions proceeds through reactions of the "uncomplexed ions" and complexes of the ferric ion with anions. The specific rate constants for reaction of the halide ion complexes of ferric ion with ferrous ion are of the same order of magnitude, and are within an order of magnitude of that for the reaction of "uncomplexed" ferric ion. The reaction of FeOH+2 is unique and is 1000-fold faster than that of the halide complexes. To test the hypothesis of a hydrogen atom transfer mechanism in the FeOH+2 - Fe+2 reaction, the rate of exchange has been measured in D_0O . The specific rate constant is lower by a factor of 2 in D₂O. A similar diminution in the rate was found for the reaction of "uncomplexed" Fe⁻³ and Fe⁺² in D₂O. If the D₂O solvent effect were much larger, it would speak unambiguously for a hydrogen atom transfer mechanism.

The exchange reaction between FeCl⁺² and Fe⁺² has now been measured in D_2O to elucidate further the role of the solvent in the rate process. To obtain the specific rate constant from the rate measurements, the complex formation constant in D_2O must be known. The latter has been studied spectrophotometrically by the method used by Rabinowitch and Stockmayer to establish the complex formation constant in ordinary water. The complex formation constant is 2.5 ± 0.1 times larger in D_2O than in H_2O . The specific rate constant for the exchange reaction between FeCl⁺² and Fe⁺² is lower by the same factor at $20^{\circ}C$.

The enhancement of the complex formation equilibrium in D_2O can be explained by the Born model for calculating the free energy of solvation of an ion. Because of the high charge, a small change in the ion radius, consistent with the difference in molar volumes between H_2O and D_2O , leads to prediction of the observed difference in complex constants between H_2O and D_2O . Considerations of a similar nature may account for the isotope effect observed in the rate measurements.

Anion Complexes of TI(I) and TI(III)

The effect of chloride, bromide, fluoride, and cyanide ions on the equilibrium adsorption of Tl(I) and Tl(III) on Amberlite IR-120(H) and

Dowex-1 chloride resins has been studied with radiothallium as a tracer. It is concluded that complexing of Tl(III) by F⁻ and CN⁻ is so weak as to be undetectable by the present method. Equilibrium constants for the chloride complexes have been derived from the anion resin measurements by the method of Coryell and Marcus. The formation constants for TlCl₂⁺, TlCl₃, TlCl₄⁻, TlCl, TlCl₂⁻, and TlCl₃⁻² are 1.1×10^3 , 1.2×10^3 , 3.3, 2.9, 0.33, and 0.13, respectively. The constant for TlCl₃⁻² has not been previously determined. Most of the other constants are in substantial agreement with the values obtained by independent methods.

Nondestructive Testing of Ancient Ceramic Objects Through Neutron Activation

As a continuation of the program of correlating the pattern of trace impurities in archaeological objects with their geographic region of origin, a study has been made of the extent to which the analysis of such objects could be performed nondestructively. It was shown that when the analysis was based upon the observation of gamma-ray activity induced in the object through neutron activation, identical results were obtained whether the entire object was irradiated and counted or whether a small sample of it was removed, irradiated, and counted. In some cases a large object was covered with a cadmium shield except for a small area exposed to irradiation. In these tests and in more extensive studies of small samples, the relative amounts of manganese, sodium, scandium, lanthanum, and chromium could be determined quantitatively in ancient ceramic objects without resorting to chemical separation or other destructive procedures.

Upon investigation of some Roman pottery fragments and of some Mayan bowls and bowl fragments from Guatemala, marked similarity was observed in the relative concentrations of all these constituents in objects thought to be produced in the same region, while the pattern of concentrations was different in objects produced in different regions.

After sufficient irradiation to obtain this information, the objects possessed some activity which would persist noticeably for several years. This residual activity, resulting principally from europium, cesium, iron, and cobalt, could easily be kept down to the range of a few microcuries by use of the protective cadium shields.

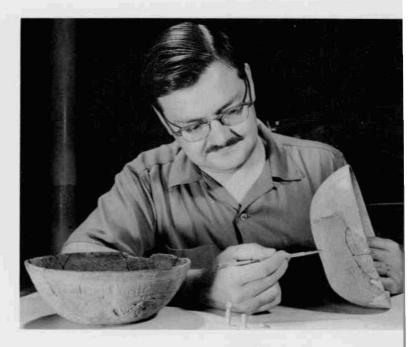


Figure 7. Sampling of ancient Mayan bowls for neutron activation analysis. The need for sampling has been eliminated in more recently developed methods.

Sufficient investigation has been made of specimens of ancient glass to reveal that similar information can be obtained about this material. However, no extensive correlation of glass analysis with region of origin has yet been observed.

MASS SPECTROMETRY

Research in mass spectrometry has been concentrated on problems of high sensitivity technique suitable for nuclear and geochemical studies. These problems generally require spectrometers free of background ion current and capable of detecting currents generated from samples as small as 10^7 atoms. In addition, separation procedures are needed which permit isolation of traces of sample from bulk targets with a minimum of contamination by naturally occurring nuclides of the product element.

Two spectrometers have been equipped with secondary emission electron multiplier detectors sensitive to ion currents of the order of 10⁻¹⁸ amp. One has been set up to determine the isotopic composition of rare gases in meteorites and rare gas products of high energy nuclear reactions. This mass spectrometer tube is fabricated from glass

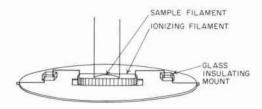


Figure 8. Sketch of double filament ionization source.

and can be completely baked at a temperature of 400°C. It is fitted with an electron impact type of ion source. Ultrahigh vacua of the order of 10⁻¹⁰ mm Hg are obtained by isolating the tube with metal high vacuum valves and pumping with an ionization gauge. Backgrounds achieved in this way correspond to less than 10⁸ atoms of rare gas.

Surface ionization techniques which do not require the ultrahigh vacua necessary for high sensitivity work with an electron impact source have been investigated with a second spectrometer. A double platinum filament ionization source (Figure 8) has been developed which permits the analysis of $10^8 \pm 5 \times 10^6$ alkali metal atoms in the presence of much larger quantities of undetermined impurities. This technique has been used for the measurement of cesium concentration in stony meteorites to obtain a measure of the cosmic abundance of cesium. A recent estimate by Suess and Urev has indicated a value 0.4 parts of cesium per million parts of silicon. Results of isotope dilution studies on the Holbrook meteorite, which has been shown to have sodium and potassium concentrations typical of a large number of chondrodites, gave a value of 0.39 parts of cesium per million parts of silicon, in good agreement with Suess and Urey's cosmic abundance vs mass curve. Studies on the Beardsley and Pasamonte meteorites, representing cases of extreme concentration and depletion of alkali metals, gave 0.82 ppm for the former and 0.09 ppm for the latter.

Surface ionization techniques have been used to determine the yields of cesium, barium, and rubidium nuclides produced by irradiation of gold targets with 3-Bev protons from the Brookhaven Cosmotron. Isotope dilution studies on reagents and gold targets with 9.7-day Cs¹³¹ as an isotope diluent indicated an over-all contamination level of stable Cs¹³³ in the target and reagents of 9×10⁹ atoms. The purest water obtainable after triple distillation from a quartz still was assayed at

 2×10^8 atoms of Cs per ml. The mass spectrometer studies showed that no cesium isotopes with A>128 were produced in appreciable independent yield by the irradiation. An upper limit of 0.002 mb was placed on cross sections for production of Cs¹³² and the neutron excess cesium isotopes, Cs¹³⁴ through Cs¹³⁷. The results were consistent with other radiochemical data and indicated that assumptions based on radiochemical data obtained from interpolated yields of long-lived and stable nuclides were valid.

CHEMICAL EFFECTS OF RADIATION

Hydrocarbons Adsorbed on Solids

An investigation of the radiation chemistry of hydrocarbons adsorbed on solids was prompted by an interesting hypothesis in the literature concerning a possible origin of natural gas. Calculations indicated that the amounts of radioactivity found in oil source bedrocks are sufficient to cause considerable cracking of the oil during geologic time. However, the gaseous products of laboratory radiolysis of hydrocarbons or other organic substances present in sediments always contain very high ratios of hydrogen to methane, while most natural gases contain little or no hydrogen. This suggested that the products of radiolysis might be different when the organic matter is highly dispersed and adsorbed on a mineral support.

Pentane was chosen for these studies since it is both easily dispersed on the solid and easily removed from it. Powdered silica with particle sizes of 100, 62, and 0.02 μ , silica gel, attapulgite, montmorillonite, and ferric oxide were used as solid substrates.

In Figure 9 the hydrogen yield (expressed as molecules per 100 ev adsorbed in the system of n-pentane and powder) is given as a function of the amount of n-pentane on the solid. If the solid acted only as an inert diluent, the theoretical curve would be expected. The curves for the $0.02-\mu$ silica and the silica gel lie well above this curve, whereas the iron oxide and the attapulgite show a negative effect. Methane yields are lower on $0.02-\mu$ silica and montmorillonite and higher on ferric oxide than would be expected for an inert diluent. These results indicate a probable interaction between the pentane and the solid phase.

The effect of the various solids on the ratios of products heavier than methane is shown in Figure

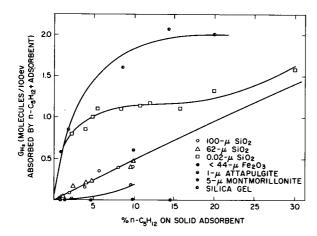


Figure 9. Hydrogen yields, $G_{\rm H_2}$ (molecules per 100 ev absorbed by n-pentane + adsorbent), versus the weight percent of n-pentane in the solid adsorbent-pentane mixture.

10. A particularly striking effect is the great increase in the iso-C₄ fraction caused by the presence of montmorillonite or ferric oxide. In all cases the solid phase appears to have altered the product distribution significantly.

The effect of the silica and silica gel on the $\rm H_2$ yield is greatest at the pentane concentration corresponding approximately to a unimolecular layer of pentane on the solid. Additional pentane beyond this seems to inhibit the process.

Work on the radiolysis of heterogeneous systems is being continued and is expected to yield additional interesting results in the near future. In view of the present results, it is not unreasonable to suppose that the bedrock of oil sources could have a great influence on the methane to hydrogen ratio in natural gas and might possibly account for the small amount of H₂ actually found in the gas.

Homogeneous Organic Systems

The investigation of several organic systems, including acetone and tetrahydrofuran, has been started this year. The photochemistry of acetone is well known; therefore a study of its radiation chemistry is quite interesting. So far most of the major products have been identified. They are given here with their approximate yields (molecules per 100 ev) in parentheses: hydrogen (1.1), carbon monoxide (1.0), methane (2.4), ethane (0.5), methyl ethyl ketone (1.3), 2,5-hexanedione (0.7), and acetic acid (yield unknown). There were

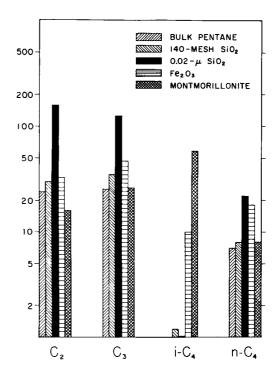


Figure 10. Hydrocarbon yields relative to i-pentane (100).

a few other very minor products which have not been identified. However, the following are definitely shown to be absent: biacetyl, ethylene, 2,4-pentanedione, aldehyde, ketene, formic acid, and water. As yet there is a lack of material balance, and there is not enough information of a kinetic nature to suggest a mechanism. The principal surprise in this system would seem to be the absence of biacetyl, since it is quite important in the photolysis.

The radiolysis of tetrahydrofuran is of interest since it is a cyclic analogue of diethyl ether, which has been studied in other laboratories. A relatively complex product spectrum was found, but particularly noteworthy was the large yield ($G \approx 0.5$) of cyclopropane. This could, in principle, be produced by the elimination of formaldehyde from the parent compound. Formaldehyde does not appear as a product, however, although it is possible that it is subsequently used up in secondary reactions. The cyclopropane may, on the other hand, be formed initially as the diradical which could go either to cyclopropane or to propylene, which is also found as a product. Cyclopentane, the hydrocarbon analogue of tetrahydrofuran, produced only a small amount of cyclopropane.

Aqueous Systems

In aqueous solutions marked variation in product yields has been observed as the ionization density of the radiation is changed. The water decomposes to give H atoms and OH radicals. These radicals are formed inhomogeneously along the track of the ionizing particle, and, as they diffuse out into the bulk of the solution, there is a high probability that they will react together to form hydrogen, hydrogen peroxide, and presumably water. As the particle energy of the radiation is lowered, the ionization density increases, the radicals are formed closer together, and the probability of combination increases.

The Brookhaven 60-in. cyclotron offers a means of conveniently and continuously varying the ionization density of the radiation. The 20-Mev deuterons and 40-Mev helium ions provide a very interesting energy region for radiation chemistry studies, being intermediate between fast electrons and natural alpha radiation.

Previous studies with cyclotron beams have been confined to 0.8~N sulfuric acid solutions. However, unexplained differences between the radiation chemistry of acid and neutral water solutions have made desirable a study of the radiolysis of neutral water systems at the cyclotron. By studying product yields in various aqueous solutions, the yields of H_2 , H_2O_2 , H, and OH can be determined for each particle energy.

Some of the results are given in Table 2. The rate of energy loss of the ionizing particle is -dE/dx. The observable water decomposition yield, that is $2G_{\rm H_2} + G_{\rm H}$, is $G_{\rm -H_20}$. This value should decrease as -dE/dx decreases according to the diffusion model, since more radicals are combining to form nonobservable water. It does decrease down to 33-Mev helium ions, but increases again for 5.3-

Table 2

Product Yields in the Radiolysis of Water for Different Radiations

Radiation	$G_{{ m H}_2}$	$G_{{ m H_2}{ m O_2}}$	$G_{\rm H}$	$G_{ m o H}$	$G_{ m -H_2O}$
Co ⁶⁰ gamma-ray	0.45	0.70	2.8	2.3	3.7
18-Mev deuteron	0.70	0.99	1.6	1.0	3.0
33-Mev helium ion	0.93	1.03	0.95	0.75	2.8
12-Mev helium ion	1.14	1.15	_		
5.3-Mev alpha (Lefort)	1.8	1.4		_	> 3.6

Mev alpha-particles, which might indicate that a new process is becoming important. It is difficult to believe that changes in the primary process are setting in at this energy. This increase probably represents a correlation in the initial positions of the H and OH radicals. In high energy (low density) tracks these radicals will tend to recombine to form water. In low energy (high density) tracks the over-all radical density is higher, and the probability of the original radical partners recombining is decreased. This results in an enhanced yield of H_2 and H_2O_2 .

In the region from 33-Mev helium ions on up, the yields agree very well with predictions based on the radical diffusion model. Work has also been done on concentrated solutions of solutes reactive towards H atoms and OH radicals. These solutes affect the H_2 and H_2O_2 yields in a manner that agrees well with the model.

The difference between neutral and acid solutions has been heightened in this work. With Co⁶⁰ gamma-rays the $\rm H_2$ yield was about 10% lower in acid than in neutral solution. The two exhibit the same behavior with 18-Mev deuterons, but the difference in $\rm H_2$ yield is reversed with 33-Mev helium ions, acid solutions giving a 15% higher yield. No satisfactory explanation for this has been developed.

CHEMICAL EFFECTS OF NUCLEAR TRANSFORMATIONS

Theoretical

A theoretical study has been made of the chemical effects of nuclear recoil in solids. A model based upon the Seitz and Koehler treatment of the slowing-down of energetic atoms has been proposed: in this treatment the atom loses its final few hundred ev of energy by a succession of hard-sphere elastic collisions. Of the energy lost by the recoil atom, approximately one half is effective in producing interstitial-vacancy pairs, at an expenditure of about 25 ev per pair in well-bound solids. The rapid loss of energy by collisions having a relatively small separation results in heating a small zone of the crystal momentarily to a high temperature. Such a zone has been termed a "displacement spike." The proposed model postulates that specific chemical reactions (for example exchange, free radical recombination, substitution, isomerization, dissociation) involving the recoil atom can occur during the lifetime of the hot zone, and equations are given to indicate how the probability of such processes might be calculated.

Isotope Effects in the Szilard-Chalmers Reaction

An experimental study has been made of the hot-atom chemistry of bromine in the crystalline alkali bromates. Both Br⁸⁰ (4.6-hr half-life) and Br⁸² (36-hr half-life) were followed, and large differences in the retentions of the two isotopes appeared upon thermal annealing of the crystals. Of all the salts studied, only lithium bromate exhibits anomalous behavior in the distribution of recoil bromine atoms among the different possible oxidation states.

Differences in the behavior of different isotopes of the same element were found in another hotatom study. When organic media containing iodine atoms (n-propyl iodide and solutions of iodine in cyclohexane) are irradiated with neutrons from a cyclotron, both fast and slow neutron reactions occur, the former yielding I¹²⁶ (13-day half-life) and the latter I128 (25-min half-life). Thus a direct comparison could be made between the total organic yields of the two isotopes in the same solution. It was found that yields of I126 and I128 were identical in the *n*-propyl iodide but considerably different in the iodine-cyclohexane solutions, the I126 showing greater probability of entering organic combination. This was attributed to the more extensive reaction of iodine atoms with a larger fragment background in the I126 case.

Recoil Triton Reactions

Some studies have also been made of the reactions of recoil tritons with gaseous methane. The tritons were produced alternatively by the $He^3(n,p)$ or $Li^6(n,\alpha)$ reaction. The products observed were HT, CH₃T, C₂H₅T and C₂H₃T, C₃ compounds, and higher hydrocarbons. The results indicated that under all conditions of irradiation (high and low neutron fluxes and even with added iodine vapor as a radical scavenger) the yield of CH₃T was roughly constant (26 to 31%). However, the yield of HT depended upon the radiation (neutron plus gamma) level. When iodine was added, the yield of HT and C2 and C3 tritiated hydrocarbons dropped sharply, and tritiated alkyl iodides were formed. It has been possible to account for some of these results by invoking a mechanism of hot reactions, which produce most of the CH₃T and HT, and thermalized reactions, which are sensitive to iodine scavengers.

ORGANIC CHEMISTRY

Organic Reaction Mechanisms

The effect of acidity and carbinol structure on the acid-catalyzed O18 exchange rate between several tertiary carbinols and the aqueous medium has been investigated in order to provide additional detailed information on the mechanism of carbinol-olefin interconversion. It was recently shown that the rate constant for the O18 exchange of t-butyl alcohol with 0.45 M H₂SO₄ at 55° is 27 times greater than the rate constant for the formation of isobutylene from t-butyl alcohol under the same conditions. If it is assumed that the mechanism of O18 exchange proceeds by a reaction sequence which is common to that of the carbinololefin interconversion, this result demonstrates the existence of a reactive intermediate preceding the rate determining step in the elimination reaction to form olefin. Evidence from the dependence of rate on acidity and on the structure of the carbinol indicates that the mechanisms of the O18 exchange and the carbinol dehydration reactions do in fact involve common steps.

$$ROH + H_3O^+ \underset{\text{fast}}{\overset{K_b}{\rightleftharpoons}} ROH_2^+ + H_2O \tag{1}$$

$$ROH_2^+ \underset{k_L}{\overset{k_1}{\rightleftharpoons}} R^+ + H_2O \tag{2}$$

$$R^+ + H_2O \underset{k_4}{\overset{k_3}{\rightleftharpoons}} olefin + H_3O^+$$
 (3)

Step k_1 is proposed as the rate determining step for the O^{18} exchange, while k_3 is the rate determining step for the elimination reaction. R^+ is a carbonium ion intermediate or an intermediate such as $H_2O...R^+...OH_2$ which has appreciable carbonium ion character.

Biosynthesis of Nicotine

Previous work on the biosynthesis of nicotine carried out in collaboration with the Botany Department of Columbia University indicated that nicotinic acid was a precursor of the pyridine ring of nicotine. It was therefore of interest to determine the specific point of attack on the pyridine ring during the biosynthetic process. To this end, the specifically labeled 2-, 5-, and 6-tritio-nicotinic

acids were prepared, to be supplied to sterile tobacco root cultures for the study of their precursor activity. The methods of preparation are given in Equations (1) to (3) below.

$$\begin{array}{c|c} CH_3 & CH_3 \\ \hline \\ Br & \hline {1. \, C_4 H_9 Li} \\ \hline \\ & N & T \\ \end{array} \begin{array}{c} CH_3 \\ \hline \\ & KMnO_4 \\ \hline \\ & N & T \\ \end{array}$$

$$\begin{array}{c} \text{COOH} \\ \hline \\ \text{COOH} \end{array} \xrightarrow{\text{HTO}} \begin{array}{c} \text{COOT} \\ \hline \\ \text{COOT} \end{array} \xrightarrow{\begin{array}{c} 1. \ \Delta \\ \hline \\ \text{H}_2\text{O} \end{array}} \begin{array}{c} \text{COOH} \\ \hline \\ \text{N} \end{array}$$

$$\frac{Br}{\frac{1. C_4H_9Li}{2. HTO}} \xrightarrow{T} \frac{KMnO_4}{N}$$

$$\begin{array}{cccc}
T & COOH & T & COOH \\
& & \Delta & & \\
N & COOH & & N
\end{array}$$
(2)

$$\begin{array}{c} CH_{3} \\ Br \end{array} \xrightarrow{\begin{array}{c} CH_{3} \\ \hline 2. \ HTO \end{array}} \begin{array}{c} CH_{3} \\ \hline T \end{array} \xrightarrow{\begin{array}{c} CH_{3} \\ \hline \end{array}} \begin{array}{c} COOH \\ \hline \end{array}$$

The 4-deutero acid was prepared as indicated in Equation (4).

$$CI CH_3 \xrightarrow{D_2SO_4} \xrightarrow{D_2SO_4} \xrightarrow{KMnO_4} \xrightarrow{COOH}$$

$$(4)$$

Each of these compounds was supplied to the root cultures under appropriate standard conditions. The feedings of the 2- and 5-labeled acids gave radiochemical yields in the range of 10 to 15% after 15 to 20 days of growth. The radiochemical yield increased exponentially with length of feeding during the first 115 days in a manner parallel to the growth of the roots. In marked contrast, the 6-labeled acid showed very low incorporation (less than 1% in all cases) into the nicotine produced in the plant. This is a clear indication of chemical attack on this position during the biosynthesis process. It might be suggested that this is due to reversible pyridone formation at the 6 position by a particular enzyme system. Feeding results for the 4-deutero acid are not yet available.

Carbon-14-labeled ornithine, shown by other workers to be the probable precursor of the pyrrolidine ring of nicotine, was fed under similar conditions and also gave radiochemical yields of the order of 15%.

In an investigation on anabasine formation it was shown that the 2-tritio acid was incorporated in the anabasine molecule. It was also shown that carbon-14-labeled lysine was incorporated in the piperidine ring in anabasine in agreement with the results of other workers.

Further studies are being undertaken to attempt to find precursors of nicotinic acid in to-bacco plants, since the usual pathway through tryptophan and anthranilic acid does not appear to hold in this case.

Carbon-14 Recoil Studies

As part of a continuing study of the mechanism and applications of the recoil method of labeling, further investigations of aromatic systems have been undertaken. It had been shown previously that the synthesis product, toluene, was produced by the irradiation of benzene in admixture with 2-methylpyrazine as the nitrogen source. In the present work toluene was irradiated in admixture with 2-methylpyrazine as the nitrogen source and with the xylenes and ethylbenzene added as carriers. Extensive purification by fractional distillation and by gas-liquid chromatography gave samples of these compounds which were radiochemically pure. The results are listed in Table 3. It is to be noted that the xylenes were not formed in a direct statistical relation to the number of

Table 3

Toluene + 2-Methylpyrazine

	Radiochemical yield, %	Specific activity, mμC/mg C	Replaceable hydrogens
Toluene	1.99	0.133	
o-Xylene	0.96	0.274*	2
m-Xylene	1.35	0.220*	2
p-Xylene	0.46	0.135*	1
Ethylbenzene	0.85	0.122*	3

^{*}Carrier material.

hydrogens available for replacement. A marked deviation from a statistical result also obtains in ethylbenzene. The high yield of m-xylene (the thermodynamically most stable xylene) may support the hypothesis that the intermediate in the labeling process has a sufficient lifetime to allow establishment of partial equilibrium between the isomers before collapse to the final product occurs. The low yield in replacement of methyl hydrogens indicates a clear preference for aromatic hydrogen substitution over side chain aliphatic hydrogen substitution.

Degradation of the re-entry product, toluene, and the synthesis products, o-xylene and ethylbenzene, gave the results indicated in Table 4. This supports the evidence obtained in the acetamide system and presented in an earlier report. In reentry products (e.g., labeled toluene from toluene, and labeled acetamide from acetamide) where

random replacement would be expected on statistical grounds, such randomness is not observed. Indeed the activity in the methyl group is 23% lower than expected for random replacement. In the synthesis products, o-xylene and ethylbenzene, where specific labeling might be expected, some smearing of the label is observed. It is, however, of interest to note that in this system more of the activity is found in the expected position than was found in the expected position in propionamide obtained from acetamide (CH₃—CH₂—COOH; 52%, 24%, 24%, respectively, after hydrolysis).

The significance of these degradations in relation to the use of the recoil method for labeling purposes is clear. The user of these compounds for trace purposes must be aware, insofar as one can generalize from available evidence, that neither random labeling nor specific labeling is found in those cases where such labeling might be expected. The deviation from a statistical distribution again emphasizes the contention that chemical mechanisms are operative in deciding the positional fate of the carbon-14. A purely statistical picture for atom replacement is not tenable.

These results closely parallel those reported for the synthesis product, toluene, obtained from benzene. A possible mechanism in this case is the reversible formation of the cycloheptatrienylium (tropylium) ion. Sufficient energy for such a reaction is probably available, since theoretical considerations indicate an energy of about 50 ev associated with the region in which the motion of the carbon-14 becomes diffusive. Another possible mechanism would be the formation of a

Table 4

Activity Distribution in Products from Toluene Irradiation

	Toluene		o-Xylene		I	Ethylbenzene		
		—— CH ₃		CH ₃		— CH₂—	——СН _з	
% Calculated	85.7	14.3*	0	100	0	0	100	
% Found	89	11	15	85	7	13	80	

^{*}If completely random.

"hot" labeled methylene radical. Attack on benzene would lead to norcaradiene which can then ring open to cycloheptatriene. Rearrangement of ring hydrogens followed by reversal of each step will ultimately lead to labeled toluene. The degree of labeling by position in toluene produced by this mechanism might be different from that in toluene resulting from the tropylium ion intermediate, and might thereby serve as a test of these mechanisms.

STRUCTURAL CHEMISTRY

Molecular Orbital Calculations

In a gas composed of non-dipolar molecules, the quadrupole moment of the individual molecule plays a large role in determining intermolecular interactions. Workers in other laboratories have recently obtained experimental values for the quadrupole moment of carbon dioxide from measurements of the dielectric constant, the temperature dependence of the second virial coefficient, and the microwave collision diameter. For purposes of comparison a calculation of the quadrupole moment has been carried out by use of the purely theoretical molecular orbital description of the molecule given by Mulligan. The value obtained agrees reasonably well with the values derived from the dielectric constant and second virial coefficient but not with that derived from the microwave collision diameter.

A tabulation of especially simple formulas for the molecular integrals involved in the calculation of dipole moments from molecular orbital wave functions has been prepared.

Infrared Spectrum and Force Constants of the Nitrite Ion

The infrared spectrum of the nitrite ion has been investigated with the use of N¹⁵-labeled NaNO₂, KNO₂, and AgNO₂. This work is a continuation of the determination of force constants in small molecules and is quite analogous to the previously reported work on nitrogen dioxide.

Vibrational frequencies of the nitrite ion in crystals and in aqueous solution were measured with a Perkin-Elmer Model 21 spectrometer. From these measurements the frequency assignment of Table 5 may be made. While the data are given for crystalline NaNO₂, those for KNO₂ and AgNO₂ are very similar to these, as are the

Table 5 $\label{eq:table 5}$ Vibrational Frequencies of NaN $^{14}O_2$ and NaN $^{15}O_2$

	Frequency, cm ⁻¹			
Vibration	N ¹⁴	N^{15}		
$v_1(a_1)$	1328 ±2	1303 ±2		
$v_2(a_1)$	828.2 ± 0.4	823.6 ± 0.4		
$v_3(b_1)$	1261 ± 3	_		
$\nu_1 + \nu_3(B_1)$	2548 ± 3	2513 ± 6		

frequencies for solutions. This assignment differs from some of the previous infrared investigations but is in good agreement with Raman spectra of aqueous solutions.

From these data values may be calculated for the complete set of valence force constants: f_d , the N—O bond-stretching constant; f_a/d^2 , the constant for deformation of the interbond angle; f_{dd} , that for simultaneous stretching of both bonds; and f_{da}/d , that for simultaneous bond stretching and angle deformation. The values of these are given in Table 6. As in the case of NO₂, the large value of f_{dd} can be attributed to resonance interactions arising from such structures as O—N=O, O=N—O⁻; or alternatively, it may result from repulsion between the oxygen atoms.

At about 160° there is a change in the crystal structure of sodium nitrite, and x-ray diffraction data indicate that the N—O bond is about 20% longer than it is at room temperature. If this is true, one would expect a large change in the force constants and hence in the vibrational frequencies. However, no change in the position of either the $\nu_1 + \nu_3$ band or the ν_2 band was noted at temperatures as high as 200° . This makes it difficult to accept such a large change in bond length as the x-ray work indicates.

Neutron Diffraction Studies

Extinction Effects. Increased use of single crystals rather than crystal powders in neutron diffraction investigations has stimulated a detailed examination of extinction effects. In the simplest approximation, the intensity diffracted from a crystal is proportional to its volume. If the crystal is large enough, loss of intensity in the incident beam due to the diffraction process itself causes this approximation to become invalid. This behavior is known

Table 6
orce Constants for Nitrite Ion stalline NaNO2) in Millidynes/A

f_d	7.69 ± 0.10
f_{α}/d^2	1.75 ± 0.04
f_{dd}	1.94 ± 0.13
$f_{d\alpha}/d$	0.505 ± 0.113

as extinction and may be conveniently considered as two separate effects, primary and secondary extinction, depending on whether the effect is coherent or incoherent. Previous treatments have been carried out only for infinite flat crystal plates, an ideal crystal shape which is only rarely realized even approximately in actual diffraction experiments. A numerical procedure has been set up for determining the secondary extinction coefficient for arbitrarily shaped crystals, and values of this coefficient have been calculated for cylindrical crystals and rectangular crystals of various dimensions. If the secondary extinction is severe, the extinction coefficients become markedly dependent on the Bragg angle for all crystals, and on the orientation of the crystal relative to the incident beam for less simply shaped crystals.

Interesting extinction effects occur when neutrons are scattered from magnetic materials. In calculating the extinction coefficients for magnetic reflections the two directions of neutron polarization must be treated separately. Such a treatment leads to the following conclusions. 1) In both magnetized and unmagnetized crystals, mixed nuclear and magnetic reflections will suffer more from primary extinction than will either pure nuclear or pure magnetic reflections. 2) In magnetized crystals, reflections with magnetic contributions will also be more seriously affected by secondary extinctions than will pure nuclear reflections. 3) An examination of these two effects for a particular crystal allows a clear-cut separation to be made between the amounts of primary and secondary extinction present. From this information good estimates can be obtained of both the mosaic block size and mosaic spread in the crystal. 4) Precession of the neutron spin in a magnetized sample which exhibits severe extinction gives rise to a periodic rise and fall of intensity as a function of the internal magnetic field. A method is thus

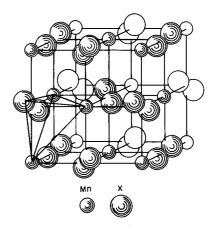


Figure 11. Structure of pyrite.

provided for measuring this internal field as a function of the external field.

Antiferromagnetic Structures of MnS2, MnSe2, and $MnTe_2$. Previous work on the polymorphic forms of MnS has shown some interesting correlations between the observed magnetic structures and the notion of an indirect exchange coupling mechanism. In an effort to extend this correlation, an investigation of MnS₂, MnSe₂, and MnTe₂ was undertaken. These materials crystallize with the pyrite structure shown in Figure 11. The structure is a NaCllike arrangement of M and X2 groups, with the axes of the X2 groups parallel to the various body diagonals. A salient feature of the structure is the presence of nearly regular tetrahedra whose corner positions are occupied by three metal atoms and one member of an X2 group, and whose center is occupied by the other member of the X₂ pair. All three compounds become antiferromagnetic at temperatures near that of liquid nitrogen or below. Neutron diffraction patterns, obtained at liquid helium temperatures, show well developed magnetic superlattice lines. The magnetic structures deduced from these patterns are shown in Figure 12. Table 7 further characterizes the observed magnetic structures in terms of nearest and nextnearest neighbor arrangements. In MnS2 the original chemical unit cell must be doubled in one direction to obtain the magnetic unit cell. In MnSe₂ the unit cell has to be tripled in one direction, while in MnTe₂ it is the same as the chemical one. It is seen from the table that all three compounds, despite the variation in magnetic structure type, have the same nearest-neighbor distribution.

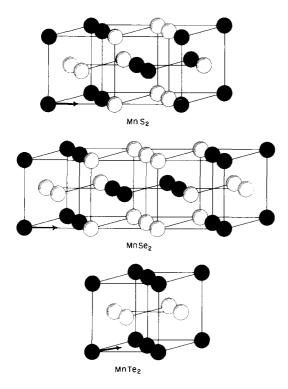


Figure 12. Antiferromagnetic structures of MnS₂, MnSe₂, and MnTe₂. Only the metal atoms are shown. The magnetic moment direction is indicated by an arrow, and the black and white spheres represent moments parallel and antiparallel to this direction.

This distribution can, perhaps, be explained on the basis of the aforementioned (Mn₃X)—X tetrahedra which would favor nearest-neighbor coupling if one invokes an indirect exchange mechanism utilizing the nearly tetrahedral Mn—X—Mn linkages. However, there does not seem to be any obvious explanation for the difference in the actual structure types which are observed.

Homogeneity and Phosphorescence of Solutions at Low Temperatures

The degree of homogeneity of solutions fluid at liquid nitrogen temperature which contain both polar and nonpolar molecules has never been investigated. Possibly the solutions are sharply inhomogeneous and consist of "icebergs" of the polar constituent in a "sea" of the nonpolar solvent. Indication of the microviscosity within the "icebergs" was sought by means of the phosphorescence of an organic substance in the mixed solvent of such chemical character that it was soluble in the pure polar but not in the pure nonpolar solvent.

It is well known that many organic substances phosphoresce in solution, provided that the latter is in a rigid form, as in a glass. Softening of the glass eliminates the phosphorescence. Hence, if the organic substance (when in a mixed solvent at the temperature of liquid nitrogen) is really embedded in a rigid "iceberg," it would phosphoresce even though the solution as a whole were mobile.

When the indole derivative 5-hydroxytrypt-amine was dissolved in ethanol to which a small quantity of methanol was added to produce a clear glass at liquid nitrogen temperature, a strong phosphorescence could be produced at this temperature. In contrast, the same concentration of hydroxytryptamine present in a clear mobile solution containing 20% ethanol in equal proportions of propane and propene, showed no phosphorescence at liquid nitrogen temperature. The viscosity of the solution was then increased by replacing the hydrocarbons with more and more ethanol. With increase in viscosity, phosphorescence became visible. A solution which contained 50% ethanol in the same hydrocarbons was so viscous at liquid nitro-

				Table 7		
Compound		neighbor oution*	Next-neares distrib	<u> </u>	Spin direction	Ordering type
MnS_2	8↑↓	4↑↑	2↑↓	4↑↑	Parallel to unique axis†	Third kind
\mathbf{MnSe}_2	8↑↓	4↑↑	² / ₃ {2↑↓ ¹ / ₃ {0↑↓		Parallel to unique axis†	Mixed
$MnTe_2$	8↑↓	4↑↑	011	6↑↑	In ferromagnetic sheets	First kind

^{*}The distribution of Mn neighbors about any Mn atom.

[†]The axis along which the original chemical unit cell is enlarged.

gen temperature that it required several minutes for the meniscus to flow and adjust itself to the horizontal after an inclined tube containing the solution was rotated 180°. This solution, containing the same concentration of hydroxytryptamine, phosphoresced with an intensity about one third of that emanating from the ethanol glass.

High macroscopic viscosity is then required also in these systems before the microscopic viscosity is sufficiently high to permit phosphorescence, that is, to achieve effective trapping of excited states.

The conclusion follows that many solutions which have been employed in the chemistry at low temperatures may be regarded as homogeneous with sufficient approximation for many purposes. However, in the extremely viscous solutions the concentration of rigid regions about the dissolved substance becomes appreciable – to an extent which probably depends also on the polar character of the solute.

Phosphorescence Spectra of Some Indole Derivatives at Low Temperatures

The phosphorescence and fluorescence spectra of indole and two of its derivatives, tryptamine and 5-hydroxytryptamine, were taken from room temperature to that of liquid nitrogen. The work of Bowman, Caulfield, and Underfriend on the fluorescence of these substances in aqueous solutions at room temperature had shown that the first two substances, as well as indoleacetic acid, had indistinguishable, structureless, bell-shaped emission with a peak at 3300 A. The fluorescence band of hydroxytryptamine had the same general shape except that its maximum was at 3500 A. In 3 N hydrochloric acid this peak had shifted to 5500 A.

We find that in addition to fluorescence, phosphorescence also appears at liquid nitrogen temperature after the substances are dissolved in a variety of solvents including water. In a solvent containing nine parts of ethanol to one part of methanol, fluorescence was found to increase in intensity as the temperature was lowered until the solution became rigid (at about 115°K). The intensity then decreased, and at the same time phosphorescence became evident and continued to increase in intensity as the temperature was further reduced.

In contrast to the lack of structure at room temperature, band structure appeared in the fluorescence at liquid nitrogen temperature. Even more detailed structure was exhibited by the phosphorescence, to a degree which permitted easy discrimination between the substances. There were, however, marked resemblances in the features of the phosphorescence spectra, which were, of course, to be related to their common possession of the indole ring.

The intensity of the fluorescence at room temperature in the yellow region depended on pH. In fact there was a distribution in the fluorescence between the blue and yellow regions which shifted in favor of the yellow with decreasing pH. In absolute alchol the hydroxtryptamine fluoresced in the ultraviolet region without addition of acid. The intensity of this fluorescence at room temperature was greater than that from the acidic aqueous solution.

Effective Symmetries of Fields About lons in Solutions

The numbers of lines within some of the groups which compose the spectrum of europium ion had furnished the point group symmetries of the fields about the ions in solutions of europic chloride. The symmetry of the fields about the ions in alchol proved to be C_{2v} and in aqueous solutions D_{2h} . Electric dipole radiation is forbidden in D_{2h} because of the presence of a center of inversion, and indeed the intensity of this kind of radiation relative to that of magnetic dipole radiation was weak, whereas both types were about equally intense in C_{2v} . Thus the replacement of some of the alchol by water brought about an abrupt change in the intensities of electric dipole radiation and left those of magnetic dipole radiation virtually unchanged. However, there were other electric dipole transitions which did not respond to such replacement of solvent. These were the strongest and at the same time rather diffuse transitions.

The absorption spectrum of gadolinium ion, also in solutions of the chloride, showed similar behavior. Some of the transitions suffered a reduction in their intensities when water replaced the alcohol, while others did not. The latter were also generally the most intense groups. It should be remembered that europium ion has an even number of electrons in the unfilled 4f shell with basic state 7F_0 , while gadolinium ion has an odd number with basic state $^8S_{7/2}$, so that their similar behaviors seem to be rather general in character. Thus the ions in some of their energy states appear

to recognize dissymmetries in their environmental fields to which other states do not respond appreciably. The half-lives of the discrete states of europium utilized for determining the symmetries are long, of the order of hundredths or tenths of seconds, so that averaging out of the dissymmetries arising from the instantaneous positions of the oscillating ions, dipoles, etc., leads to the presence of a center of symmetry. However, the more intense transitions, those having higher transition probabilities and thus shorter half-lives in their excited states, are exposed to lower effective symmetries corresponding to the more nearly instantaneous phases of the fluctuations when the environmental molecules are displaced from average positions.

The spectra of praseodymium ion in the visible and ultraviolet region are entirely electric dipole transitions and are of greater intensity in general than those of europium. The spectrum of praseodymium chloride in alcohol differed little in its intensity from that of its aqueous solution. It is, of course, also possible that the microscopic symmetry about praseodymium ion in aqueous solution is not the same as about europium, as occurs in some instances in crystals of their corresponding salts. In the systematic determinations of crystal structures of salts of the rare earth series, it has been shown that in some salts a certain symmetry will prevail for a portion of the series and then a new symmetry will set in and hold for the succeeding portion, usually to the very end of the series. Thus if a break in symmetry occurs in the series between praseodymium (atomic number 59) and europium (atomic number 63), in all probability the symmetry will then remain the same in the salts of gadolinium (atomic number 64) as in those of europium. The solutions of the two latter ions would then provide the same microscopic symmetry, and the responses of each spectrum to different effective symmetries is to be accounted for on the same basis.

Engineering

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

The research of the Nuclear Engineering Department has continued to be centered on the development of new reactor systems, or components thereof, that will further the economic development of nuclear energy. The listing of the Liquid Metal Fuel Reactor on the long-range reactor development program of the Atomic Energy Commission has resulted in increased activity. The Nuclear Engineering Department, in cooperation with the Reactor Department, has also contributed to the Brookhaven research reactor program, which includes the Medical Research Reactor, a proposed high flux research reactor, and the new fueling of the graphite air cooled research reactor.

LIQUID METAL FUEL REACTOR

On November 7, 1956, the Atomic Energy Commission signed a contract with The Babcock and Wilcox Company for the design, construction, and operation of a Liquid Metal Fuel Reactor Experiment, the LMFRE. The Laboratory's increased responsibility for the research and development directly required for this experiment has resulted in an increase in both staff and operating budget. During the past year, over 35 guest engineers and scientists from industry, both from this country and from abroad, have come to the Laboratory to assist and gain experience in reactor design and technology problems. The 11,000square-foot works area building, designed to house large experimental loops containing uraniumbismuth fuels and processing salts has been completed (Figure 1). To the critical and exponential assembly area already established has been added a new facility to contain another neutron source reactor for the experimental and critical studies of the LMFRE. The new engineering building, which had been authorized for design and construction this year, was held up as a result of a broad government policy covering new building construction after a preliminary design study had been carried out by the Architectural Planning Division.

The progress made during the past year in the LMFR program is summarized below.

Reactor Physics

Studies of the statics and kinetics of various liquid metal fuel reactors have continued. Computations relating to the control and shielding of the LMFRE and of the enriched uranium in-pile loop were completed. Studies of the effect of coolant channel diameter and graphite permeability on temperature distributions were completed. A report on the effect of fluid compressibility on the transient pressures that may arise in a liquid fueled reactor was submitted for publication. Theoretical studies of the open and closed loop kinetics of LMFR systems are continuing.

Although uranium to fuel the LMFR exponential experiments is not yet on hand, it has been possible to do certain preliminary studies which will be of value later. The properties of the graphite to be used have been investigated, and the thermal neutron diffusion length was found to be 55.85 ± 0.16 cm at a specific gravity of 1.60. Preliminary measurements of the bismuth properties have shown its thermal neutron diffusion length to be 38.3 cm.

Fuel Processing

One of the unique aspects of the LMFR is the possibility of continuous removal of fission products to maintain a low concentration of these reactor poisons in the fuel. The fission products fall into three general classifications: 1) those that can be selectively removed with fused salt (the FPS's), leaving the uranium in the fuel; 2) those that can be removed by volatilization (the FPV's); and 3) the remainder (the FPN's). From a reactor-poisoning standpoint, the first two groups are by



Figure 1. The new works area building which will house the 4-in. utility test loop.

far the most important; they are, therefore, the ones that have received the most attention.

Research on the removal of FPS's has been carried on in the pyrochemical field during the past year. Much of the work has been undertaken with the goal of supplying the engineers with the information needed to design a processing plant. Part of the program, however, has been devoted to fundamental research on high temperature systems and is of wider applicability.

Of the applied chemical work, the most important has continued to be the measurement of the partition of fission product elements between liquid metal and liquid salt phases. The systems are complex, involving both physical and chemical equilibria, and many variables must be taken into account. An intensive study of the behavior of a few fission products has been undertaken in the hope of interpreting their partition behavior in terms of their known properties and those of the other components of the system. A great many experiments have been carried out on cerium and neodymium, for example. The distribution of each of these has been determined in the presence of varying quantities of magnesium in the metal phase; in the presence and absence of uranium in the metal; and with two different salt compositions. From the observed dependence of distribution on magnesium concentration it was possible to deduce that the species in the salt phase is the trivalent chloride, CeCl3 or NdCl3. The presence of uranium had little or no effect, nor did the replacement of the usual salt, which is the ternary eutectic MgCl₂-KCl-NaCl, by the binary eutectic

MgCl₂-NaCl. The observed numerical values of the distribution coefficients agreed well with those calculated from the free energies of formation of the chlorides involved and the free energies of mixing of the salt and metal phases, as estimated or determined from emf measurements as described below. A few experiments on samarium showed the dependence of its distribution coefficient on magnesium concentration to be that expected if it were oxidized to a bivalent chloride, SmCl₂. This is in agreement with the known fact that for samarium (unlike cerium and neodymium) the most stable oxidation state is +2. The chloride SmCl2 is more stable than CeCl3 or NdCl₃, so that higher values for the salt/metal concentration ratio would be expected in the case of samarium; and this difference in fact was observed. With zirconium, distribution experiments gave results less precise than in the other cases, but its behavior was consistent with the hypothesis that ZrCl₂ is the most stable compound; its oxidation to ZrCl4 seems very unlikely. Zirconium is extracted from the metal by the salt to about the same extent as uranium; that is, its separation factor is around unity. For the other elements mentioned, separation factors of the order of 100 have been measured, at least at low magnesium concentrations (below 50 ppm). In principle the separation factor should be nearly independent of magnesium, but in practice it falls off significantly when the magnesium exceeds 100 ppm. Since the rare earth behavior agrees well with theoretical expectation, the difficulty is to be sought in the chemistry of uranium in such systems. Precision has been far more difficult to attain in uranium distribution experiments than in those with other elements, and the scatter of data is such that the oxidation level of uranium in the salt remains unknown. It may be that it is not present as the halide at all, but that impurities to which the rare earths are inert react with it. It has seemed advisable to look into the whole question of the state of uranium in salt mixtures by approaches other than salt-metal partition experiments. Optical and electrical investigations appear promising, and some progress has been made along these lines both at Brookhaven and in the laboratories of subcontractors. A Beckman DU model spectrophotometer has been modified by replacing the usual cell holder with a special furnace suitable for heating quartz optical cells

to high temperatures. With this apparatus it should be possible to study the visible and ultraviolet absorption spectra of a wide variety of salt melts and to learn something about the degree of complexing by uranium in various environments. The same apparatus can also be used for vapor spectroscopy, and a study of bismuth iodide vapor and its decomposition products over a range of temperatures and pressures has been begun. Spectroscopy also appears to have good possibilities as a quick analytical method for fused salts. This application is being explored, on subcontract, by H.M. Haendler of the University of New Hampshire, who has modified a Perkin-Elmer apparatus for this purpose. His results show that the specific absorption of U*** in chloride melts is strong enough in the visible region to give a fairly sensitive measure of its concentration, and it is probable that its ultraviolet absorption will be even higher. If so, and if fission product absorption does not interfere, a much-needed instrumental method will be available for monitoring the saltphase composition in a continuous extraction process.

Application of the polarographic technique to fused salts has met with some success. The dropping bismuth microelectrode has been developed to the point that it behaves nearly as well as dropping mercury in aqueous systems and gives the same type of current-voltage curves. Good proportionality has been found between concentrations of reducible solute, such as PbCl₂ or ZrCl₂, and the diffusion current; and when two such solutes are present together, two easily distinguishable waves are produced. It is possible that this technique can, like spectroscopy, be developed into an analytical method for process salt streams. It is more complicated, however, and will probably be of more value as a tool for investigating the chemistry of salt melts. Quantities such as the diffusion coefficients of the reducible ions can be calculated from the diffusion current. If polarography is to be used at all for salt analysis, a stationary microelectrode would probably be more suitable. It is this aspect of the problem that Carter Laboratories is investigating for BNL.

Use of electrode concentration cells to give thermodynamic information about liquid bismuth alloys has continued. The problem of getting reproducible readings with magnesium-bismuth electrodes, which had given more trouble than

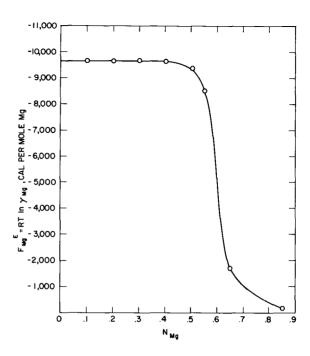


Figure 2. Excess partial molal free energy of Mg versus mole fraction Mg for liquid Mg-Bi alloys. Standard state is solid Mg. Some alloys are super-cooled liquids.

most on account of the chemical activity and volatility of magnesium, was finally solved, and a series of cells was measured in which the entire range of alloy composition was covered. The system showed extreme deviations from ideality. This is illustrated in Figure 2, in which the excess partial molar free energy of magnesium in the mixture is plotted against the mole fraction.

Information of this sort about salt mixtures can also be obtained from emf measurements. Several cells of the general composition

$$Mg/MgCl_2(x)$$
, $KCl(1-x)/Cl^2$

have been measured, and it is planned to cover the entire range of concentrations. With each cell measurements are being made over a temperature range in order to provide data on entropy as well as free energy. First results indicate that deviations from ideality in this system are small.

Another project in the field of high temperature electrochemistry has been the development of a reference electrode. In the salt contact process proposed for the purification of the LMFR fuel, a potential may be considered to reside at the interface between metal and salt, its value being governed by the relative amounts of oxidized and

reduced material in that system. For the routine measurement of this potential an electrode has been made which consists of the half-cell

Zn/1% ZnCl₂-99% NaCl-KCl-MgCl₂/soda glass.

The glass serves both as an intermediate electrolyte, permeable to sodium ions, and as a mechanical envelope. The assembly is a test-tube-shaped object which can be lowered into the process salt. This salt will consist of the nearly pure ternary eutectic, and it has been shown experimentally that under such circumstances the diffusion potential introduced by the soda glass membrane is negligible. The electrode will have a practical use in revealing any malfunction of the processing system which shows up in a deviation from the normal emf.

With reference to the problem of removing the volatile fission products (FPV's) from an LMFR fuel, some theoretical studies were conducted, and an extensive experimental program was initiated in January. From the standpoint of reactor poisoning, the problem of FPV removal is essentially one of xenon-135 removal; and at first it appeared, from a kinetics standpoint, that a preferred way to remove the xenon would be to desorb its precursor, iodine. However, theoretical work has indicated that fission product iodine probably forms mostly nonvolatile iodides, which, moreover, have low solubilities in bismuth. This could mean that the iodine would collect on nonwetted surfaces and there decay to xenon, which would preclude the possibility of removing xenon by desorption of its precursor from the fuel. The experimental evidence obtained to date in both tracer and in-pile experiments seems to support this conclusion.

The two principal volatile fission products are the noble gases xenon and krypton; and the experimental program now under way has two objectives: 1) to study the chemical and physical behavior of the precursors and daughters of these two elements in an active LMFR fuel, and 2) to study the kinetics of their removal from an LMFR fuel in degassing equipment.

The chemistry of breeder blanket materials and of the more noble fission products (FPN's) has been the subject of limited research programs. An attempt has been made to ascertain the relative stability of protactinium chloride by following its behavior in salt-bismuth equilibration experi-

ments in which thorium and uranium were also present. Results are incomplete, but the stability appears to be nearly as great as that of the uranium and thorium chlorides. Of the FPN group, silver and tellurium have been subjected to somewhat similar experiments, in which bismuth alloys of these metals were equilibrated with a salt phase containing 6% BiCl₃. The concentration ratios, solute in salt/solute in metal, were 0.3 and 1.0 for Ag and Te respectively. The transfer of silver was found to be reversible.

The so-called bench contactor program is for studying salt-metal reactions on a scale about two-hundred-fold greater than that of the experiments described above. The bench contactors are stainless steel vessels having a capacity of about two liters. Liners of different materials can be used.

Molten bismuth containing up to 1000 ppm uranium, up to 15 ppm cerium, and up to 225 ppm magnesium was equilibrated with fused $MgCl_2$ -NaCl-KCl eutectic in several experiments at 500° C for periods of up to 12 months. Equilibrium distributions of uranium and cerium, a representative rare-earth fission product, between metal and salt phases were determined, and then separation factors were calculated.

The separation factor for the process is defined as

S.F. =
$$K_{\text{Ce}}/K_{\text{U}} = \frac{\text{Ce in salt/Ce in Bi}}{\text{U in salt/U in Bi}}$$

and observed values have ranged from 200 to 2000, which are very satisfactory from an engineering standpoint. These results, in qualitative agreement with theory, agree fairly well with those of previous gram-scale experiments and with those obtained in an in-pile loop. Special contactors are being built to study the oxidation of fission products and uranium from LMFR fuel with BiCl₃ dissolved in the KCl-NaCl-MgCl₂ eutectic. These have removable liners and stirrers and permit improved sampling.

Extensive corrosion tests are under way for the purpose of finding a suitable construction material for containing fused chlorides under all possible plant conditions. Up to now type 347 stainless steel has been used quite successfully for containing fused chlorides under isothermal conditions and in the absence of large amounts of highly oxidizing materials such as BiCl₃. However, early tests in which tabs of this steel were immersed in

static KCl-NaCl-MgCl₂ mixture containing 1000 to 2000 ppm BiCl₃ showed intergranular penetration of up to 40 μ after 1000 hr at 500°C. Materials being tested include the stainless steels of both the 300 and 400 series, low-chrome steel, inconel, molybdenum, and tantalum. The salt corrosion tests are carried out under static, dynamic-isothermal, and dynamic-nonisothermal conditions, both in the presence and absence of a bismuth phase.

The disk-and-doughnut type of extraction column appears to have promise for FPS removal on an engineering scale, and this type will be first tried in Loop N. The fluid dynamics of such columns have been studied with mercury and water, the latter being the continuous phase, in order to determine preferred designs. Such factors as drop size, coalescence, and back mixing have been studied, the latter by the use of dyes. In this work, high-speed motion-picture photography was an important tool.

Test Loops

During the year several loops were being designed, built, or operated. The most significant was probably Loop G. This is a large figure-eight loop built for the purpose of conducting corrosion-erosion tests on steels under high velocity and non-isothermal conditions. A number of revisions were made in the loop to improve its performance and suitability for corrosion testing, and considerable effort was spent on pump development. The corrosion results obtained are given in the next section, "Corrosion and Mass Transfer."

Loop H-1, a loop testing liquid bismuth pumps with capacities of 5 to 10 gpm and having heads up to 40 ft, was built and operated. A similar loop, Loop H-2, was being designed at the year's end. Loop M is still in the construction stage because of the pressure of higher priority work; however, at year's end it was well over 90% complete and should be ready for operation by August. This is an all stainless steel (347) loop which will be used to test and develop instrumentation and hardware components for fused salt service. It contains two canned-rotor pumps connected in parallel (one Allis-Chalmers and one General Electric) and is designed to operate at 500°C with the KCl-NaCl-MgCl₂ eutectic.

Another loop, Loop N, was designed, and a contract for its fabrication was being negotiated

with the Catalytic Construction Company at the end of the year. This is a large, complex loop which will be used for testing various column designs and operating conditions for the extraction of fission products from LMFR fuels with fused salts.

A 4-in, utility test loop is under construction. It will consist of two 4-in. pipe size pumping loops for uranium-bismuth fuel service. One loop contains a furnace, pump, dump tank, and one side of an exchanger. The other loop consists of the other side of the exchanger, a pump, an air-cooled cooler, and a dump tank. In addition both loops will contain valves, instruments, heating circuits, etc. This test system will be used to obtain engineering scale information on design, procurement, and operation of components that conform in size to the 5-Mw LMFRE originally contemplated by the Laboratory. A contract for the over-all engineering design of this loop was placed with the Catalytic Construction Company in the summer of 1956. Contracts for components such as the furnace, pumps, heat exchanger, cooler, valves, and some instruments had been placed previously. Because severe corrosion was found on certain welds in Loop G in October 1956, all work on these contracts was stopped until further corrosion tests on chrome alloy steel could be completed. Early in May results on these additional tests were considered sufficiently encouraging, and work on the 4-in. utility test loop contracts was resumed. The loops are to be made of 2\% Cr-1\% Mo alloy steel. It is designed for a heat input of 8,500,000 Btu/hr (2½ Mw) with a temperature difference of 135°F and a flow of 360 gpm U-Bi-Zr-Mg in the primary circuit. The lowest temperature will be 750°F, the highest 885°F. If feasible, sodium will be used in the secondary loop, and certain instruments will be added to simulate LMFRE controls. Arrangements have been made to have the Babcock and Wilcox Company operate the 4-in. loop. It will be assembled in the new works area building and should be ready for initial operation in the late spring of 1958.

An in-pile radiation loop has been designed and its fabrication commenced. This is a cooperative effort between the Babcock and Wilcox Company and BNL. In general, BNL has designed and will fabricate the parts that will go into the reactor, the pumps, and the instrumentation, while Babcock and Wilcox is handling the exter-

nal piping, structure, exchanger, cooler, furnace, etc. The loop will convey a solution of U-Bi-Zr-Mg through a pipe in the BNL reactor at a rate of a few gpm. Since U235 will be used in the bismuth, fission will take place. The loop will be used primarily to determine the corrosion behavior of various steels in the presence of radiation (neutrons and fission products). Samples of steel and graphite inserted in the loop will be studied for other radiation-induced changes. A high level facility for examining radioactive specimens is being designed. This unit should permit examination of all the components of the above loop. Equipment for operating, examining, and testing is either on order or being developed for this hot facility.

In addition to the above, a few smaller thermal convection loops were constructed for salt corrosion work. Also, a large number of loops were operated by the Metallurgy Group; these are discussed in the following section.

Corrosion and Mass Transfer

The thermal convection loop program has been expanded and has yielded very valuable, if inconclusive, results. Some 40 loops have now been run in which the upper temperature of the hot leg has been held at 550°C and the temperature differential between hot and cold leg has been varied between 40° and 150°C. The test material in most of these experiments has been a low chrome steel (2¹/₄% Cr-1% Mo-0.4% Mn). The results of these tests may be summarized as follows. If the zirconium and magnesium concentrations in the uranium-bismuth alloy are maintained at approximately 250 and 360 ppm respectively, these loops will run for very long times without plugging, i.e., such loops have been shut down after 13,000 hr without having formed à solid plug in the cold leg. However, after 3000 to 5000 hr of thermal circulation the hot leg is seen to have been attacked quite severely. This attack which apparently progresses with time, is referred to as pit type corrosion for lack of a better descriptive term. Actually, the pits extend laterally as well as in depth, although to date no loop has been perforated as a result of corrosion. With temperature differentials of the order of 90°C (550° to 460°) the severity of attack is markedly reduced. Very little deposition is noted in the cold leg. With temperature differentials above 100°C (550° to

450°) the type of attack described above is noted. The welds, which in these early loops were made with a 5 chrome welding rod, were also severely attacked. When calcium is substituted for magnesium as the deoxidizing agent, loops plug in a much shorter time. Of all the loops run to date, the one giving the most favorable results, i.e., no pit type corrosion and very little precipitation, was of Bessemer steel. This loop operated for 12,000 hr at a temperature differential of 135°C.

The newer loops, started in the past fiscal year, are being run to test some ideas evolved as a result of the previous runs. In particular, the temperature differential is being varied between 100° and 125°C, the upper temperature being either 550°, 525°, or 500°C. The effect of heat treatment of the test material on the behavior under operating conditions is also being tested. The effect of using different types of welding rods to join 21/4 chrome is also being tested. Finally, the effects of nitriding the steel prior to test and of varying the concentration of inhibitors are also being determined. Although these loops have run only for about 3000 to 5000 hr, which is too short a time for conclusions to be drawn, most of them have shown no corrosion in the hot leg and very little precipitation in the cold leg as determined by radiography. However, one result obtained is anomalous in that a new batch of steel of the same general composition has shown the development of pits both in the weld and in the pipe wall prior to imposition of the temperature differential. This loop had been given an annealing heat treatment, which may have been a factor in its behavior, although it has been suspected for some time that slight variations in composition of the steel may be sufficient to give the observed poor resistance to corrosion.

The fourth run on the electromagnetically pumped loop (referred to in last year's report) has been completed. The loop was shut down because of a plug which formed as a result of a power failure after 2500 hr of operation at 550° to 400°C. Examination of the loop showed extensive corrosion in the region operated above 500°C. A large amount of deposit was found in the finned cooler section (coldest section). However, the plug which cut off circulation was due to localized precipitation of zirconium, magnesium, and uranium. Two other loop runs have been completed, one with Loop G, a mechanically pumped loop, in

which the temperature differential was 75°C (525° to 450°). The velocity of the flow through the hot leg specimen was between 4 and 5 ft/sec. The test section consisted of samples of 2\(^1\)4 chrome, 11/4 chrome, 410 stainless, and Bessemer steels with various heat treatments. Numerous types of welding rod were used to determine the effect of different welding rod compositions. Welds joining 21/4 to 21/4 which were made with 5 chrome rod were attacked in the 1000-hr run. None of the welds joining 21/4 to 21/4 chrome steel with 21/4 chrome welding rod showed attack. Welds executed with type 410 welding rod joining 410 to 410 and a weld in which 21/4 chrome welding rod was used to join 410 to 410 showed light attack. Slight but uniform corrosion of the 410 steel was noted. A similar test specimen which is being run in an electromagnetically pumped loop (velocity of circulation in the hot leg ≈ 2 ft/sec) has shown no corrosion after 2000 hr of operation and no deposition in the cold leg (radiographic examination).

In order to obtain a better understanding of the corrosion behavior of the test specimens in the engineering tests, fundamental corrosion studies have been continued. It has been shown that in static tests run at temperatures as high as 780°C, pure iron is not attacked by bismuth solution saturated with zirconium or by bismuth solution containing as little as 325 ppm zirconium if the magnesium concentration is 2600 ppm. When low-carbon steels, 21/4 chrome steel, and 5 chrome steels are contacted with a U-Mg-Bi solution at 700° to 750°C, surface films form which have complex x-ray patterns, some lines of which are identifiable as uranium nitride. In another series of experiments, steels with the basic composition 2¹/₄% Cr -1% Mo but with varying nitrogen to aluminum ratios were contacted with bismuthzirconium solutions at 650° to 820°C. ZrN films formed on those steels which had a nitrogen to aluminum atomic ratio greater than one; ZrC films formed on those for which this ratio was less than one. Both types of films were identifiable by x-ray diffraction. The same series of steels were contacted consecutively first with Zr-Mg-Bi and then with U-Mg-Bi solutions. In all cases, even when the order of contacting was reversed, uranium nitride films were noted on the steel specimens, the amount depending on the order of contacting and on the nitrogen to aluminum ratio. Most of the

steels subjected to this test were corroded. When the steels were tested in a solution which contained zirconium and uranium as well as magnesium in the bismuth, no uranium nitride lines could be found. However, a slight alpha activity was detected.

The studies on the solution rates of 21/4 chrome steels into bismuth containing magnesium and zirconium were continued. The rates are very similar to those obtained with a 5 chrome steel. The specific solution rate constants continuously decreased with time of contact.

The studies on the effect of titanium on the solubility of iron in bismuth have also been continued. Titanium decreases the solubility of iron in bismuth at temperatures above 500°C. The extent of this decrease is approximately proportional to the 0.4 power of the amount of titanium present. The solubility of chromium in bismuth saturated with titanium is nearly doubled at temperatures above 500°C.

The solubilities of the fission products Nd, Sm, Ce, Ba, Sr, Ge, Ra, Rh, La, and Pd in Bi have been determined.

Blanket Development

The recent work on phase studies in the thorium bismuthide system has shown that the composition of the compound in equilibrium with pure bismuth has the probable formula ThBi2 rather than Th₃Bi₅. Satisfactory dispersions of ThBi₂ in bismuth have now been produced in batches as large as 90 lb by stirring thorium powder into molten bismuth at 550°C in an inert atmosphere. Under the subcontract with Horizons Inc. for the development of a method for constituting a thoriumbismuth dispersion, slurries have been made which are satisfactory with respect to thorium content as well as size and shape of thorium bismuthide particles. The thorium is electrodeposited from a mixture of thorium chloride, sodium chloride, potassium chloride, and calcium chloride into a molten bismuth cathode which is stirred to force the deposited thorium into the bismuth. These dispersions did, however, contain 0.2 wt % chloride which must be eliminated if this method is to prove satisfactory. Studies on the reconstitution of thorium bismuthide dispersions have shown that quenching from high temperatures to 300°C will yield a fine platelet dispersion which can be made more equiaxed by heat treatment. The tem-

perature of heat treatment to obtain fluidity depends on the percent thorium in the melt. Attempts to reconstitute a slurry by shotting techniques have proved unsuccessful. The shot size obtained was too large and the cooling rate too slow to yield platelets of ThBi₂ small enough for heat treatment. Further work along this line is continuing. Gas atomization is also being investigated. An ultrasonic technique being tried at Aeroprojects Inc. for the reconstitution of thorium bismuthide slurries shows promise. Tests to determine whether elements added in small amounts to thorium bismuthide solutions would change the mode of precipitation have proven unsuccessful, although small additions of tellurium did inhibit particle growth in 5% thorium dispersions.

Recent work on measurements of the rate of transfer of protactinium and uranium from solid thorium bismuthide to the liquid phase bismuth have shown that the rates are primarily dependent on particle growth and not on diffusion. The equilibrium distribution of Pa and U has been determined by both low and high temperature equilibration studies. The distribution of Pa (Pa concentration in the solid phase divided by Pa concentration in the liquid in a 5% Th-Bi alloy) has been found to be 51 at 550°C and 130 at 400°C. The distribution ratios for uranium are 3.8 and 4.8 under the same conditions. At 400°C the Pa enrichment in the liquid phase is 20 and the uranium enrichment is 530.

Two slurry loops were set up and operated during the past year. The first consisted of four vertical 2-in. series-connected channels drilled in a 5-ft graphite block contained in a steel container. The plan was to pump the slurry isothermally with a centrifugal pump in order to determine the settling and redispersion characteristics of the slurry. Circulation was not obtained because the bismuth added to fill the pore voids of the graphite was insufficient. The fluidizing liquid of the slurry was sucked into the graphite; this left a thorium slurry of 20% Th content, which sets as a solid. The second loop, made of 24% Cr-1% Mo steel, was mechanically pumped. Its purpose was to test the effect of a temperature differential on the tendency for plugging in the cold sections of the loop. The loop was filled with 7% thorium bismuthide slurry containing 300 ppm zirconium. After isothermal operation at 1 fps, a temperature differential of 70°C (500° to 430°) was imposed

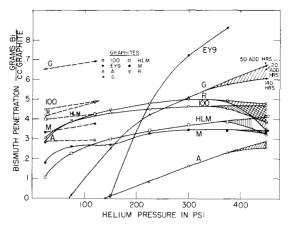


Figure 3. Bi penetration versus He pressure; successive immersions of 20 hr; temperature =550°C; outgassed 550°C for 20 hr. Dashed lines for reduced pressure after 450-psi impregnation.

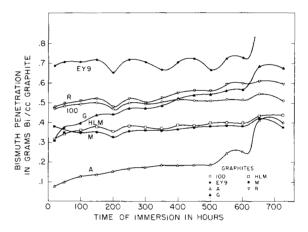


Figure 4. Bi penetration versus time; successive immersion of same specimen; temperature =550°C; pressure =250 psi; outgassed 550°C for 20 hr.

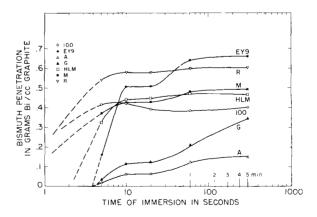


Figure 5. Bi penetration versus time; temperature = 550°C; He pressure = 250 psi; outgassed 550°C for 20 hr.

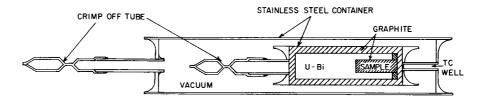


Figure 6. U-Bi capsule.

on the system. A relay failure temporarily shut off power to the loop. Flow ceased and the temperature in the cold leg dropped to 300°C. Seven hours after flow was established with a temperature differential of 70°C and a flow rate of ¾ fps, it became apparent that deposition was occurring. Flow stopped as a result of another power shut-off. An attempt to start circulation was unsuccessful. The apparent tendency for slurry particles to deposit in the cold portion of a loop poses a serious problem in the use of this type of dispersion.

Graphite-Bismuth-Uranium Studies

Approximately 25 samples submitted by the Great Lakes Carbon Company, the National Carbon Company, and the Graphite Specialties Company have been tested for bismuth uptake at pressures of 1 to 500 psi at 550°C, for 5 sec to 3000 hr. Of the graphites tested to date, only two types show some promise for LMFR use. The bismuth uptake in these graphites is of the order of 0.3 g/cc graphite (Figures 3, 4, and 5). The results in last year's report are now known to be incorrect because the technique used for measuring bismuth uptake was found to be faulty. Study of the diffusion rate of uranium into a graphite structure previously impregnated with bismuth has been started. The equipment for measuring the thermal conductivity in the temperature range 300° to 650°C has been completed and is being tested. Equipment for forming layers of ZrC on graphite has also been completed. These coated graphites will be studied under irradiation to determine the effect of fission product bombardment.

Much effort has gone into the development and construction of capsules for the irradiation testing of graphite and steel in a uranium-bismuth solution. The capsule now in use (Figure 6) consists of a graphite container for the U-Bi solution which is sealed in a stainless steel jacket. The latter is, in turn, encased in another jacket, and the space

between the two is evacuated. This capsule design is intended to permit irradiation at high temperatures with fission heat used as the only source of heat. A temperature of approximately 700°C has been obtained in one of the capsules tested. A capsule for the dry irradiation of graphite samples is being developed at Nuclear Development Associates. This capsule will be placed in the MTR and irradiated at LMFR temperatures to determine the radiation-produced changes in properties of the new types of graphite under development. Another experiment for studying the irradiation effects on the new graphites in the MTR under controlled temperature conditions has also been built, which will make use of a horizontal hole in the MTR. This equipment has been under test and is being modified.

EXPERIMENTAL REACTOR PHYSICS

Uranium-Water Lattice Program

The basic program of measuring lattice parameters of water moderated, slightly enriched uranium rod fueled reactor cores is now nearly finished. In the end, about 46 lattices will have been investigated, and the critical sizes and neutron economics throughout this region of interest will therefore be well known. This program has already established its worth in providing a reliable experimental basis for theoretical generalization. In addition to tabulated values of reactor core parameters, the following results, among others, have been achieved:

- 1) The demonstration of high fast fission fractions with a strong influence on prolonged reactor core lifetime and direct U²³⁸ burning.
- 2) The clarification of the role of epicadmium 1/v absorptions and fissions in the neutron cycle in these reactors.
- 3) Reliable experimental information on neutron absorption in U²³⁸ resonances in rods.
- 4) The finding of migration areas divorced

- from uncertainties in the values of effective delayed neutron yields.
- 5) The determination of the degree of thermalization in water moderated reactors.

During the past year the basic program has been extended by measurements with plutonium fuel, so that information on long-term behavior and on plutonium burning can be developed. Work on a water moderated system employing the Th²³²-U²³³ cycle has begun. A small amount of experimental data has already been generated from both these types of measurements.

Graphite-Natural Uranium Reactors

A certain amount of interest in the properties of graphite – natural uranium systems has continued, mostly because of the existence at Brookhaven of a research reactor of this kind. This interest has been displayed principally in a series of measurements which establish the correct design parameters of this reactor, ex post facto. From these and from data generated in the water lattice program has come what we believe to be the most reliable value of η for natural uranium reactors deduced so far: $\eta = 1.309 \pm 0.006$. This is to be compared with the cross section value, $\eta = 1.331 \pm 0.016$, and with the Manhattan Project value, $\eta = 1.315$.

Medical Research Reactor Studies

This year the critical assembly studies were completed for the MRR, which have provided information on the necessary critical mass, the refueling problem, control rod values and characteristics, and patient treatment fluxes. The results of these studies were incorporated into the MRR design and will assist in establishing its initial loading and operation.

Summer Institute

A sizable part of the group's activity during the summer of 1956 was devoted to conducting experiments for the Summer Institute. Preparations have been made to provide a similar service during the coming summer.

THEORETICAL REACTOR PHYSICS

Theoretical work on reactor physics has been concentrated on liquid metal fueled reactors and on hydrogen moderated systems.

The studies of resonance capture in heterogeneous, water moderated reactors by Monte Carlo methods has continued with the investigation of interference effects and of energy degradation by heavy moderators. The Monte Carlo program for water moderated rod lattices is nearing completion, and the program will next be used for the investigation of neutron capture in bismuth resonances. In the work on uranium-water lattices emphasis is being shifted to the study of slab lattices. On the analytical side a variational method has been developed for homogeneous systems which yields accurate results for single resonances. The method is being used to investigate the effect of incomplete flux recovery between resonances. The first-collision method for lumped fuel arrangements is being used for general studies of resonance capture in uranium fueled lattices. This method is free of many of the limitations of both the standard U.S. and U.S.S.R. work on the subject, although it may be reduced to either form with sufficient approximation. Monte Carlo programs for treating neutron absorption and slowing down in lattices at high energies, and more accurate numerical methods of treating resonance capture in homogeneous systems, are being developed in collaboration with members of the Applied Mathematics Division.

Studies relating to the conversion of the BNL reactor to enriched fuel are continuing. With 36 central channels loaded with enriched fuel, a thermal flux of 1×10^{13} neutrons/cm²-sec has been achieved. When the conversion is completed, a thermal flux of about 2.5×10^{13} is expected, with the resonance flux increased by 50%.

Preliminary studies of a small, high flux research reactor for basic research at BNL have been carried out in collaboration with members of other departments. The aim is to provide high fission energy flux for irradiation damage studies, resonance flux for fast chopper experiments, and a variety of thermal beam holes in the reflector. Optimum conditions are obtained by maximizing the specific power, minimizing the core volume, and limiting the size of the experimental facilities. Both NaK-Be and D₂O systems have been explored. With heavy water as coolant and reflector, and at a power level of 20 Mw, a total flux of 1.5×10^{15} in the core and a peak thermal flux of 5×10^{14} in the reflector can be achieved. By increasing the U235 content of MTR-type fuel plates in the core, the problems of xenon poisoning and fuel burn-up are found to be considerably reduced.

HEAT TRANSFER STUDIES

A liquid metal heat transfer program has been under way since 1951, the purpose of which is to obtain coefficients for flow of mercury outside of staggered tube banks. Such information is directly applicable to the design of LMFR heat exchangers, mercury being a good substitute for bismuth. Last year, the cross flow work was completed, the data therefrom were satisfactorily correlated with the important variables, and a program of in-line flow experiments was initiated. The new test section consists of a bundle of 19 tubular heaters, 0.5-in. o.d. by 5 ft long, arranged on an equilateral triangular grid with ¹¹/₁₆ in. between centers. Data will be taken over the Reynolds number range 8000 to 80,000.

FLUORIDE VOLATILITY PROJECT

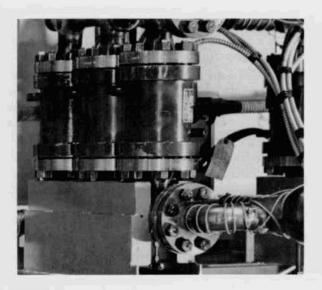
This study deals with the dissolution of natural uranium fuel elements in an interhalogen mixture consisting mostly of BrF₃. The other constituents are BrF₅, UF₆, and Br₂, in varying amounts. The purpose of the project is to study the continuous dissolution of uranium on a pilot plant scale. The plant has a capacity of 5 lb/hr. After several weeks

of testing and equipment revision, the plant was ready for operation in January. Factors under investigation included temperature, fluid velocity, uranium history, and composition of dissolver solution.

Eight dissolution runs were carried out with unirradiated natural uranium fuel elements. In these runs, a single charge of uranium was used, the dissolution temperature was 120° C, the flow rate of dissolver solution was 44 gpm, and the UF₆ content was varied from 0 to 4.5 M%.

On May 15, during the ninth run, a series of rapid explosions occurred in the dissolver section of the plant (Figure 7). Prior to the first explosion, there was no indication of any operational abnormalties. The explosions involved 30 gal interhalogen mixture and 2.5 lb natural uranium metal. All the uranium was consumed by the reaction. The interhalogen mixture was approximately 90 M% BrF₃, 5 M% BrF₅, and 5 M% UF₆. A rupture in the equipment and sheet metal enclosure resulted in one worker being seriously burned by liquid and vapor. He returned to work after three weeks; his recovery is now complete. Three other workers were treated for relatively minor burns and returned to work the next day.

From equipment damage effects it is estimated that local metal temperatures and pressures reached as high as 2500°F and 6000 psi, respectively. In addition to the bursting of the rupture disc on the dissolver, one other rupture occurred



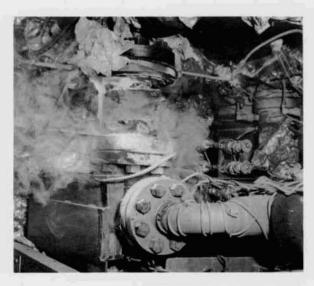


Figure 7. A pump in the fluoride volatility experiment before and after the explosion.

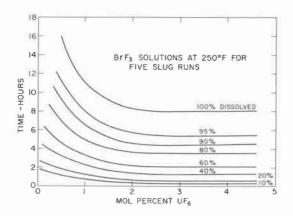


Figure 8. Effect of UF₆ concentration in BrF₃ solution on dissolution rate of natural uranium at 120°C.

in the system: a canned-rotor pump, having a bursting strength of about 3500 psi, was blown wide open. It is estimated that 470 lb interhalogens, and 40 lb uranium as UF₆, were vaporized to the atmosphere. Approximately 160 lb of solution containing 13 lb uranium were accounted for in the lines and pressure relief tank. The time required to restore the pilot plant to its original condition is estimated to be about eight months.

The explosive reactions occurred in the dissolver vessel as a result of violent chemical reactions between uranium and an interhalogen mixture. The exact conditions which triggered the explosions have not been definitely established. However, based on the evidence collected, the most probable explanation is that a fragment of uranium was somehow raised either partially or wholly into the vapor space where, because of poor heat removal, a runaway reaction ensued.

Prior to the accident, the plant operated exceedingly well, and valuable data were obtained. Figure 8 shows the effect of UF₆ concentration on dissolution time, based on data from all nine runs. It is seen that UF₆ content has a marked accelerating effect on the dissolution rate up to about 2 M%.

Fission Product Utilization and Radiation Catalysis

In 1951 the Atomic Energy Commission requested this Laboratory to initiate a research program to determine possible economic uses for the so-called fission product wastes as radiation sources. This program has uncovered a consider-

able number of interesting processes which have been described in previous reports. Since industry has been stimulated to take up the development of these processes, the Reactor Development Division of the AEC has terminated this program at Brookhaven as of June 1957. However, some studies of the effects on catalysis of gamma and other radiations are being continued with the support of the Research Division of the Atomic Energy Commission.

Radiation has been used to produce a large number of graft copolymers by several techniques. One technique employs the irradiation of a polymer, usually polyethylene, in the presence of a vinyl monomer. A second technique comprises the pre-irradiation of the polymer in air or in vacuum and the subsequent addition of monomer. The grafting process is believed to occur by at least two mechanisms. When air is present the major initiation of reaction proceeds from decomposition of peroxides formed in the irradiation step. When the polymer is irradiated in vacuum, polymerization is believed to occur from a stable free radical site in the polymer. Studies in air and vacuum at different temperatures and irradiation dosages tend to support these ideas. Photomicrographs have been made of the graft copolymers prepared by different techniques, which indicate that the pre-irradiation technique produces a more homogeneous copolymer.

The radiation catalysis program covers mainly work on solid state polymerization of acrylamide and related solid monomers and a study of the effect of neutron irradiation on an alumina-molybdena catalyst used in hydrocarbon dehydrogenation reactions.

Acrylamide is being studied by optical microscope methods to determine the changes in crystal structure during its polymerization by radiation in the solid state. It appears that the birefringence which reflects crystallinity is lost as the polymerization occurs, which indicates that the polymer produced is not oriented. An x-ray machine and auxiliary equipment are being installed to study further the relationship between crystal structure and rates of polymerization in the solid state.

Samples of alumina-molybdena catalyst have been irradiated with various neutron dosages under different conditions. The effect on surface area is being studied. A study is also being made to determine any effect on catalytic activity in the dehydrogenation of hexane to benzene. Results to date are fragmentary and inconsistent.

Food Irradiation Reactor Studies

In April 1956 the Laboratory was requested to prepare a conceptual design of a reactor to provide intense fields of gamma radiation for the irradiation of food (the FIR). This study was completed in July 1956, and in concept involved circulating solutions of indium salts through a reactor blanket and then through an irradiator. Shortly thereafter the Laboratory was requested to institute a research and development program to provide experimental information needed for the design of such a reactor and irradiator. Data were needed in two areas: 1) verification by experiment of calculations of dose distribution in food packages irradiated by aqueous radioactive indium solutions, and 2) investigation of corrosion, radiation stability, and chemical properties of the proposed aqueous indium solutions.

The dose distribution studies were concerned with the total dose received in the center of a food package as a function of the specific activity of the radiation source, as well as with the relative dose received in various parts of the food package. Two types of irradiators were designed, one referred to as a drum and the other as a slab. A building has been altered to house the experimental irradiators and auxiliary equipment, and the major equipment has been assembled.

Corrosion studies have been carried out on type 316 stainless steel in indium sulfate solutions of varying compositions at reflux temperatures. In all cases 0.5 wt % H₂SO₄ was present to preserve the chemical stability of the sulfate solution. Corrosion was found to be severe, but was the least for 15 wt % indium sulfate. Inhibitors reduced corrosion from 0.005 in./yr to 0.002 to 0.003 in./ yr. Further study of type 316 SS in an inhibited sulfate solution at 70°C gave corrosion rates of the order of 0.00002 in./yr. It was finally found that at 70°C, the proposed operating temperature of the FIR, 50 wt % indium sulfate solution with 0.5 wt % H₂SO₄ exhibited acceptable corrosion rates on 302 and 316 stainless steels; at 100°C these same systems showed a thousand-fold greater corrosion rate.

Tests with indium nitrate in nitric acid at 70°C also give corrosion rates of the order of 0.00002 to 0.00003 in./yr. Corrosion in this system at reflux

temperature increased by a factor of less than 10. Current work involves the determination of a corrosion-time curve for the system 316 SS versus a solution containing 375 g indium (as nitrate) and 55.4 g nitric acid per liter of solution at 70°C. [This solution is approximately 50 wt % In(NO₃)₃ and 5 wt % HNO₃.]

The effect of prolonged gamma irradiation of this nitrate solution in the presence of type 316 SS at 70°C was investigated. Up to a total dose in the range of 140×10^6 rad (delivered at 2×10^5 rad/hr over a period of a month), no evidence of excessive solution deterioration was observed. A slow initial increase in radiolytic gas pressure was observed, but this approached a fairly insignificant equilibrium value (6 to 8 psig) in the sealed container used in this experiment. No enhanced corrosion of the stainless steel was observed.

A few simple in-pile irradiations were conducted to observe the effect of reactor radiations on the corrosion of type 316 SS in the nitrate solution. Although these tests were far from conclusive, there was evidence that a corrosion rate in excess of that measured in the absence of such radiation might be encountered.

During the course of the determination of the time-corrosion behavior of type 316 SS in the nitrate solution, some instability of the solution was noticed. A finely divided white precipitate appears after about 60 days at 70°C and after 7 days at reflux temperatures. This precipitate is thought to be hydrolytically formed indium hydroxide. The same type of behavior has been noticed with indium sulfate solutions.

WASTE PROCESSING DEVELOPMENT STUDIES

Xenon and Krypton Recovery

Within the past year a research program has been in progress for developing an absorption stripping system for removal and recovery of xenon and krypton from reactor and fuel processing plant purge gas streams on a continuous basis. The equilibrium solubilities of Xe, Kr, A, He, N₂, O₂, and air have been measured in various solvents. In general, the data show that the less the polarity of the solvent, the greater the solubility of the noble gas. Also, the heavier the noble gas, the greater the solubility in a particular solvent. The longer-chain saturated hydrocarbons, i.e., n-hep-

Table 1
Solubility of Gas in Liquid Amsco 123-15 at 15°C and 1 Atmosphere Pressure

Gas	Temperature, °C	cc Gas per cc Liquid
Xe	24	2.10
Kr	29	0.64
He	30	0.0
N_2	20	0.01
O_2	20	0.19

tane and higher, appear to have appreciable capacities for xenon – of the order of 2 to 3 cc Xe per cc liquid solvent at room temperature and 1 atmosphere total pressure. Amsco 123-15, a kerosene base solvent, has been selected for further engineering studies because of the following characteristics: selectivity, relatively high flash point, low vapor pressure, relatively good radiation stability, and low cost. Table 1 summarizes the solubilities of various gases in liquid Amsco. Measurements indicate that the solubility of xenon and krypton in Amsco decreases at higher temperatures; thus recovery of the noble gas from the solvent is possible.

By a tracer method of analysis with pile-irradiated natural xenon and gamma scintillation counting, it has been possible to measure the equilibrium solubility of xenon in a gas mixture containing 1000 ppm Xe in N₂. The Henry's law constant has been found to be of the same order of magnitude at the low partial pressure of xenon as at 1 atmosphere. It is planned to establish equilibrium values for the system Xe-N₂-Amsco at lower xenon concentrations and at various temperatures, and in the range now found at processing plants.

Several preliminary runs in a 1-in.-diameter, 3-in.-high absorption column packed with a ¹/₄-in. Raschig ring, with a feed stream containing 969 ppm Xe in N₂, have indicated a height of a theoretical unit (H.T.U.) of approximately 0.33 ft. With the help of the active tracer method of analysis, the variation of H.T.U. as a function of column capacity is being further investigated.

In the same absorption column, with a mass spectrometric method of analysis, a preliminary run with a stream containing 5700 ppm Kr in N₂ gave an H.T.U. value of 0.74 ft. It is planned to

determine equilibrium values for the system KrN_2 -Amsco at concentrations below 500 ppm in the gas phase, and to establish H.T.U. values as a function of the capacity of an absorption column, by use of Kr^{85} in a radioactive tracer method of analysis.

ULTIMATE WASTE DISPOSAL

The well established program on the ion exchange and fixation of fission products in clays and metal oxides has been continued. An engineering design study of a full-scale plant for the calcination to stable oxides of wastes from aluminum and zirconium fuel elements has been carried out in conjunction with the Blaw-Knox Company. The successful design and remote operation of such a unit appears entirely feasible, although extensive engineering and test work would be required. The total cost, exclusive of buildings, of a plant to process 100 gal/hr zirconium waste was estimated to be \$3,700,000.

A bench-scale calciner unit for treating zirconium wastes has been studied with respect to quality of product, through-put rate, composition of off-gases, and corrosion due to HF and oxides of nitrogen. Tests are in progress to determine corrosion on some 50 different metal specimens under conditions approximating actual operation.

The feasibility of using ion-permeable membranes in the pretreatment of zirconium wastes is being studied, chiefly under subcontract with Ionics Inc.

The corrosion and other problems encountered in the calcining of zirconium wastes have emphasized the desirability of exploring other methods of fuel element reprocessing, and such a program is now under way.

SPECIAL RADIOISOTOPES DEVELOPMENT

Yttrium-90

A successful system has been devised for separating this important β^- -emitting isotope from its long-lived β^- -emitting strontium parent. The device, a Dowex-50 ion exchange column on which 28-year Sr⁹⁰ is firmly fixed, is simple and convenient and may be used repeatedly by the customer in his own laboratory. Long-term tests extending over nearly a year have shown that the Sr⁹⁰ contamination in the product from a column carrying

100 mC Sr⁹⁰ remains exceedingly low, being of the order of 10⁻⁷% of the Y⁹⁰ activity milked, and that the strontium band moves down the column at such a slow rate that the device will probably have a useful life of at least a year. An effort is being made to find a rapid method of proving the absence of Sr⁹⁰ in each milking.

Magnesium-28

This isotope, without which certain medical research has heretofore been impossible, is being supplied routinely to an ever increasing number of doctors. It is now produced in specific activities of 1 mC Mg²⁸-Al²⁸ equilibrium activity per g stable magnesium through the neutron irradiation of an alloy of magnesium and lithium (enriched to 95% Li⁶). At present this specific activity is higher than that obtainable by any other method. The triton flux required for the $Mg^{26}(t, p)Mg^{28}$ reaction and obtained from the $Li^6(n,t)He^4$ reaction is maintained at a high level by sealing the Li-Mg alloy in helium to exclude oxygen which would parasitically capture tritons to give the $O^{16}(t,n)F^{18}$ reaction. A 1-mil foil of pure iron placed between the alloy and the aluminum can, prevents chemical reaction between the target and the can during the irradiation.

Fluorine-18

A new chemical separation process, in which the F^{18} is carried on $Mg(OH)_2$ precipitate instead of $Fe(OH)_3$, is superior to the production method in use during the previous year; it produces carrierfree F^{18} in a shorter length of time and in good yield. Even higher yields can be obtained by the addition of a very small amount of fluoride carrier. The process lends itself more readily than the older method to shielded, remote operation.

The use of Li⁶₂CO₃ (from the Li⁶ wastes from Mg²⁸ production) increases the F¹⁸ yields by a factor of at least 6; and a new ion exchange method partially developed during the year is expected to improve the process still more. If sufficient F¹⁸, say 100 to 500 mC, could be produced as easily as 10 mC by the old method, it might be possible to widen the shipping range to include the eastern half of the United States.

lodine-132

A new and greatly improved type of I¹³² generator has been devised and put an the market. The

product from this new type has virtually no tellurium contamination, and therefore does not produce in patients the "garlic breath" caused by the product from previous generators. The foaming sometimes encountered in milking earlier generators is completely eliminated. The product from the new generator contains no sodium acetate, and therefore is suitable for direct use in iodinating human serum albumin.

The new generator consists of a small column of alumina on which Te¹³² is firmly fixed. The milking procedure is the simplest possible: 25 ml very dilute ammonia solution is poured onto the top of the column, and the product which drains off is at once collected, ready for immediate use.

lodine-133

The iodine-133 production process has been modified to allow an increase in the product concentration from 2 mC/ml to about 11 mC/ml. The new process, in which the starting material is loose $\rm U_3O_8$ powder wrapped in aluminum foil rather than the steel-jacketed pressed $\rm U_3O_8$ pellets used previously, gives good chemical separation yields in about 45 min and requires a minimum volume of reagents.

METEOROLOGY

The work of the Meteorology Group continues to be divided between research and service functions as in the past. The present emphasis is on research and development, with approximately 70% of the effort devoted to this category. Studies of atmospheric turbulence and diffusion by an oil-fog tracer technique constitute the most prominent part of the program. In the past year much attention has been devoted especially to the stable atmospheric conditions typical of the night hours. The importance of these conditions has been emphasized by a special study of power reactor safety recently completed at Brookhaven. The very slow diffusion typical of the nocturnal case becomes the most important feature in estimating the distance to which a hazard may extend when a very large release of fission products is postulated. This reactor safety study itself became a large part of the meteorological program from September to January, and the conclusions reached will have an important bearing on future work of the Group.

Diffusion in Stable Conditions

The study of diffusion during the past year has been devoted almost exclusively to the temperature inversion condition, in continuation of the experiments begun in 1955-56. The work has extended and confirmed the hypothesis that diffusion during temperature inversions must be treated as a two-stage process. In the first stage the parameters of the effluent jet are dominant, giving way to a much slower, natural diffusion process. These results are useful in defining the second portion of the diffusion, and it has been shown that the centerline concentrations tend to decrease almost linearly with distance. Although the data are not complete enough for a positive conclusion, the rate of concentration decrease does not seem to be materially affected by either the wind speed or the steepness of the inversion. While the characteristics of the Brookhaven test stack are very different from those encountered in most practical problems in that the initial diffusion is small, the importance of this initial rapid mixing is vividly illustrated in the oil-fog data. Classical diffusion formulas would overestimate concentrations close to the source by a factor of 100 or more if this phase were neglected.

The measurements obtained are in agreement with other inversion data that have recently become available from two elevated sources, the test facility at the Hanford Works and the stacks of large power plants of the Tennessee Valley Authority.

Pollen Studies

A second series of ragweed pollen measurements was undertaken in the late summer of 1956 in cooperation with the State of New York. The earlier data suggested serious defects in the usual sampling techniques.

Accordingly, two wind vanes were modified to hold Durham slide samplers in a fixed orientation to the wind direction, and a pair of simple wind tunnels were set up to provide continuous air flow over another set of slides and filters at the base of the tower. These devices proved conclusively that the primary problem in pollen sampling is improvement of the equipment. The Durham slide collector is very markedly affected by both wind direction and speed, with typical variations in count up to a factor of 4 attributable to these

variables. Even the filter samplers are affected by wind speed, as yet to an uncertain degree, and it is not possible to achieve isokinetic sampling.

Reactor Safety Study

An unanticipated program occupied a large fraction of the meteorological effort from September to February. This was the study of the hazards associated with power reactors completed by the Brookhaven staff at the request of the Atomic Energy Commission.

The meteorological portion of this work was confined to predicting the distribution of fission products in the atmosphere and the deposition on ground and vegetation surfaces that might follow an accidental release.

From the meteorological point of view, the most interesting aspect of the study was the strong dependence of dose rates and deposition values on atmospheric stability and rainfall processes, which is so great that the over-all area contaminated can vary by a factor of several thousand on the basis of these variables alone. More challenging was the fact that the study revealed important gaps in our knowledge of certain aspects of these problems. The first of these had to do with the type and scale of diffusion studies. Almost none have been conducted at low levels to distances of 100 or more miles from the source, so that the entire diffusion prediction was necessarily based on a tenuous extrapolation of values associated with small-scale tests. The measurements of nuclear bomb debris have reached appropriate distances, but unfortunately at altitudes hardly typical of this problem. In terms of the deposition of particulates, the problem is not simply one of scale, but of a general lack of suitable experimental data obtained in the field with adequate auxiliary measurements. There was little choice but to use gravitational settling approximations, despite their very probable inaccuracy in terms of particles less than 1 μ in size. The study has stimulated interest in these two problems, and both are included in future research plans.

Department of the Air Force Meteorological Study

The extensive climatological study conducted under the auspices of the U.S. Air Force Geophysical Research Directorate has been finished except for publication of the final report. This study, begun three years ago, includes a very detailed analysis of the low-level wind and temperature structure. This is designed to improve the understanding of the relation between small-scale meteorological features and the larger-scale patterns as defined by weather maps and observations at standard stations throughout the world.

Instrumentation

The major instrumentation project in the meteorology plans is the conversion of the data recording system from chart records to paper tape. The most serious problem stemmed from the requirement that all data must be read consecutively within a 2-sec interval in the detailed studies. This has finally been solved with a paper-tape punch, and the work is proceeding smoothly. Much of the necessary conversion equipment is on order, and some major items such as the punch have been delivered.

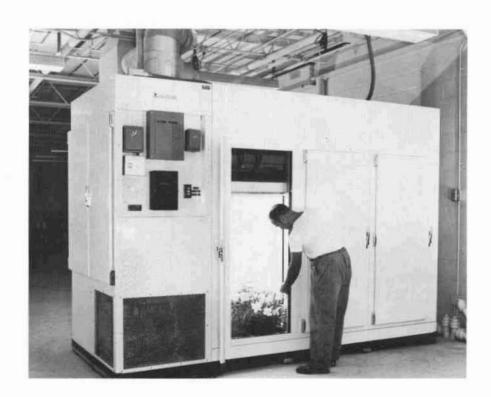
There are many less extensive instrumental projects, but one of long standing has been carried to satisfactory completion. This is the development of a device to analyze and record automatically the wind gustiness classification which, together with wind speed and direction, serves as the basis for the prediction of ground-level concentrations of stack cooling air and the oil-fog test effluent. The instrument completely removes the subjective elements formerly present in the visual analysis of gustiness.

· · · · · · · · · · · · · · · · · · ·	 		
			*
			• }
			į.
			2
			i i
			• 1
			•
			:
			3
			.
			•
			₹ .
			:
			1
			3
			į
			į.
			1

LIFE SCIENCES



Figure 1. New gamma greenhouse. The 15-curie Co⁶⁰ gamma-ray source is contained in the pipe at the center of the picture, and when not in operation is about 15 ft underground. In operation, it is elevated to just below the lead cap, which is present to prevent skyshine from affecting plants in neighboring greenhouses. Heavy concrete shielding prevents direct radiation from reaching nearby greenhouses and laboratories.



Biology

The program of the Biology Department has continued along the lines already established. The facilities of the Department have been used to capacity, and two new facilities have been added. One of these is a new gamma greenhouse. The old one had become very badly overcrowded, and the new one, while not employing a larger Co60 source, allows about four times as many plants to be grown at high dosage rates. In addition a second smaller source has been added; it is now possible to grow plants in the greenhouse at dose rates ranging from lethal down almost to background rates. This is important for genetic studies. The second new facility is an addition to the building which contains plant growth chambers. Only one chamber is now in use, but others are being designed and constructed. These chambers permit the growth of plants under the precisely controlled conditions of temperature, humidity, and light intensity essential for many plant studies.

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.

As in the past few years, the influx of summer visitors has saturated the Department's facilities. In addition to foreign visitors, 10 scientists and 25 students are working here this summer. This program has become an important part of the research and educational activities of the Biology Department. During the year 13 scientists from 10 foreign countries contributed to the research program of the Department and at the same time received training in special techniques. They worked here for periods ranging from a few weeks to 15 months and accounted for an appreciable fraction of the effort of the Department. In addi-

Figure 2. New plant growth cabinet. These cabinets provide growing space in which the temperature, humidity, and light intensity can be precisely controlled. Many types of experimental work on plants can be done only under such controlled conditions.

tion, a great many foreign and domestic scientists visited the Department for periods of a week or less.

MAMMALIAN PHYSIOLOGY

Radiation-Induced Aging

Analysis of mammalian radiation damage appears to show three primary causes of death, depending on the radiation dose. At high doses the animals die in about 3.5 days from acute intestinal injury. At smaller doses the animals may survive the intestinal injury only to succumb at 10 to 14 days to "bone marrow" death. If they survive this period, they will still die prematurely from some unknown cause. The symptoms are the same as those of old age, and the animals seem to die of the same diseases as do old animals. Since the bone marrow is extremely sensitive to radiation, and since the reasons for "bone marrow" death are so vague, it seemed worth while to determine whether or not injury to the bone marrow was responsible for this late death. Also, if it was involved, there was a chance that a bone marrow stimulus would aid recovery and thus prolong the life of the irradiated animals.

In order to perform these experiments without waiting about two years for mice to age, a technique has been worked out of giving mice small doses of radiation separated by 7 days. These animals do not die of the acute causes of radiation but do die in 3 to 4 months of "old age." This technique greatly accelerates the radiation-induced aging studies.

It has been shown that shielding a small section of bone marrow, which prevents the "bone marrow" death, does not in any way affect the radiation-induced aging. Furthermore, various hematopoietic stimulants such as typhoid toxin, tetanus toxin, typhoid toxoid, tetanus toxoid, and turpentine injections, applied either as single doses or as small repeated doses over long periods of time, do not affect the course of the radiation-induced aging. Thus it seems reasonably clear that the

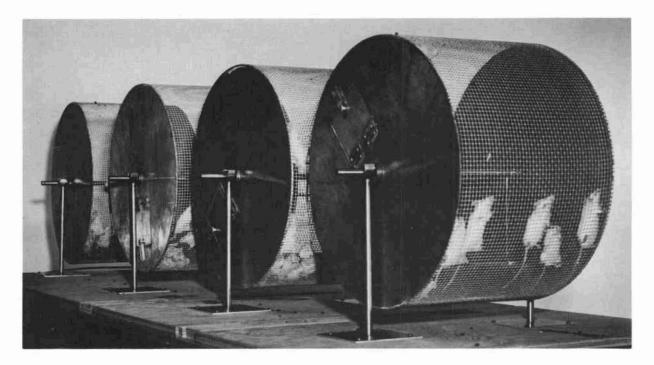


Figure 3. Exercise wheels for mice. The drums are driven slowly so that the mice must run to remain upright. This apparatus is used to determine the effect of exercise on the course of recovery from radiation injury and on normal aging.

bone marrow is not involved in radiation-induced aging.

One of the prevalent theories of aging attributes it to an accumulation of somatic mutations in the organism. This theory is supported by the fact that radiation, a powerful mutagenic agent, apparently accelerates aging. Experiments have been performed using another mutagenic agent, nitrogen mustard, instead of radiation. The experiments are not yet complete, but a preliminary estimate indicates that animals receiving nitrogen mustard live as long as the controls, provided they do not die acutely. This argues rather strongly against the somatic mutation theory of aging.

It is assumed by most workers in this area that there are two biological components to a dose of radiation, one reparable and one irreparable. Some early experiments indicated that the irreparable fraction of a dose of radiation was much larger for neutrons than for x-rays, in other words, that neutrons are much more effective than x-rays in producing premature aging. The data on which this conclusion was based are rather old, and neutron sources and dosimetry were not as well developed as at present; therefore, a series of experi-

ments was undertaken to verify it. The conclusion has not been confirmed. If mice are given doses of x-rays and fast neutrons comparable in their acute effects, then the effects of the two radiations on the life span are also found to be quite comparable. This result is quite surprising, not only because of the previous data, but also because the two radiations seem to affect different organ systems in the animal.

In conjunction with these long-term radiation studies, an analysis is being made of the ocular changes which result from different kinds of radiation. In addition to a high percentage of cataracts, especially in the neutron irradiated mice, a number of corneal opacities have been observed in both irradiated and normal mice.

Acute Effects of Radiation

A study has been under way for several years on the metabolic aspects of the radiation syndrome. Intensive study of the changes in carbohydrate metabolism in irradiated rats has been in progress for some time. All the results to date indicate that whole-body irradiation in some manner resets the regulatory mechanisms governing carbohydrate

levels, so that both liver and blood have a higher available sugar content than in comparable control animals. That an intact pituitary-adrenal system is necessary for the effects on liver glycogen has been demonstrated; however, in the absence of pituitary or adrenal function, the rat can still increase his blood sugar after irradiation. How this is accomplished is not yet understood. The source of the additional sugar in irradiated animals is also in doubt. It would seem, if the breakdown of protein after irradiation were responsible, that some sign of this would be found in the amino acid levels of the blood. However, experiments demonstrated that irradiation had no effect on blood amino acids, although the lactic acid content of blood was increased slightly.

A detailed study of nitrogen metabolism in irradiated animals has been started because it appears from the literature that significant disturbance of nitrogen metabolism occurs at dose levels below 100 r, while the carbohydrate disturbances so far examined require appreciably higher doses of x-rays before significant differences are apparent by the methods employed. It thus appears that nitrogen metabolism may be more sensitive to irradiation than carbohydrate metabolism. Despite the fact that amino acid levels of blood are unaffected by irradiation, the total nitrogen excretion of irradiated fasted rats is much higher than that of fasting control rats on the first day after irradiation. By the fourth or fifth day the situation is apparently reversed, the control rats seeming to have the higher excretion. The cause of this reversal is unknown and is under study.

One of the important findings reported last year was the discovery that hamsters develop a disturbance of balance following a dose of radiation to the head. An analysis of this effect shows it to be a disturbance of the inner ear. There seems to be an acute inflammatory edema from the local blood vessels into the labyrinth, so that the symptoms are due to excessive fluid pressure of the endolymph. If the animals live for several weeks, numerous secondary changes follow including degeneration of the vestibular nuclei in the brain.

Recovery from an acute radiation injury seems to depend largely on whether the injured and killed cells can be replaced before the animal succumbs to a lack of these cells. Relatively little is known about the physiology or histology of cell renewal; consequently a rather large study of it

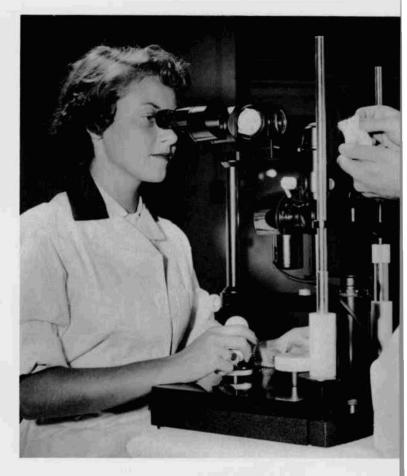


Figure 4. A mouse is being examined for a possible cataract by means of a slit lamp. This is part of a large study of radiation-induced ocular changes. These are especially prominent after neutron exposures; there will often be cataracts in 100% of the mice surviving a large dose of neutrons.

has been undertaken. The first step is the development of adequate methods for labeling cells so that their subsequent history can be followed. This has been done by injecting tritium-labeled thymidine into an animal. The thymidine is incorporated into the chromosome structure only of the cells which are undergoing cell division at the time of injection and into no others. The labeled thymidine stays in the cell as long as it lives, and even if the cell undergoes division the label stays entirely with one of the daughter cells; thus the original cell can be followed. This labeling technique promises to be of great usefulness not only for the radiation problem but also for many others.

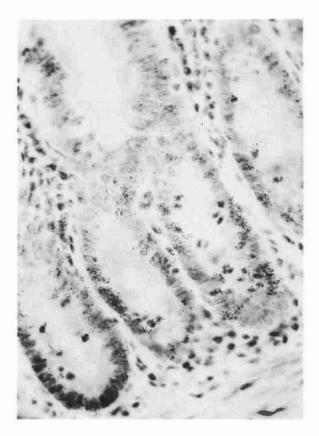


Figure 5. Autoradiograph of section of mouse intestine taken 7 hr after the injection of tritium-labeled thymidine. It is seen that some of the cells have become labeled, and these cells will remain labeled indefinitely in spite of repeated cell divisions. This technique, which is being perfected, promises to be very useful for studies of cell generation and regeneration.

Immunological Studies

By the use of tracer techniques it has been possible to study both the synthesis and breakdown of antibody after a booster injection of diphtheria toxoid. A similar kinetic analysis has now been completed with a different antigen-antibody system, the immune response to cholera vaccine. Three important conclusions which contribute to the understanding of the immune process can be drawn from the results obtained.

1) The rate of antibody synthesis in the booster response is independent of the nature of the antigen. Essentially identical rates were observed whether the antigen was a crystalline preparation of diphtheria toxoid with a molecular weight of 70,000 or a complex cholera vaccine with a molecular weight in the millions. Furthermore, these

rates were determined at different sampling sites; in the cholera experiments the amount of antibody excreted in the feces per unit time was measured, while in the diphtheria experiments the concentration of antibody was determined at the locus of antibody synthesis, the lymphatic tissue.

- 2) In most experimental animals, and presumably also in humans, there is a continual synthesis of antibodies which react with the cholera antigen. This conclusion is based on the fact that a booster rate of antibody formation was obtained after a single injection of cholera vaccine. Many of the apparent differences in antibody response to soluble and insoluble antigens can be explained on this basis.
- 3) Guinea pig antibodies to cholera vaccine and diphtheria toxoid are catabolized at essentially the same rate as normal gamma globulin. The experimentally determined values for the half-lives were 5.9 days for diphtheria antitoxin, 5.8 days for cholera antibody, and 5.4 days for gamma globulin. The small differences were not statistically significant. Thus the properties of gamma globulin molecules which are modified in producing specific antibodies cannot be those which determine the rate of enzymatic breakdown.

Carbohydrate Metabolism

The use of C¹⁴-glucose in minute amounts to tag the blood glucose pool of the dog has given important information about the influence on carbohydrate metabolism of the "diabetogenic" hormones. This work has been done in collaboration with a group at the New York University Medical School.

As background information it should be mentioned that when the pituitary gland is removed from a diabetic (depancreatized) dog the diabetes is alleviated. In such an animal the administration of either of two hormones, cortisone or pituitary growth hormone, causes the reappearance of diabetes. These hormones are referred to as "diabetogenic," although it is clear that when present in normal amounts in the animal with an intact pancreas they do not produce diabetes. When these hormones are deleted by hypophysectomy from the dog with an intact pancreas, the result is an animal with a subnormal blood glucose level and an exaggerated sensitivity to blood sugar lowering agents such as intravenously administered insulin.

In such an animal either cortisone or growth hormone administration corrects these deficiencies.

The current studies have established that growth hormone (like cortisone) produces its effects mainly by increasing the amount of glucose put into the blood by the liver in the resting fasting state and by increasing the capacity of the liver to pour out glucose when challenged by severe hypoglycemia (e.g., after intravenous insulin administration).

In the case of cortisone treatment the extra glucose put out by the liver has been shown by others to be derived from raw material furnished by extra protein breakdown. Growth hormone on the other hand, conserves protein nitrogen at the same time that it is causing an increase in the metabolic rate and an increase in the burning of fat for energy production. Since it has generally been considered impossible for the animal to produce extra glucose from fatty acids, the extra glucose output induced by growth hormone was unexpected. However, very recently the enzymologists Kornberg, Beevers, and Krebs have described in the castor bean and in a microorganism a reaction sequence capable of producing sugars in net yield from fatty acid fragments. The operation of such a system also in mammalian liver seems likely but remains to be established.

The current finding that a major action of growth hormone is to increase glucose output by the liver is an important development toward the understanding of the hormonal control of metabolic processes. Previously the knowledge of the influence of growth hormone on glucose metabolism was confined to its inhibitory effect on glucose uptake by the tissues. This previous understanding was difficult to correlate with the growth promoting and nitrogen retaining effects of the hormone and with its capacity to cause the movement of fats from the peripheral tissues to the liver.

Histopathology

Studies have been undertaken to give a histopathological description of ocular changes resulting from virus diseases including hog cholera, canine distemper, and malignant catarrh of cattle. These diseases cause inflammatory changes consisting of retinitis, optic neuritis, and in some cases leucocytic infiltrations of the iris and ciliary body. A search of the literature has revealed several isolated examples of similar findings in the case of other virus diseases. From this it seems reasonable to conclude that many if not all viruses cause intraocular lesions in the course of natural infection, a general conclusion which hitherto has not been suspected.

GENETICS

Mutation-Dose Relationship

Clonal lines of snapdragon heterozygous for flower color have been irradiated with chronic gamma-rays from cobalt-60 and acute x-rays. Pink or white flecks and sectors of various sizes on purple flowers are interpreted as somatic mutations induced at different times in flower development. Acute x-ray treatment of preflowering stages caused no visible change in flowers opening prior to the 15th day after irradiation. Dense mottling on the 16th to 19th days was succeeded on the 20th and 21st days by numerous countable 8-cell mutant spots. The number of spots induced by 1000 r gave a preliminary mutation rate estimate of 19×10⁻⁶ per cell per roentgen. Chronic irradiation in the gamma field and gamma greenhouse showed a linear response of mutation rate to daily dose rate, with seasonal variation of rates. There have been occasional indications of nonlinearity, but further tests have failed to show any significantly higher mutagenic efficiency of dose rates below 6 r/day.

Microbial Genetics

Bacterial infection by temperate bacterial viruses or bacteriophages may produce either of two results. The infected cell may be destroyed after a short latent period, liberating hundreds of progeny phages; or the host may survive the infection, giving rise to a hereditary changed clone. The surviving clone is immune to subsequent infection by the phage and can produce the phage in the absence of fresh infection. The infecting phage disappears as such, but its genetic material is integrated into the bacterial genome and provides the genetic control for the hereditary changes. The altered state of the bacterium is known as lysogeny, and the term prophage is used to designate the controlling entity of the lysogenic condition.

The wild type of phage P22 of Salmonella typhimunim is temperate. A large number of spontaneously arising mutants of P22 affecting the ability to lysogenize have been examined. Phenotypically



Figure 6. Agar plate demonstrating lysogeny in bacterial cultures infected with virus. The clear spots represent destruction of the bacteria by the virus. Some of the bacteria are able to incorporate the virus into their genetic structure, synthesize new virus, and release this virus into the medium to kill surrounding bacteria. This is known as lysogeny, and is demonstrated here by the dark spots surrounded by a clear halo.

all such mutants fall into three groups. One group of mutants is still temperate, but lysogenizes somewhat more poorly than the wild type. The mutants of the other two groups fail to lysogenize by themselves. If, however, bacteria are infected with mixed phage of both these groups, lysogenization occurs. That is, two mutants, each of which is unable to lysogenize, are, when put together in the same cell, able to interact physiologically to give the lysogenic condition, with one of these mutants as prophage.

Genetically all the mutations fall into a circumscribed region of the phage linkage map. By taking advantage of the discovery (by Jacob and Wollman) that ultraviolet irradiation of the phage before infection greatly increases the frequency of genetic recombination, it has been established that the three classes of phage mutations affecting the ability of the phage to lysogenize fall into three distinct and closely linked pseudoallelic series or functional units. The mutations of any one class can be mapped in a single unit.

Taylor has hypothesized a model of the chromosome consisting of DNA double helices spaced as

side chains on a backbone. The assumption that a functional unit might be arranged as a side chain has been tested genetically with P22 and found lacking. Further genetic studies are in progress with these mutants.

Radiation-Induced Mutations

Results of a study of some genetic and cytogenetic effects of ultraviolet and x-ray radiations on barley pollen indicate that the relative proportion of mutations per chromosome translocation recovered is greater for ultraviolet than for x-rays at a comparable level of pollen survival. However, the chromosomal rearrangements as well as the mutations produced by ultraviolet light appeared to be similar in all respects to those observed or reported earlier for x-ray or gammaray treatments of the same crop. This suggests that the same kind of mechanism may be operating for the production of genetic changes by the two physically different radiations, but that repair or aftereffect phenomena may be responsible for the differences indicated.

Studies on the artificial induction and cytogenetic nature of disease resistance mutants in wheat and oats have continued. One of the main problems under investigation has been the possible role of contamination by wind-blown pollen from natural resistance sources in stem resistance mutation experiments. Because pollen sterility is induced readily by radiation, natural hybridization might be greatly increased even in a highly self-pollinated crop plant like oats. To study this question, extremely rigid measures have been taken to eliminate natural crossing as a source of error by using 1) distinct genetic markers, 2) special procedures for isolating the irradiated generation, and 3) only tested single plant lines of the variety originally from a single plant grown under isolation. Furthermore, all stocks are grown on the Laboratory site, which permits perfect isolation from even the nearest fields located several miles away. It now appears probable that in earlier studies (Konzak 1954) a number of the resistant plants resulted from natural crosses with oats from a neighboring field, since results of a new experiment indicate that the actual induced mutation frequency for stem rust resistance in oats will be only a fraction of 1% calculated on a per plant progeny basis. Among the three stem rust resistant mutants isolated from a limited test conducted

this past season, however, one has a rust reaction type not previously observed in nature. Stocks of certain mutants can be maintained, and true breeding lines have been selected; but in the case of the new type of resistance mutant, all resistant and susceptible progeny have been highly seed sterile. Preliminary cytological analyses indicate that the sterility may be due to chromosomal alterations induced by the radiation treatment. An attempt is being made to determine the relationship of chromosomal rearrangements to the new type of rust resistance. More extensive experiments are in progress to determine the induced frequency of the rust resistance types.

In the wheat experiments, some possible 15B rust resistant mutants and two apparently new types of seedling chlorophyll deficient mutants have been isolated. Both chlorophyll mutants are fully viable, and their chlorophyll content apparently increases at high temperatures. The chlorophyll mutants have considerable potential value both for ordinary genetic and back mutation studies, since such easily recognized seedling marker characters are rarely found in this crop. Cytological studies indicate that some chromosomal rearrangement seems to have accompanied the latter mutants also, but there seems to be little association with the rearrangement. Further tests will be necessary to establish whether or not the apparent 15B resistance is real.

Self-Incompatibility in Plants

The genetic plasticity of certain genes results in extensive series of mutant alleles, each occupying the same locus but having slightly different end products. The most extensive of such allelic series are known for the S locus, which results in self-incompatibility in perhaps 5000 species of plants. Incompatibility is manifest via the inhibition of pollen germination or of pollen-tube growth when a plant is self-pollinated, thus enforcing hybridization and preserving heterosis.

Self-incompatibility has been reported from ca 1000 homomorphic plants, for which there is evidence available concerning the inheritance of more than 100 species. The single locus-multiple allelic scheme (rarely, duplicate loci) has been found applicable to all intensively studied species. Two different systems are constructed on this basic scheme: 1) the gametophytic system, in which pollen phenotype is determined autonomously by

the S allele in the pollen, and 2) the sporophytic system, in which pollen behavior is dictated sporophytically by the maternal S genotype. These systems differ basically only in the time of S allele action in microsporogenesis. This action must occur during or after meiosis in gametophytic species and premeiotically in sporophytic species.

In the course of compiling a card file of self-incompatible species, it has become evident that all gametophytic species represent plant families having binucleate pollen grains (in which sperm formation occurs after pollen germination) while sporophytic species (with one possible exception) have trinucleate grains. The incompatibility is expressed as pollen-tube inhibition in the former and as the inhibition of pollen germination in the latter. Further, the bi- and trinucleate conditions are correlated with external pollen morphology (3- and 6-colpate respectively) in certain families (e.g., Labiatae). The timing is relatively the same for each of these phenomena – early gene action in sporophytic, late in gametophytic species.

Studies of these related phenomena are in progress on self-incompatible species from 25 different plant families. Special attention is focused on attempts to duplicate inhibition in vitro and to isolate inhibitory substances. Genetic stocks are being prepared to test for the frequency of mutants as a result of natural and induced alteration of the S gene.

Radiation Dose-Survival Relationships in Fungi

This research problem has been concluded and the results have been submitted for publication in *Phytopathology*.

Dose-survival curves were obtained for urediospores of flax rust (Melampsora lini), wheat stem rust, oat stem rust, and oat crown rust exposed to ultraviolet light (UV), x-rays, gamma-rays, thermal neutrons, and fast neutrons. Spore germination on water agar was inhibited by UV but not by the other radiations mentioned, thus survival was necessarily evaluated by quantitative measurements of host plant infection.

Spores of flax rust were approximately twice as sensitive as those of the other three species to treatment with x-rays, gamma-rays, and neutrons; in UV exposures the relative sensitivity ratio was roughly 10:1. The calculated target number (number of biologically sensitive sites) was established as 4 for flax rust and 2 for the other three species. In

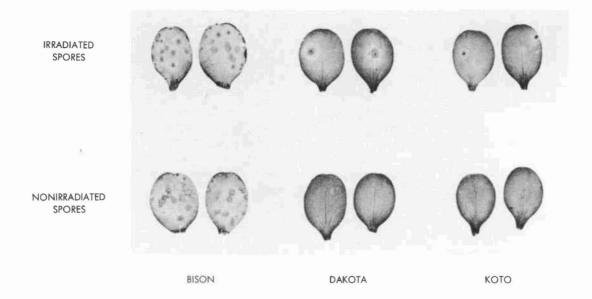


Figure 7. Method for detection of pathogenic radiation-induced mutants of flax rust (M. lini). The rust spores are irradiated and samples are placed on leaves of flax varieties, here varieties Dakota and Koto, which are normally immune to this disease. It will be seen that pustules of a mutant form of rust have formed, while the unirradiated rust will not form pustules on these varieties. The variety Bison, which is normally susceptible to this disease, is included in the tests to demonstrate viability of the cultures. By this method a study is being made of the possible range of mutants which might be expected in a disease of this kind.

a comparison of the rbe (relative biological effectiveness) of the radiations, fast neutrons were roughly 10 times more effective than x-rays at doses producing more than 90% lethality.

Spore water content, controlled by the level of relative humidity during irradiation, strongly affected sensitivity to x-rays and UV. Sensitivity increased sharply at humidity levels exceeding 50 to 60% r.h. (spore water content ca 50%); at 98% r.h. the sensitivity was twice that at 52%.

The sensitivity of flax rust hyphae (vegetative stage) to x-rays was approximately 10 times greater than that of the urediospores (resting stage) irradiated at the maximum spore water content.

Radiation-Induced Mutations for Pathogenicity

Mutations for spore color and for pathogenicity (from avirulence to virulence) have been induced in race 1 of the flax rust fungus (M. lini). The two rust loci studied were heterozygous for avirulence on the flax varieties Dakota and Koto; thus the mutants occurred as virulent infection types on these normally immune varities. The mutation rate of the Dakota rust locus exceeded that of the Koto rust locus by a factor of approximately 7:1.

Recent experiments designed to evaluate the relationship between mutation frequency and radiation dose indicate an essentially linear increase of frequency with increase in x-ray dose. In a comparison of x-ray treatments at the extremes of spore water content (ca 20 and 70%), the slopes of the curves were similar when mutation frequency (based on survivors) was plotted against LD (lethal dose) level but differed sharply when plotted against incident dose. Spores x-rayed at a high water content (ca 70%) required only about one-half the dose needed for a comparable mutation frequency at a lower water content (ca 20%). Thus spore hydration apparently increased the mutation efficiency as well as the "killing" (presumably a more complex, multitarget system) efficiency. The data for UV and fast neutron treatments, although not yet completely analyzed, suggest a "saturation" effect at the high dose levels. The mutation rate apparently reaches a peak and falls sharply at the highest doses, but this requires confirmation. At a given level of lethality the induced rate obtained with neutrons was similar to that obtained with x-rays but exceeded that of the UV treatments by a factor of at least 3:1.

The maximum mutation frequency observed, for the Dakota rust locus, approximated 1.2% (equivalent to 1 mutant per 84 survivors) for the LD90 dose with x-rays.

Drosophila Genetics

Chromosome structure has been examined in relation to the genetic effects produced by deficiencies of divalent metals, principally calcium and magnesium. A hypothesis has been followed according to which calcium and magnesium are in part responsible for the structural stability of the chromosome. Some Drosophila experiments were designed in which the metal chelating agent ethylenediaminetetraacetic acid (EDTA) was used to raise the frequency of both genetic crossingover and recessive lethals. The former was successfully accomplished, the latter was not. During these experiments an unusual phenomenon was noted, i.e., one in ten of an F2 progeny were dwarfs or midgets when grown on a standard Drosophila food containing 0.006 M EDTA. These dwarfs are termed "phenocopies" because selected pair matings had progeny of normal size when cultured on media without EDTA. Inbred lines started from single pairs of dwarfs were studied, and susceptibility to diminutive size in the presence of EDTA was found to be inherited. Some lines gave 30% dwarfs while others gave less than

Further experiments were done to find the principal metal tied up in the fly. Salts of magnesium, calcium, manganese, ferrous iron, cobalt, zinc, copper, and ferric iron were added to Drosophila food containing EDTA. By using the special properties of EDTA it was possible to show that zinc, and no metal before zinc, completely suppressed dwarfing. The metals are listed above in order of degree of stability, from lowest to highest. Zinc was apparently the critical metal required for normal size development in the presence of EDTA. The finding emphasized the fact that heavy metals were chelated before calcium or magnesium.

Genetic Relationships of Alkaloid Synthesis

The genus *Nicotiana* is uniquely suitable for relating chemical with genetic studies because alkaloids are characteristically present, the species relationships are well understood, and both interspecific hybridization and induced allopolyploidy are readily accomplished. Of the 60 recognized

species 52 have been obtained for study and 28 representative ones have now been analyzed for alkaloid content. In addition, 3 interspecific hybrids, 22 amphidiploids, and 7 three-species combinations have been analyzed.

The alkaloids can be rapidly and accurately determined by paper chromatography techniques. After extraction from green leaf material the alkaloids are separated by descending filter paper chromatography, and the spots are detected by the location of colored complexes formed by reaction with p-aminobenzoic acid and cyanogen bromide.

Of the 28 species tested 24 contain the three alkaloids nicotine, anabasine, and nornicotine; and in the remaining 4 one or two of these alkaloids were present. In 13 species the main alkaloid was nicotine, in 6 nornicotine, in 5 anabasine, and in 4 there were equal amounts of two of these principal alkaloids. In addition, at least six unknowns were detected which gave distinct RF values for colored spots on the chromatograms indicating that they are tertiary pyridine compounds. They are not reactive with ninhydrin or p-dimethylaminobenzaldehyde and therefore are not α - or β -amino acids or indoles. Observations on their absorption spectra in the ultraviolet region showed the unknowns to possess spectra of a characteristic alkaloid type. The individual Nicotiana species contained from none to all six of the unknowns. Eleven of those analyzed had five unknowns.

Among the amphidiploids all possible combinations of species with predominantly the same and with different main alkaloids were investigated. No generalizations have yet become evident except that each species combination is unique and essentially unpredictable. More precise methods for expressing alkaloid content quantitatively, which are now being developed, are needed for complete evaluation of the species combinations. With regard to the unknowns the results show that, according to the species hybridized, the amphidiploids may contain more or fewer than the parent species and they may be the same or different.

Arabidopsis as a Genetic Tool

The short growth cycle crucifer, Arabidopsis thaliana, is a promising experimental plant for genetic research. Since a complete generation, from sowing to harvest, can be obtained in about



Figure 8. Plants of *Arabidopsis thaliana* which are being developed as material suitable for studies in genetics of higher plants. These plants, shown full size, flower within 30 days of sowing the seed, which allows many generations per year. The plant on the right is a radiation-induced mutant having variegated leaves.

35 days under controlled conditions, it is particularly convenient for testing the effectiveness of various mutagenic agents.

Radiation of dry seed with gamma-rays and thermal neutrons shows the following. 1) The rate of seedling emergence is decreased gradually with dose, but if sufficient time is allowed ultimate emergence is not drastically affected even at the highest dose employed, 5×10^5 r. 2) In contrast, survival is abruptly affected within a very narrow range of doses. 3) The sublethal dose varies in dif-

ferent experiments depending apparently on the physiological state of the seed at the time of radiation. 4) In cultures obtained from different sublethal doses about 7% of the individual R2 and N2 families segregate for distinct, easily recognized seedling mutants which have not been observed in the control. 5) No striking differences were noted in rate of mutation from different sublethal doses, but the results are not yet conclusive. The total number of R2 families screened is not yet large enough, 64 for the sublethal dose of 2×10^4 r in one

experiment and 78 for the sublethal dose of 5×10^4 r in another experiment, with a total of 161 control cultures. 6) Of 16 distinct mutants found, one with variegated leaf has not been reported previously in *Arabidopsis*. The culture 90-49 which segregated for this unstable mutant consisted of 26 albino, 199 variegated, and 586 normal seedlings.

Immediate objectives are 1) to determine the conditions which modify a particular lot of seed to resist higher doses and 2) to ascertain whether or not an increase in sublethal dose, due to such modification, is associated with higher mutation rate. Answers to these questions may be obtained more quickly with *Arabidopsis* than with any other known higher plant.

Our observations suggest that Arabidopsis may be useful also in the study of certain geneticenvironment interactions affecting such characters as time of flowering and an unstable type of incompatibility.

Cooperative Radiation Mutation Program

This marks the fifth year of formal operation of the Brookhaven Cooperative Radiation Mutation Program, by means of which plant breeders and geneticists throughout the world have been able to make use of the radiation facilities at Brookhaven in their attempts at crop improvement. Growing plants have been irradiated in the gamma radiation field, and seeds and cuttings have been exposed to neutrons generated in the nuclear reactor or to x-rays from a 250-kvp therapy unit.

The interest in this new field is indicated by the number of projects initiated. Irradiations have been performed for some 150 scientists in the United States and Canada who have been testing more than 70 different crop plants. In addition, cooperative projects have been started with more than 30 scientists in 20 other nations representing all 5 of the other continents. The crops involved include most of the cereal grains, some grasses, trailing indigo, grape cuttings, abaca, cacao, coffee, soybeans, dates, almonds, rice, jute, rubber, and papaya, among others. Most of this work requires several years from the time the radiations are performed to the time mutations are selected and compared with existing varieties.

Fruit trees grown in the gamma field for one to three years and then removed and permitted to return to normal growth have been under analysis for possible mutations by cooperating investigators. Two beneficial mutations have been reported in the Fairhaven variety of peaches by scientists at Rutgers University. Fruit that ripens approximately 10 days earlier than that on the rest of the tree has appeared on one branch. A second branch on a different tree has produced fruit that ripens some three weeks more slowly than is characteristic. First observed last year, these two radiationinduced mutations have been confirmed this season. They are potentially capable of increasing by more than one month the season over which fruit of this variety can be available. Buds from these mutations will now be grafted onto other trees, and when a large enough population of these new types is established they will be tested for satisfactory quality with respect to other important criteria. These represent the first results reported from the fruit trees subjected to gamma irradiation in 1952 when this program was initiated.

CELL PHYSIOLOGY

The Mechanism of Duplication of Chromosomes

Information on the macromolecular organization of chromosomes and their mode of duplication has been difficult to obtain in spite of numerous attempts. One point of attack, long recognized but until recently unattainable, was the selective labeling of some component of the chromosome, the distribution of which could be seen in succeeding cell divisions. Thymidine appeared to be the constituent of DNA required for this experiment, but the labels so far employed have not been satisfactory for microscopic visualization by autoradiographic means. In order to determine whether an individual chromosome among several in a cell is radioactive, autoradiographs with resolution to chromosomal dimensions must be obtained. Resolution at this level is difficult if not impossible to obtain with most isotopes, since the range of their beta-particles is relatively great. Theoretically tritium should provide the highest resolution obtainable, since the beta-particles have a maximum energy of only 18 kev, corresponding to a range of little more than a micron in photographic emulsions. Consequently, the Medical Department had developed a method for preparing tritiumlabeled thymidine, and kindly provided some of this material with sufficiently high specific activity.

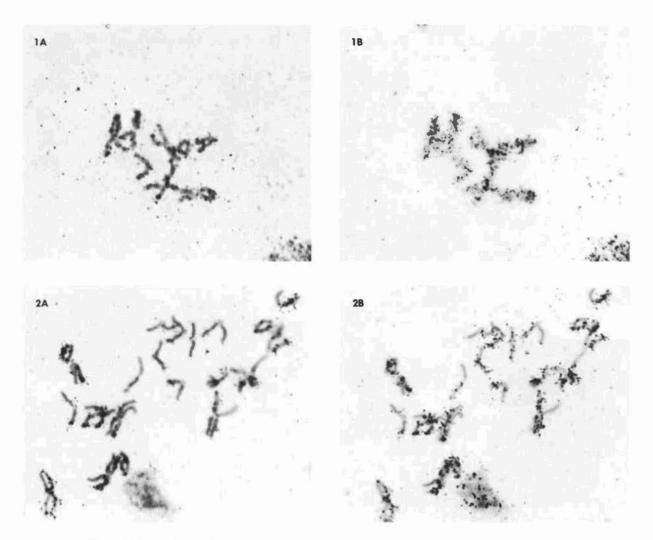


Figure. 9. Autoradiographs of chromosomes of *Vicia faba* labeled with tritium-labeled thymidine. On the left are photomicrographs taken with the microscope focused on the chromosomes, and on the right, focused on the photographic emulsion over the chromosomes. Above, 1A and 1B, are pictures of cells fixed shortly after a cell division executed in the labeled medium, and show that all chromosomes are uniformly labeled. The lower photographs, 2A and 2B, were taken following an additional cell division in unlabeled medium, and show that half the chromosomes are now labeled and half unlabeled.

Since thymidine is a precursor of DNA, growing cells in labeled thymidine should result in the labeling of the newly formed DNA molecules associated with the chromosomes. The distribution of these could then be followed in later divisions by means of autoradiographs.

Seedlings of *Vicia faba* were grown in a mineral nutrient solution containing this radioactive thymidine. This plant was selected because it has 12 large chromosomes, one pair of which is morphologically distinct, and because the length of the division cycle and the time of DNA synthesis

in the cycle are known. After growth of the seedlings in the isotope solution for the appropriate time, the roots were thoroughly washed with water and the seedlings were transferred to a nonradioactive mineral solution containing colchicine for further growth. At appropriate intervals roots were fixed, stained, and squashed on microscopic slides. Stripping film was applied and autoradiographs were prepared. The colchicine made it possible to determine by inspection how many cell divisions had taken place following the application of the colchicine. Thus, by proper timing it was

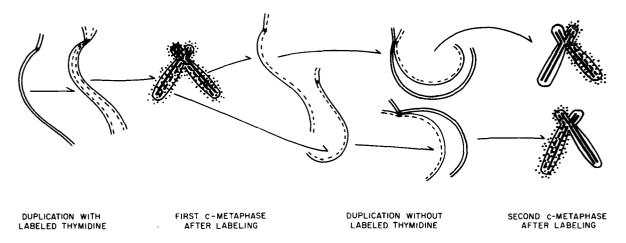


Figure 10. Schematic drawing of mechanism of chromosome duplication, as revealed by the autoradiographic study using tritium-labeled thymidine shown in Figure 9. In this study the normal chromosome was found to be composed of two strands of DNA, which replicated itself during cell division by a template mechanism.

possible to obtain cells which had undergone one, two, or three cell divisions after labeling by the tritium-labeled thymidine. Analysis of the autoradiographs showed that both daughter chromosomes resulting from duplication in the presence of labeled thymidine appeared to be equally and uniformly labeled. After an ensuing duplication in the absence of the labeled DNA precursor, the label appeared in only one of the two daughter chromosomes.

The autoradiographs showed conclusively that the thymidine built into the DNA of a chromosome is part of a physical entity that remains intact during succeeding replications and nuclear divisions except for an occasional chromatid exchange. They further showed that a chromosome is composed of two such entities probably complementary to each other. Thus, during cell division each of these entities replicates to form a chromosome with four entities. The chromosome divides so that each chromatid (daughter chromosome) regularly receives an "original" and a "new" unit.

On the basis of these results, a chromosome model has been constructed with two complementary units and a scheme of replication analogous to the Watson-Crick model of DNA.

Calcium Binding in Nuclei

Plants of *Lilium longiflorum* were grown in water culture containing the isotope calcium-45. After flowering the pollen was found to have incorporated some of the Ca⁴⁵ from the nutrient solution.

"Hot" pollen was put on the stigma of "cold" flowers. About two days after pollination the pollen tubes were dissected out from inside the hollow style of the flower and were fixed and covered with stripping film to detect the relatively soft radiation of the Ca⁴⁵ beta-rays. With the pollen tube technique Ca⁴⁵ in the cytoplasm is diluted manyfold (at least 1000 times). After a proper exposure time the stripping film was developed. It was most gratifying to find the high grain count over the nuclei and chromosomes and a low grain count, close to "background," over cytoplasm. These data indicate that calcium is firmly bound in the chromosomes, and also that Ca45 shows little if any exchange with nonradioactive calcium. The loss of Ca45 in the nucleus can be studied by varying the hydrogen ion concentration to ascertain the pH stability of the bound isotope. Such evidence can indicate whether or not phosphate ester groups of DNA (according to our hypothesis) are holding the calcium. The pollen tube technique can be used to test whether or not other metals or substances (protein or RNA) are in structural constituents of the chromosome.

Morphogenetic Studies

When seedlings of Kalanchoe "Brilliant Star" were given approximately 1500 r of x-rays applied to the shoot tip, temporary inhibition of leaf formation occurred. After resumption of leaf production, the process proceeds at a rate accelerated to the point that ultimately the irradiated plants

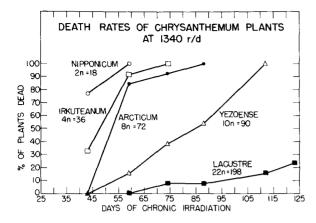


Figure 11. Graph showing radiation sensitivity of chrysanthemum plants having different degrees of polyploidy. The correlation shown here between radiosensitivity and polyploidy might be anticipated on theoretical grounds. However, there are unfortunately other plants in which no such correlation appears to exist, and reasons for this apparent contradiction are now under active investigation.

have a slightly greater number of leaves. The internodes which were developing most vigorously at the time of irradiation achieved only ca 50% of their normal length; but the internode which is produced immediately thereafter is about one-third longer than its control. When the youngest leaves were removed from irradiated plants during the post-irradiation period, the newly formed internodes were much shortened, but one exceptionally long internode was always present. Thus, the unusual combination of internode length reduction and elongation does not appear to be a simple auxin phenomenon. Both reduction and elongation appear to be due primarily to cell number rather than cell size.

When plants of the same species are exposed to chronic irradiation, the terminal growing point ceases to function normally at dose rates of about 240 r/day. At 50 r/day the rate of leaf production is merely slowed down to about 50% of the control rate. With increasing age of the plant at initiation of treatment, higher dosages are required for results of similar magnitude. Regardless of the dose applied (330 r/day maximum up to now) the activity of lateral growth centers is affected only to a minor extent, and ultimately even the cells of the terminal growing point resume their activity, although the original pattern of growth in terms of leaf arrangement and internode pattern is not maintained.

Tumor Induction

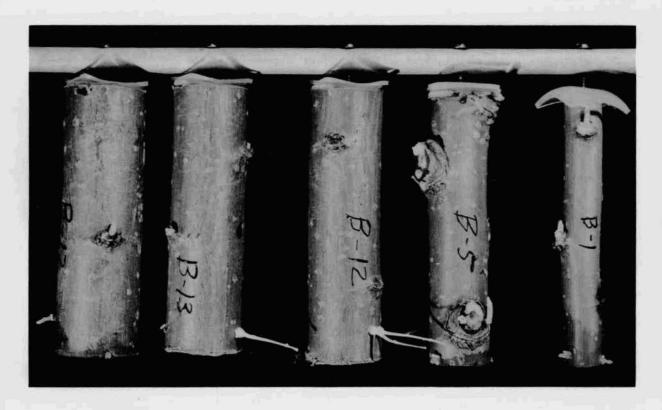
When plants of Graptopetalum paraguayense were exposed to semiacute irradiations, a high frequency of tumor-like growth centers was observed in the leaves. Anatomical studies indicated that these were de novo structures probably arising independently and at random in the mesophyll tissue. Ontogenetic studies are in progress to determine the origin and course of development of these structures. They appear to be quite different from the previously reported tumors produced on Nicotiana by radiation.

Auxin Metabolism

Studies on the control of root growth by light and growth hormones are being continued. Previous reports have established that a very sensitive system exists in the poplar stem by means of which root primordia, present in the stem, are inhibited from growing by very brief exposures to low intensity light. The most recent studies with this system indicate that the photoreceptor for the light inhibition is a pigment of the root primordium directly and not a pigment of the bark of the stem.

The role of auxin has been investigated with the idea in mind that light may be destroying auxin and thus accomplishing inhibition of root growth. Experiments involving the application of auxin to stem segments partially shielded from light indicate that in this material auxin is not appreciably destroyed by light and therefore probably is not involved in the root inhibition.

Previous work has shown that auxin, applied to the apex of stem segments taken from trees in active growth, will activate the growth of the root primordia present in the stem. The auxin will convert a segment on which roots are polarized and appear only at the base to an unpolarized condition in which the roots are uniformly distributed along the length of the segment. However, once activated, the subsequent growth of these roots cannot be affected even by very high concentrations of auxin. This finding appeared to contradict reports in the literature that roots are the most sensitive organ of the plant with respect to auxin and that they are generally inhibited by very low auxin concentrations. Roots were then immersed in auxin solutions of varying concentration and inhibition was obtained. This has been interpreted to mean that auxin must reach the root tip to bring about inhibition. This was accomplished by the



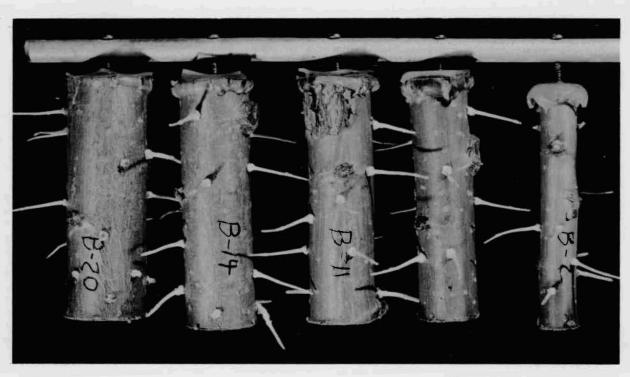


Figure 12. Poplar cuttings showing (top) normal root formation at the base of the cutting, and (bottom) root formation when auxin is added to the apex of each cutting through an agar block on top. This demonstrates that all parts of the cutting are quite capable of root production if it is initiated by the proper auxin concentration.

immersion experiment. However, when the auxin was applied to the stem and then translocated to the site of the root primordia and there activated their growth, the roots very quickly established a polarized condition which prevented auxin from being transported from the base of the organ apically. This one-way transport of auxin, from apex to base but not from base to apex, has long been recognized as a prominant feature of auxin physiology in the stem but has not hitherto been carefully considered in roots. The establishment of this unidirectional movement of auxin in roots may explain the apparent enigma that roots require relatively high auxin concentrations for initiation but are inhibited in growth by very low concentrations.

Nematode Research

Nematodes have long been known as important parasites of man and domestic animals. Within the last three decades the importance of nematodes as parasites of plants has been recognized. They are now known to parasitize most agricultural crops and ornamental plants, causing great loss of yield in many parts of the world. Their toll is slow and undramatic, and they are, for the most part, hidden in the soil.

The project was initiated to survey the radiosensitivity of plant parasitic and free-living soil nematodes. This information is of interest in itself, since comparatively little is known of the general biology of these forms. If some plant-nematode combinations exist in which the nematodes are more radiosensitive than the plants, a method may be found to free living plants of nematode infection. For example, *Trichinella spiralis*, a nematode parasite of swine, is sterilized at 10,000 r of x-irradiation. Many plants will survive this amount.

Two approaches have been followed. In the first pure cultures of parasites are established, and masses of infected roots are irradiated to serve as inoculum. The second method is to sample a mixed population of free-living and parasitic forms in infested soil before irradiation. Portions of this soil are then irradiated and potted as inoculum. After several months sampling is again carried out to determine at what dose each type of nematode failed to survive. Results on plant parasitic forms thus far have shown that root-knot nematodes continue to reproduce at 60,000 r of x-rays or gamma-rays; very few eggs are produced

after 120,000 r. Ditylenchus sp., a parasite of mushroom, reproduces slowly after 60,000 r but not at higher dosages; Pratylenchus sp., the meadow nematode, behaves like root-knot. Two forms of nonparasitic nematodes are carried in test tube cultures. The vinegar eel, Turbatrix aceti, fails to grow after 40,000 r; whereas Panagrellus silusiae, grown on oatmeal, is sterilized at 80,000 r.

Photosynthesis

Investigations on the biochemical properties of subcellular structures in plant and microbial organisms have continued. Particular emphasis has been placed on the funtion of the chloroplast of plant cells and its relationship to the whole process of photosynthesis. The capture of light energy by chlorophyll in the process of converting solar energy to bound chemical energy has long been known to occur on the chloroplast where the chlorophyll is bound. The production of chemical energy in the form of high energy phosphate and the fixation of carbon dioxide and its subsequent reduction to sugars have been under active investigation in the past several years. The association of these processes with the chloroplast structure has been shown in this and other laboratories. In the past year a detailed study has been made of both the energy metabolism and carbon dioxide fixation of a wide variety of photosynthetic organisms having a broad evolutionary span and an increasing complexity of chlorophyll containing structures.

By the use of C¹⁴O₂ in association with the processes of paper chromatography and autoradiography, all the steps in the fixation of CO₂ and the production of sugar have been shown to be associated with the chloroplast in one higher plant (spinach), several green algae, and the more primitive yellow-brown alga *Ochromonas*. In contrast the photosynthetic bacteria, the most primitive of the photosynthetic organisms studied which contain a plastid bound chlorophyll and energy producing system, do not contain a plastid bound CO₂ fixing system. Thus for the first time an intracellular separation of the energy conversion steps and the sugar synthesizing step of photosynthesis has been demonstrated.

Of extreme interest is the point that in these primitive photosynthetic sulfur producing bacteria a new light dependent carbon fixing mechanism has been discovered. This is the first time that a

second light dependent CO2 fixing step has been shown. The classical photosynthetic CO₂ fixing system involves the addition of CO2 to a fivecarbon sugar to give two three-carbon acid precursors on the way to sugar synthesis (ribose diphosphate + CO₂ → 2 phosphoglyceric acids). This new system involves the carboxylation of a three-carbon acid phosphate to give a four-carbon acid which is rapidly transferred to an amino acid (phosphoenolpyruvic acid + CO² → oxaloacetic acid + phosphate \(\frac{\tansaminated}{\tansaminated}\) aspartic acid). This reaction was recently discovered as a dark reaction in other organisms. However, here in photosynthesis we now have for the first time two simultaneous CO2 fixing steps dependent upon light, one leading to sugars and one directly to protein.

The study of the production of high energy phosphate by light, which is the plant's way of trapping solar energy, has been carried out in the photosynthetic bacteria *Chromatium*. Cellular particulates have been isolated and purified that contain all the photochemical pigments, and these structures can produce high energy phosphate from light. This process must be simpler than previously envisaged, as the size and composition of these structures (125 A) limits the amount of protein available for enzymatic activity. Studies using isotopes of both phosphorus and sulfur are under way which may clarify the actual mechanism of conversion of solar to chemical energy.

Membrane Permeability

The net os motic flux of water across a membrane separating solutions of different solute composition can be regarded as the difference between the rates of flow of water in the two directions. From experiments employing conventional chemical techniques it is possible to compute a permeation coefficient which should be applicable under all conditions to a particular membrane. It should be possible to check this coefficient directly by means of isotopically labeled water. When this has been done in the past, very wide discrepancies have been found between values obtained by the tracer experiments and by computation.

One hypothesis advanced to account for this discrepancy assumes that water flows through these membranes not only by diffusion, as previously supposed, but also by bulk movement of fluid through relatively large pores, whenever

there is a difference in the solute concentrations of the two solutions.

Experiments have recently been initiated in order to elucidate this discrepancy and to prove or disprove the bulk flow concept. In these experiments pressure applied to one of the solutions has been used as a parameter, and the change in permeation coefficient has been measured as a function of pressure by isotopic tracer methods as well as by conventional chemical ones.

The experiments are by no means complete, but results to date are consistent with the idea that it is not necessary to invoke the additional concept of bulk flow to explain net water flow due to solute concentration differences. Probably a change in the assumptions usually made in computing the permeation coefficient under the different conditions will reconcile the present discrepancies and allow these flows to be explained entirely on the basis of classical diffusion ideas.

BIOCHEMISTRY

The Active Site of Enzyme Action

Enzymes are the key protein molecules which catalyze the dynamic processes in biological systems. Because they are large molecules whereas a number of compounds on which they act are small, it has long been felt that only a small portion of the enzyme actually takes part in the reaction. Recent work supports this finding, but work to establish the structure of the "active site" has been delayed because it has not been possible to identify this site. Either the label used is stable but acts at positions other than the active site, or it acts only at the active site but migrates or decomposes when the enzyme is degraded. By choosing an enzyme, phosphoglucomutase, which is known to be phosphorylated, it has been possible to label the protein with P32 without destroying the enzyme's activity. By suitable chemical tests the label was shown to be present only at the active site and to stay on the same amino acid during the degradation of the protein. In this way it was shown that serine is the amino acid at the active site to which the phosphate is attached.

Moreover, by using this radioactive serine as a marker, it has been possible to "map out" other amino acids at the active site. It has been found, for example, that six of these are the same for the enzyme phosphoglucomutase as they are for the en-

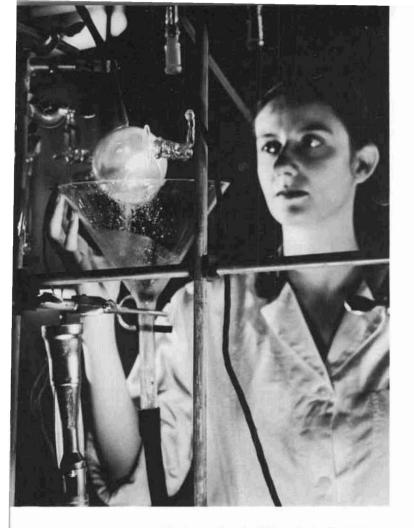


Figure 13. To determine the O¹⁸ content of phosphate compounds the phosphate is converted to carbon monoxide, which is assayed in the mass spectrometer by enclosing the sample and pure carbon in a molybdenum foil heated to 1350°C while the outside of the evacuated bulb is cooled by a stream of water. In the experiment shown here this technique was used to study the chemical links in tobacco mosaic virus.

zyme chymotrypsin. Since these enzymes have very different specificities, i.e., they act on very differently shaped molecules, it is concluded that these six amino acids are involved in the bond-breaking function of the enzyme and not in the specificity part. This is one of the first clues relating enzyme structure to function.

The Glucose-Galactose Interconversion

It has been known for some time that biological systems, mammalian as well as bacterial, can convert glucose to galactose. Four alternative pathways were possible, and consideration showed that the combined use of the isotopes tritium and oxygen-18 would indicate which was correct. The displacement pathway would give O¹⁸ but no

tritium in the product, whereas the aldol cleavage pathway would give tritium but no O^{18} . Dehydration-rehydration would give both O^{18} and tritium incorporation, whereas oxidation-reduction would give neither. Performing the experiment in T_2O^{18} indicated that the oxidation-reduction pathway was the correct one, and later the coenzyme (DPN) responsible for the conversion was identified.

The Synthesis of Hemin

Protoheme, a complex of iron and protoporphyrin, combines with a number of proteins to give biologically active substances, e.g., hemoglobin, the oxygen-carrying pigment of red blood cells, is the combination of heme and the protein globin. Other examples are the cytochromes, each made up of heme and a particler protein, that are concerned in the oxidative metabolism of foodstuffs.

Some information has been obtained about the formation of heme from the red cells of the duck. Duck blood is used because, like that of other birds, it contains a greater proportion of young red cells than the blood of mammals. When the duck blood is incubated with ionic radioactive iron, some of the iron can be recovered as hemin, a form of protoheme. Likewise, when extracts of the red cells are incubated with iron and porphyrin, the iron can be recovered as hemin. The heme-forming activity of the cell extracts depends on the acidity and temperature at which the reaction is run and is lost upon heating. Thus, a protein may be involved in the activity and the protein may be an enzyme, although this is not yet certain.

X-irradiation of the animal has little effect on the heme-forming activity of blood cell extracts. This is in contrast to the loss of the ability of the intact cells to take up iron after irradiation of the animal. Presumably iron uptake is a function of the age of the cells, while heme formation is not.

The Mechanism of Enzyme Inactivation

The enzyme D-amino acid oxidase consists of a flavin component and a protein in reversible combination. The oxidase and its protein component are each inactivated by oxygen, in both cases by action on the protein. Substances that combine with the oxidase and inhibit its enzymic action protect it against inactivation by oxygen. However, the substances do not protect the protein alone against inactivation by oxygen. It appears, therefore, that in the formation of inhibitor-

oxidase complexes, the order of events is reaction between protein and flavin to form the oxidase and then reaction between oxidase and inhibitor.

There may be a parallel between these findings and the protective effect of various substances against irradiation. In part such protection is afforded by supplying the organism material that provides for attack an alternate to tissue components. A further component of such protection may result from specific reaction between the protective substances and tissue components.

Radiation Decomposition of Yeast

Yeast cells, Saccharomyces cereviceae, uniformly labeled with P³² lose a negligible amount of radioactivity to the suspending medium over two periods of 24 hr. Irradiation of the cells with ultraviolet light from a high-pressure mercury arc delivering 178 erg/mm²/sec to the surface of a stirred yeast suspension causes a dramatic release of P³² to the medium. Cells irradiated for 20 min lose 50% of their phosphate in a 4-hr period.

The nature of the phosphate compounds escaping from the cell has been studied by paper chromatography. Inorganic phosphate, phosphoglyceric acid, and adenylic acid have been identified. Adenosine triphosphate and adenosine diphosphate are not present. A number of phosphate compounds are present which adsorb on charcoal and absorb maximally in the vicinity of 260 mµ. These are probably nucleotides, but none of them can be chromatographically identified with the well-known mono-, di-, or trinucleotides. A phosphopeptide and two other peptides are also found in the leakage mixture. The following free amino acids have been identified: aspartic acid, glutamic acid, alanine, glycine, threonine, valine, phenylalanine, proline, hydroxyproline, and asparagine.

A comparison of the chromatograms of leakage substances with those of alcohol extracts of non-irradiated cells reveals that certain substances, e.g., the above-mentioned phosphopeptide and several nucleotides, are not free in the cell. It may be inferred that these compounds appear in the medium as a result of photodegradation of cellular materials or because of the stimulation of synthesis in the cell. It seems that this is a system in which specific chemical changes in cells caused by the absorption of radiant energy can be studied.

BIOPHYSICS

Neutron Irradiation Facilities

Further work has continued on the calibration of the thermal and fast neutron irradiation facilities. Tissue equivalent ionization chambers have been constructed and tested, and as a result neutron measurements now seem quite accurate.

Cosmotron Studies

One prevalent theory of radiobiological effect is that the biological effectiveness of a particular type of radiation is directly proportional to its linear energy transfer (LET) value. Most radiations, including low energy neutrons and protons, fit this concept very well. As the energy of the protons is increased, the LET decreases, and at energies in the billion-volt region it should be at or below that of gamma-rays. This then should afford an excellent test of the theory, since, if protons at this energy do indeed behave biologically like gamma-rays, then it seems entirely reasonable to generalize and assume that all biological effects are proportional to the LET of the radiation producing them.

Two experiments have been performed with the external proton beam of the Cosmotron. In the first both mice and *Habrobracon* (wasp) eggs were exposed. The exposure times were not gauged very accurately, but results with both materials indicated a biological effectiveness about equal to that of gamma-rays. The second experiment, with mice only, indicated a somewhat higher value. The dosimetry in these experiments was not perfect, but probably the worst source of error was the inhomogeniety of the proton beam. Thus the monitoring film and chambers averaged a different dose than did the mice. This is especially unfortunate in the case of mice, since one small section of bone marrow receiving an appreciably lower dose than the rest of the body can afford a large measure of protection. However, it seems safe to conclude at the present time that the effectiveness of this radiation is not greatly different from that of gamma-rays, and more precise values must await further experiments.

Relative Biological Effectiveness (rbe)

Since the fast neutron facility is now quite well calibrated, a study was undertaken to measure the rbe of fast neutrons vs x-rays. Values for this constant in the literature range from 1 to almost 5.

The neutron flux and energy spectrum being known, a calculation could be made of the energy released by this flux in tissue, and this was checked by means of a tissue equivalent ionization chamber. The value obtained, with the mid-lethal dose for mice as the biological criterion, was 1.7. This is almost identical to the latest value from Los Alamos, and differs considerably from a number of recent values from other laboratories.

Delayed Radiation Effects in Seeds

When a biological material is subjected to radiation, the direct effects of the radiation are assumed to be complete a small fraction of a second after the cessation of the treatment. In some studies on dose rate effect in dormant seeds, it was discovered that following an x-ray treatment the seeds continued to exhibit injury for long periods of time. In other words, seeds irradiated and germinated immediately showed far less damage than seeds given the same treatment but stored even for a few hours before germination.

An analysis of the effect shows that the curve of damage vs storage time has two principal components, a fast component complete in 24 hr or less and a slow component which lasts for many weeks. The effect is highly dependent on the water content of the seed during and after the exposure. At low moisture contents the seeds show a very large fast component; at high moisture contents they show almost no fast component, but a large slow component. This aftereffect can be very large; on analysis in some conditions the immediate damage amounts to only about 5% of the total damage if the seeds are stored for several weeks after irradiation.

If dry and moist seeds are irradiated under anoxic conditions and planted immediately after treatment, then the damage noted will be about the same in each. In other words, the large radio-biological difference reported for dry and moist seeds has been due entirely to this unsuspected storage effect. These aftereffects can be retarded indefinitely by storage at dry ice temperatures and conversely can be accelerated markedly by storage at elevated temperatures.

Oxygen is of paramount importance in this effect. Seeds stored in oxygen following irradiation show a much greater damage than those stored in vacuo. It makes a great difference whether the seeds are hydrated for germination with or with-

out oxygen present in the water. Thus it appears as if radicals were formed by the radiation which need oxygen in order to produce irreparable biological damage. If oxygen-free water reaches the cells before oxygen, then the radicals are neutralized and no further damage is produced.

These findings are obviously of very great importance for a general understanding of radiobiological action.

Radiobiological Theory

It is now widely accepted that the principal action of ionizing radiation on water is to produce H₃O⁺ and OH⁻ ions and OH and H radicals. Since many solutes can react with at least one of the above species of ions or radicals, irradiation of dilute solutions can provide information concerning both the reactivity of the solute surface toward activated water products and also the proportion of the reactive surface which is critical for biological activity. A revised mathematical treatment has been developed for treating those reactions with radicals which produce solute inactivation. In it inactivation is treated as three distinct processes with associated probabilities: 1) k = the probability of collision between solute and radical; 2) R = the probability that a collision will destroy the radical; and 3) S = the probability that destruction of the radical will lead to solute inactivation. The factor k can be calculated and R and Sseparated by plotting the reciprocal of the inactivation yield against the reciprocal of solute concentration: a straight line results with intercept 1/S and a slope which depends upon 1/R.

Irradiation of very dilute solutions of methylene blue and trypsin has verified the essential predictions of the theory, and preliminary results indicate that both the R and S of these two solutes depend upon pH and anion complement. It has also been found that the active site of trypsin (in 0.004 M NaH₂PO₄) occupies less than 12% (500 A²) of its surface area. A reanalysis of data published by McDonald suggests that activated ions as well as activated radicals may be capable of producing protein inactivation, since there appear to be two modes of inactivation at larger concentrations; one follows the kinetics described above, and the other kinetics usually associated with the production of an ionization in a target volume. However, in this case the estimated targets are much larger than the molecular volumes.

Medical Research

During the report year the Medical Department operated to the capacity of its present buildings. The new Medical Center now under construction for over one year should become available during the coming fiscal year, and the staff awaits the move to the new quarters with pleasurable anticipation. The investigations carried on during the past year are in the same general fields of interest as previously reported, but the work has become more intensive and there has been a marked increase in joint exploration of interrelationships of phenomona of interest to the different investigators. The work in the Medical Department provides an excellent example of the interrelationship of fundamental research, applied

research, and technological development. In this report only the major developments can be discussed.

NEUTRONS: BIOLOGICAL EFFECTS AND THERAPEUTIC APPLICATIONS

The extensive problem of neutron capture therapy has engaged the attention of a large number of Department members in a variety of experimental studies. These have ranged from further actual procedural tests in patients with glioblastoma multiforme (a malignant brain tumor) to studies aimed at giving a better model for dosimetric considerations. This year the first tentative



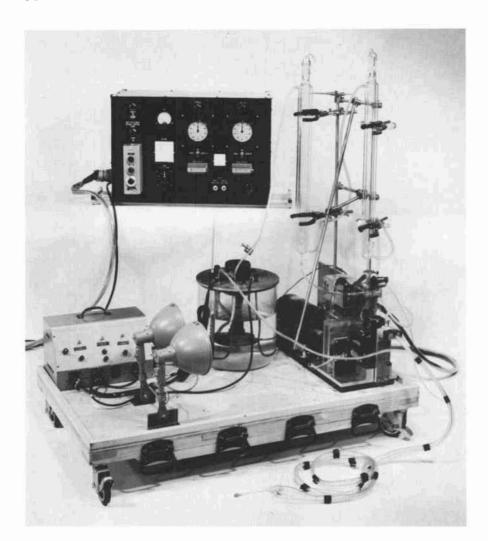


Figure 2. Remotely controlled injection apparatus for patients.

Figure 3. Control panel for remotely controlled injection apparatus for patients.



clinical trials were made with a new boron compound, sodium pentaborate, which, on the basis of animal studies, appeared to be less toxic and to have other pharmacological and physiological qualities making it more effective than the previously used sodium tetraborate borax. Careful clinical trials indicated that this new compound was safe to administer in the requisite dosage. Previously serious complications had occurred in the skin over the irradiated area; but it was believed that changing the route of administration might so alter the time at which significant skin concentration of boron accumulates that these complications could be avoided. Both animal studies (on pigs) and studies in patients were in general agreement regarding the relative rate of accumulation of boron in skin. Although the parameters of safe dosage of boron and thermal neutrons in skin have not yet been exactly determined, sufficient data were at hand so that with these clinical trials it was possible to establish a period of radiation of patients which, while having a presumed therapeutic effect, would not provoke a skin complication. With this new technique of intra-arterial injection, the main artery is used which supplies the hemisphere of the brain in which the tumor occurs. To make this procedure practical, it was necessary to develop equipment which could permit the solution to be injected at any desired rate and would deliver a calibrated, reproducible dose with time depending on the rate chosen, which would permit changes in rate at will, and which would permit shifting from one solution to another by remote control without approach to the patient. Added requirements were control of the temperature of the injected solution and multiple checks of the volume administered. Not without difficulty, and with the engineering assistance of members of the Hot Laboratory staff, a device has been developed which meets all these requirements and, because of its reliability, also gives promise of wide use in the administration of radioactive isotopes for therapeutic purposes. During this fiscal year neutron capture therapy has been administered to seven patients, all in a very advanced stage of the disease. A number of further technical procedural maneuvers remain to be perfected, but the main problems presented by this administration procedure seem to have been solved. Efforts in the immediate future will be concerned chiefly with procedural maneuvers so that advantage may be

taken of the opportunities presented by the new medical reactor as soon as it is ready for clinical use.

During this period of procedural development, studies have continued on the control of a transplantable highly invasive brain tumor of mice. Neutron capture therapy has been used in vivo, and the treated tumor then transplanted to determine the effects of the treatment. By this means, the parameters of effective exposure are being determined with regard to total neutron exposure with a given boron concentration. This experimental model has rather clearly demonstrated an increased effectiveness of boron when given as pentaborate rather than as tetraborate in equivalent boron dosage. These differences are due to qualitative and quantitative advantages gained by the difference in physiological response to the two compounds. The preliminary study on control of this experimental tumor is expected to be completed during the coming fiscal year. It will have required three years for its completion, partly because it was necessary to establish each point before the next study could be planned.

Extensive studies on the skin of pigs following thermal neutron exposure with and without boron administration demonstrated that severe skin lesions could be produced in the pig which appear to be the counterpart of the complicating skin lesion seen in some patients treated with the older procedural technique. Heavy neutron exposures alone did not appear to cause histological changes in skin structures. Long-term effects of such exposures were not studied.

Studies were made on mice of the acute relative biological effects of thermal neutrons and of the heavy particles from the $B^{10}(n,\alpha)Li^{7}$ reaction, with Co⁶⁰ gamma radiation or x-radiation used as the basis for comparison. The mice were irradiated in the medical facility of the reactor at an average flux of 1.5×10^9 n/cm²-sec. The procedures used for estimating the integrated flux were checked by intercalibration studies with the Naval Radiological Defense Laboratory in San Francisco and the Los Alamos Scientific Laboratory. With the degrees of spleen and thymus weight depression used as the indices, the apparent rbe of thermal neutrons alone was found to be 3.8 relative to Co60 gamma radiation. The apparent rbe of the heavy particles from slow neutron capture was found to be approximately 1.6; this was increased to 2.5

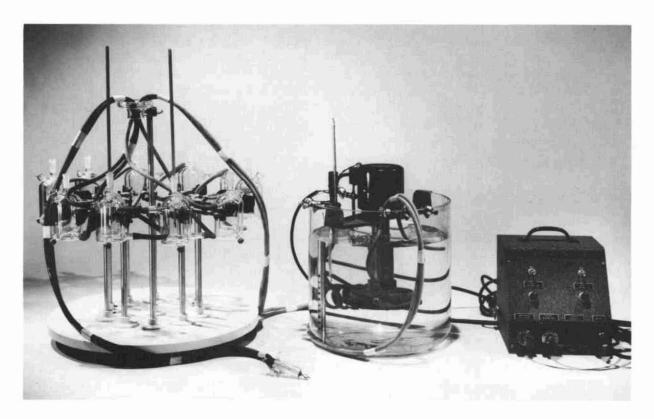


Figure 4. Heated water jacketed apparatus employed for injecting boron compounds into mice.

if only the energy liberated by the α -particle was considered in the rep determination. The significance of these studies in relation to the dosimetry of neutron capture therapy makes it desirable to continue them and ultimately to obtain more precise data under circumstances in which the assumptions necessary for calculating energy liberation within a single cell may be based on quantitative experimentation. Certainly without more data extrapolation of spleen and thymus effects to neoplasia responses must be very cautiously done, yet this is the best information currently available. Studies with mice were also carried out on the degree to which recovery from gamma irradiation and from heavy particle irradiation is possible. The method used was to give a second large exposure some weeks after the initial exposure. These procedures failed to elicit a significant "nonrecoverable" portion of radiation injury at any of the time intervals tested.

Some other aspects of this same problem were studied in experiments designed to determine the general pattern of slow neutron penetration of tissues. Because of the limited number of studies that can be done with tissues of interest, it was desirable to carry out the basic work with tissue equivalent phantoms which then could be shown to have characteristics similar to tissue. Foil activation techniques were used. In this project it was determined that a half-value layer of tissue for thermal neutrons is of the order of 2 cm. This figure has been used in estimations of the effectiveness of the Medical Research Reactor for neutron capture therapy.

To further our studies on neutrons, an adaptation of an existing ionization chamber has been developed which will be more useful for measurements in the neutron field of the medical reactor facility. By means of interchangeable chamber and electrode pieces it can be adapted to measure either the total tissue equivalent radiation dose or the gamma radiation component only.

In other directions quite diverse studies have been done. The effect of borax solutions upon the myocardium has been studied with the use of isolated heart preparations. In most of the observations the borax-glucose complex gave a considerably smaller response than that observed when borax alone was administered. These findings have buttressed our belief based on clinical observations that glucose may exert some type of protective action on the myocardium against borax.

Insofar as the central nervous system itself is concerned, we do not yet know the mechanisms nor the pathways which permit boron compounds to be distributed in normal nervous tissue. Other studies not immediately related have, however, borne on the role of carbohydrate metabolism in control of the cerebral excitatory state. Studies have been done to determine the possibility of correlating the central tranquilizing or excitatory actions of phenothiazine derivatives with their comparative effects on the glucose catabolism of isolated cerebral tissues. The study of transfer of carbohydrates from blood stream to nervous cell is under continuing development. The adequate maintenance of a relatively isolated brain presents many baffling technical problems.

A very extensive topographical and histological study has been started of the effects of neutrons on various regions of the brain, its nuclei and tracts. It is planned to examine the entire brain following autopsy to determine whether any detectable radiation changes can be demonstrated in those sections free of neoplasia, as well as to determine the extent, nature, and intensity of the changes which may have occurred within the tumor tissue. This study is being done jointly with the Department of Anatomy, Harvard Medical School, and the Armed Forces Institute of Pathology. The first three specimens which have become available for examination have shown a very gratifying restriction of apparent radiation effects to the neoplastic cells or to regions in which the neoplasm existed but had been eliminated. Until the entire series has been examined by these serial section techniques, no final conclusions can be drawn. At the same time the interrelationships and interaction between the neoplastic structures and all other parts of the brain are being studied in order to throw further light on the nature of neoplastic diseases of the central nervous system.

PROTEIN METABOLISM

During the past year chemical studies on protein metabolism have largely been concerned with collagen and glycoproteins. Also, more physiological studies have been conducted on the rate of disappearance of I¹³¹-tagged proteins derived from patients with and without various types of malignant lesions.

Collagen contains a unique amino acid, 5hydroxylysine, which was first discovered by D.D. Van Slyke. Since this is not an essential component of the diet, a knowledge of its metabolism may clarify the whole process of collagen formation and its fate. Studies were carried out in one instance to determine whether, in young growing rats, dietary hydroxylysine could serve as a precursor of the hydroxylysine residues of collagen. Previous studies had utilized a C14 label. In the present study both tritium and carbon labeling were employed. Skin collagen was used for analysis. Experiments carried out with DL-hydroxylysine labeled in carbon atom 6 with either C14 or tritium showed that dietary hydroxylysine is not a direct precursor of the collagen hydroxylysine. Following tritium labeling of hydroxylysine and its administration, or HTO administration, a small but measurable amount of tritium was incorporated into collagen hydroxylysine, presumably via lysine molecules, since the lysine of the collagen also contained detectable amounts of tritium.

In other studies efforts were made to determine the nature of the protein associated with the urinary acid mucopolysaccharide, which is a fraction similar to chondroitin sulfate. The excretion of this mucopolysaccharide has been found to be increased in untreated patients with rheumatoid arthritis and to decrease when the patient is treated either with salicylates or steroids. The preparation for protein study was obtained from urine, and analysis was carried out for elemental nitrogen, hexosamine and sialic acid by paper chromatography and ultracentrifugation. Certain characteristics capable of description by these methods were established. In another project on glycoproteins, orosomucoid, the α_1 -acid glycoprotein of human plasma, was studied. It is desirable to learn more about the nature and fate of glycoproteins, since x-irradiation has been reported to increase the glycoprotein content of human plasma. Orosomucoid is desirable for such a study because it can be obtained in a pure state and because it is the best characterized of all the plasma glycoproteins. It is composed of about 60% polypeptide and about 40% polysaccharide. A noteworthy feature of the polysaccharide part is

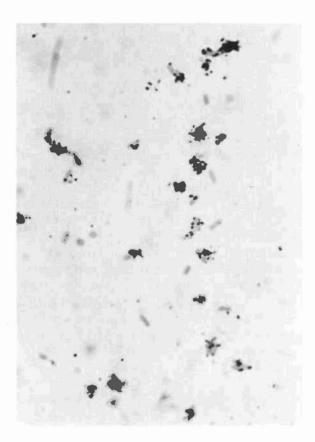


Figure 5. Bacteria (E. coli) three generations following labeling with tritiated thymidine. Note that intensity of labeling varies and that unlabeled cells have emerged.

that it is one quarter sialic acid. During a search for another type of analysis, it was discovered that an enzyme produced by a certain strain of *Clostridium perfringens* hydrolyzes the sialic acid while preserving intact the fragment of the glycoprotein. The sialic acid residues in glycoproteins have been thought to confer to mucoids the property of inhibiting the hemeagglutination brought about by influenza virus. The residues combine with the virus. The studies on glycoproteins are continuing.

In a different type of approach the disappearance rate of I¹³¹-labeled globulins is being studied in normal individuals and in patients with and without neoplastic disease. The turnover of individually tagged components of gamma-2 globulin is being determined in both man and animals.

The purpose of the basic clinical study under way is to find out whether a characteristic halflife can be determined for tagged fractions of serum proteins in neoplastic diseases. Since it had

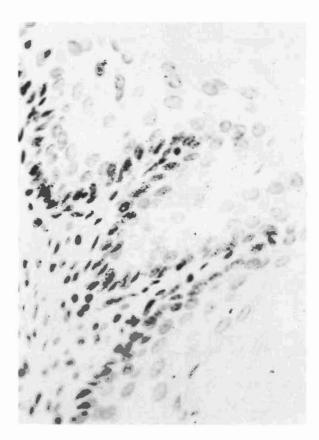


Figure 6. Tritium-labeled cells of stomach epithelium. Labeled cells are evident 7 hr after mouse received injection of tritiated thymidine.

been demonstrated here previously that in both animal and human tumors the growing neoplasm acted as a foreign protein eliciting an antibody response and that the latter occurred in highest concentration in the gamma-2 globulin fraction, this fraction was selected for labeling with I131. The turnover rate of normal gamma-2 globulin is first established in the patient, then the turnover rate of the patient's own gamma-2 globulin, and finally the turnover rate of gamma-2 globulin from a patient with a similar disease is determined in the original patient. By comparison of these turnovers, data are being accumulated to establish whether or not this procedure can be used as a diagnostic test for cancer. Theoretically, the cancer gamma-2 globulin should be turned over more rapidly than the normal; because, when it unites with the cancerous tissue as it circulates through the body, it should be destroyed in the antigenantibody reaction, whereas normal gamma-2 globulin should have been utilized only in the

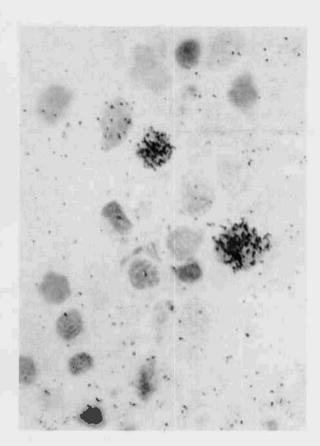


Figure 7. Chicken bone marrow labeled *in vitro* with tritiated thymidine.

normal sequence of ordinary protein metabolism. In conjunction with this study, the same preparations are being injected into rabbits to see whether the rabbit in its metabolism can distinguish between normal and cancer gamma-2 globulin. A further study in this field is being carried out in the mouse, in which the degradation rate of these tagged preparations is being determined by whole-body counts. Similarly, albumin is being studied in the mouse and subsequently will be studied in man and the rabbit.

The studies on protein metabolic relations existing between host and *Trichinella* parasites were further extended with observations on the fate of glycine-1-C¹⁴ and DL-alanine-1-C¹⁴ fed to infected mice. Isolated *Trichinella* muscle larvae were also cultured and their uptake likewise studied. The larvae were found to take up significant amounts of the labeled amino acids under both the *in vivo* and *in vitro* conditions employed. In another project a procedure was devised whereby it is possible to label thymidine and thymine with

tritium by means of a catalyzed exchange with hydrogen on the pyrimidine ring. The resultant tritium-carbon bond remains stable under a wide range of conditions. Administration of tritiated thymidine to a cell or animal is followed by labeling of the nucleic acids. This type of labeling has been accomplished with plant cells, with bacterial cells, with human tissue culture cells, and in intact animals. The labeled acids in chromosomes can readily be followed by means of radioautographs and the distribution of the label determined through successive generations. The mechanisms of cell division can be explored to a considerable degree by this procedure. In E. coli cells and in the bean, Vicia faba, the label does not appear to interfere with cell division.

CARBOHYDRATE METABOLISM

Studies of carbohydrate metabolism utilizing C14 have continued during this year. These included studies on patients with diabetes mellitus admitted to the hospital and experimental observations carried out in the laboratories of the Department. Ethanol-1-C14 was administered orally to determine whether, in the metabolism of alcohol, the intermediate aldehyde condensed with carbon dioxide to form pyruvic acid or whether acetaldehyde was converted to glycoaldehyde. While the limited amounts of radioactivity prevented extremely accurate measurement of the C14 in the 1, 2, 5 and 6 carbons, it could be determined that each of these carbons contained less than 5 to 10% of the total C14. Since the distribution was similar to that previously found for C14 from a carboxyl-labeled fatty acid, the results support the previous evidence for conversion of ethanol to acetic acid.

In another study the metabolic pathways of pentose formation by mammalian species were explored. Partially hepatectomized rats were injected with glycine-1-C¹⁴ or glycine-2-C¹⁴. The pattern of C¹⁴ distribution in desoxyribose was such as to indicate a metabolic pathway of synthesis of desoxyribose comprising a combination of a 3-carbon unit and a 2-carbon unit and to preclude an origin via glucose. The carbon-2 precursor, however, does not appear to be the same as that postulated for ribose synthesis, and thus desoxyribose does not appear to derive directly from ribose. The data suggest consider-

able activity of the hexose monophosphate oxidation pathway (pentose cycle) with extensive transketolations and transaldolations.

Other researches concerned the immediate effects of administration of adrenal steroid hormones on the major metabolic fates of intermediaries of fats and carbohydrates. Information was sought regarding the general influence of adrenal steroid hormones on the relative disposition of the common "2-carbon unit" of metabolism among various possible synthetic and catabolic pathways. Again, stable diabetic patients were used. Study of C14-pyruvic acid and αketoglutaric acid in the blood with analysis of the C14O2 of the breath was done to determine steroid effects. An effect could be shown which was accentuated by using prednisone, a synthetic analogue of cortisone. Analysis of results has not yet been completed.

Another facet of carbohydrate metabolism studied was the active transfer of monosaccharides and related substances in both entry to and exit from the red cell. Attention was primarily directed toward delineation of the nature of selectivity shown by the carrier system which appears to facilitate passage of certain of the substances through this cell membrane. A very high degree of steric selectivity in the process has been demonstrated in marked differences in movements, not only between the several isomers in a series of sugars, but even between D- and L-enantiomorphs and anomers. Tests of the validity of tentative hypotheses are being carried out with rare sugars as they can be secured. Also, competition inhibitor specificity is being studied; in this phase of the work, by far the greatest specific carrier affinity (as demonstrated by the competitive kinetics of inhibition) is phloretin. Efforts to delimit the essential configuration of this molecule, which makes for this special affinity, have not as yet revealed any primary locus of interest.

LIPID METABOLISM

Studies have continued on lipid metabolism with radioactive carbon as a label for the compounds of interest. The incorporation of acetate-2-C¹⁴ into cholesterol was studied in animals made hyperlipemic and hypercholesteremic by the injection of the aminonucleoside from the antibiotic puramycin. Decreases in total lipids and phos-

phatides, yet with a rise in total cholesterol, were found in the liver. In the kidney the same two lipid fractions decreased with the free cholesterol also decreasing but with a rise in esterified cholesterol. There was a diminished incorporation of acetate-2-C14 into the cholesterol isolated from plasma, liver, and kidney in the lipemic animals. The results are in accord with the concept that the injection of the aminonucleoside produced an impairment in the ability of the liver to remove lipid from plasma. It is of interest that compounds related in chemical structure to aminonucleoside failed to produce hyperlipemia or hypercholesteremia. In another study the incorporation was observed of glycerol-1,3-C14 into the triglycerides and phosphatides of human serum and serum lipoproteins. The observations were made on a patient with idiopathic hyperlipemia, an uncommon and little understood abnormality. A difference was found in the rates of incorporation of the labeled compound into the fractions studied. The activity of serum triglycerides was maximal at 4 hr; thereafter its decline was fairly rapid, with a half maximal activity occurring at 16 hr. The peak activity of serum phosphatides was 1/8 that of the triglycerides and was not reached until 10 hr after the administration of the labeled glycerol; half maximal activity was at 60 hr. At 7 hr the specific activity of the β -lipoprotein triglycerides was about 2½ times that of the αlipoprotein triglycerides, and the label was lost in the β -lipoprotein triglycerides at a greater rate than in the α -lipoprotein triglycerides.

MINERAL METABOLISM

Since its inception this Department has been deeply interested in the metabolism of mineral elements. Particularly, studies have been made on the kinetics of distribution of a number of the common constituents of body fluids, as well as on the effects of these elements upon metabolism and physiological state. During this year an extensive consideration of tracer theory was published. While it is applicable to tracers in general, it was evoked largely by studies on and interests in the metabolism of inorganic compounds. As the studies with elemental compounds have progressed with the use of tracer materials, it has become increasingly clear that many of our concepts regarding the behavior of mineral salts must be

modified; and, while sufficient data have not yet been obtained adequately to describe relationships under all conditions, each succeeding experimental observation becomes more rewarding.

An example of this is the study of the kinetics of distribution and metabolism of manganese. In particular, the kinetics of intracellular distribution of Mn54 and Mn56 in liver and brain have been studied. Observations on the behavior of manganese suggested a multicompartment system, which probably consists of one very fast component as yet unidentified in anatomical or physiological terms, and slower components associated with nuclei, mitochondria, or soluble cytoplasmic material. It has been established that manganous, manganic, and permanganic salts always markedly increased the turnover of radioactive manganese. The specificity of the manganese pathways is attested to by the fact that no major effect on manganese distribution or turnover could be elicited by injection of bivalent salts of copper, zinc, nickel, chromium, vanadium, cobalt, or iron in large amounts at various intervals following the injection of manganese sulfate. Likewise, no effects were noted when bromide, iodide, and rhenatex compounds were used. It was not expected that no effects would be seen on distribution kinetics with the other members of the transition group, or with those elements of Group VII in the valences studied.

In a major portion of the manganese study, a further attempt was made to localize radiomanganese in the liver of rats in order to develop a method for specific internal radiation of this organ that might have application in the control of malignant diseases. A localization of 90 to 100% of the injected dose was achieved when injections into the superior mesenteric vein were made. The isotope apeared to remain almost exclusively in the liver for about 2 to 2.5 hr. Surprising and as yet unexplained is the fact that the deposition in the liver was inhomogeneous; the extreme left segment contained 3 to 7 times the concentration of the extreme right segment for approximately 3 hr. Thereafter, a slow enrichment of other body sites by Mn54 was seen. Data suggest that a large fraction of liver manganese is excreted into the gut, while a smaller amount is distributed through the body.

In patients with Parkinson's disease, the studies on manganese kinetics continue. As yet it is not

possible to make any practical applications of the observations on the difference in behavior of radioactive manganese in various patients. This difference, while consistent, is altered from the expected pattern, and the significance of the deviations has not been established.

In a study on the physiology of the halides in gastric mucosa and the salivary glands, the secretions were observed by use of the isotopes Cl³⁸, Br⁸², I¹³¹, and At²¹¹ in pairs. The results indicated that the heavier elements are secreted by the stomach even more selectively than chlorine is and that reabsorption from the stomach is slower.

An extensive and continuing study on the role of sodium in the production and maintenance of hypertension has revealed a number of very interesting facts this year. Because weight reduction is frequently advised for patients with hypertension, it was desirable to determine, if possible, the effect of caloric restriction alone with protein intake maintained constant. Patients were kept on diets at various caloric intakes, and detailed observations were made of exchangeable sodium by means of Na24; chloride associated with sodium was estimated by use of Br82, total body water was estimated by use of tritiated water, and blood and plasma volumes were determined by labeling red cells with Cr51. Until all the data are assembled, the results of the study cannot be summarized. In the course of sodium studies in hypertensive patients it was found that connective tissue acted as a reservoir for sodium in both normotensive and hypertensive persons. The effect of the above mentioned caloric restriction has also been investigated on the changes in sodium both in patients and in suitable animals. A dog colony continues to be maintained for a long-term study of the effects of various sodium intake levels, in order to determine whether a natural evolution of hypertension can be observed by this means in a larger laboratory animal. The mucopolysaccharide excretion of these same patients is being observed to determine whether either caloric restriction or sodium restriction or both affect mucopolysaccharide excretion. The depletion of sodium in blood vessel walls and tail tendon has been studied following active measures of sodium depletion as well as the more passive measures already mentioned. Preliminary studies have been made on activation analysis as a procedure more suitable for complete electrolyte analysis than the methods

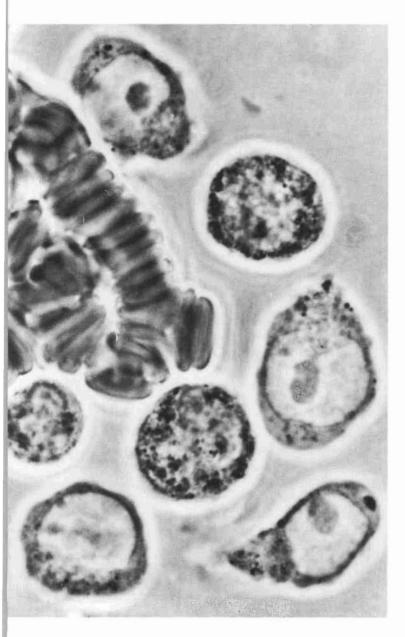


Figure 8. Photomicrograph (5000×), using phase microscopy, showing leukemic cells and red blood cells.

now in use. Thus far activation of Cl³⁷ to Cl³⁸ has been principally studied. The use of radioactive Mg²⁸ was tested in a group of patients, but the specific activity of preparations now available was found to be so low that doses of magnesium which were pharmacologically very active were required to obtain sufficient radioactive magnesium for satisfactory analysis. Therefore, these studies had to be temporarily discontinued. While potassium was frequently analyzed, no primary

studies were done involving potassium during the past fiscal year. The influence of desoxycorticosterone acetate (DOCA) was observed on sodium content of samples of the wall of the aorta and tail tendons in animals. One of the most interesting observations was on differences in oxygen uptake between thoracic and abdominal aorta, which were exaggerated by age and which correlated with frequency of occurrence of atherosclerosis in the two regions. Differences in sodium content were also noted. Preliminary studies on radiation effects on connective tissue derived from tail tendon indicate changes in oxygen uptake following radiation, but it has not yet been established whether or not changes in sodium content parallel these.

VITAMIN METABOLISM

Specific studies are under way on the metabolism of Co60-labeled vitamin B12. Other studies concern the metabolism of possible precursors and compounds closely related to niacin. The vitamin B₁₂ studies showed that external counting indicates a large fraction of Co60-labeled B12 going to the liver, but the turnover of the B₁₀ as measured by in vivo counting is very slow. Over a 2-mo period there was only a negligible decrease. These studies were done in patients and animals. Further exploration of animal tissues showed the highest concentrations in terms of $\mu C/g$ of tissue to be not in the liver but in the pituitary, adrenals, pancreas, kidney, and gastric mucosa. Preliminary analysis of biliary excretion in the dog showed a fast and a slow component. Studies on the plasma clearance of the vitamin in patients and normal individuals have shown a very slow clearance (hours) in patients with chronic myelogenous leukemia and agnogenic myeloid metaplasia as compared to normal individuals (minutes) and patients with polycythemia vera (minutes). The bound Co60-labeled B12 is carried by the alpha globulins.

In the niacin studies, the metabolism of tryptophane was studied in relation to quinolinic acid and 3-hydroxyanthranilic acid. Adult rats received tryptophane labeled with C¹⁴ in the 3a, 7, and 7a positions of the benzene ring. Of the labeled ring carbon approximately 25% appeared in the expired carbon dioxide and 15% in the urine. The quinolinic acid isolated from the urine

had 65 to 75% as much C¹⁴ per mole as the administered tryptophane instead of the 100% expected if all had come from the tryptophane. The N¹-methylnicotinamide had a C¹⁴ content indicating that 20% came from the administered tryptophane. Other studies showed that picolinic acid was the major product of 3-hydroxyan-thranilate in the cat. Studies on tritium-labeled quinolinic acid yielded results compatible with the interpretation that the labeled acid may have been less rapidly metabolized than the unlabeled. Such observations have obvious importance in connection with the significance of researches in which labeled compounds are used.

RADIATION EFFECTS ON BIOLOGICAL SYSTEMS

A large number of studies have been concerned with a wide range of effects of radiation from molecular denaturation to cancerogenesis. Radiation of acetylcholinesterase is known to result in inactivation of this enzyme. Graphical analysis of the inactivation data revealed a two-component exponential relation of the remaining enzymatic activity to irradiation dose. Further, it was shown that the slow component was equal to a minute sedimentable fraction of an active enzyme preparation, while the fast component was equal to the supernatant enzyme solution. This resolution of radiological analysis to centrifugal analysis of an apparently homogeneous in vitro system led to examination of animal tissues by the same technique. The electric eel organ was chosen both because it is very rich in readily solubilized acetylcholinesterase and because it is very high in water content (92%). Effects of irradiation on fresh and dried segments were determined in an effort to elucidate what role water might play in inactivation. The lyophilized and fresh preparations were found to be inactivated at identical rates. Other studies proved that there were no chemical protectors present in the tissue. It therefore seemed to be true that acetylcholinesterase in the eel organ was separated from tissue fluid and was intimately associated with cellular particles. In another study the size and shape of the radiosensitive acetylcholinesterase unit was determined by subjecting the preparation to bombardment by Co60 gamma-rays, 2-Mev electrons from the Van de Graaff generator, 40-Mev alpha-particles, and 10-Mev protons delivered by the Brookhaven 60-in. cyclotron. The radiosensitive unit of the enzyme was calculated to have a molecular weight of 105,000 and to be nonspherical. On the assumption of a cylindrical shape, the unit was calculated to be 360 A long and 21 A in diameter.

To determine biological effects of radiation, a precise and accurate measure of the dose is required. The energy output of the source is but one part in this determination. Exposure geometry is another and may well play a decisive role through shielding afforded by tissues themselves when a large body is used. A careful study was carried out on the influence of exposure geometry on the pattern of radiation dose delivered to large animal phantoms. It was shown experimentally that the tissue dose and thus the biological response can differ by a factor of greater than 2 for a given exposure expressed conventionally in terms of entrance air dose. With unilateral exposures, the tissue dose distribution is markedly nonhomogeneous even with the most penetrating laboratory radiations. Bilateral radiation with 250-kvp x-rays was found to yield essentially uniform tissue dose distribution, and no appreciable increase in uniformity was obtained with higher energy machines or with more complicated techniques. The relationships of geometry and energy to dose received apply also to the practical problem of sterilizing large volumes of food. Considerations raised in this discussion point to the meaninglessness of an LD50 dose for man unless the conditions of exposure are carefully determined. In another approach to this problem the biological response of patients receiving for disease conditions essentially whole-body radiation from internally administered gamma emitting isotopes is being compared with their response to comparable doses of radiation delivered by other means.

By use of immune mechanisms to demonstrate the biological response to radiation exposure and to elucidate the roles of various tissues in immune responses, it was found that, following Co⁶⁰ gamma irradiation of 650 rep to mice, morphological changes in lymphatic tissues as exemplified by the thymus gland could be generally correlated with the alteration in ability of the irradiated animal to produce tetanus antitoxin. The more undifferentiated cells of the reticulo-endothelial system would appear to have the capacity to pro-



Figure 9. Tissue culture of human cells (HeLa) labeled with tritiated thymidine. Cells are in mitosis as evidenced by clustering of silver grains within nucleus.

duce antitoxin in the absence of mature lymphocytes or plasma cells. The radiosensitivity of intraocular implants of spleen, lymph node, thymus, and Peyer's patch tissues is being tested with Co⁶⁰ gamma radiation and with beta radiation derived in one instance from a Tl²⁰⁴ source and in the other from a Sr⁹⁰ source. The different energies are being compared in their effectiveness in relation to known tissue depths.

During the year an 18-mo study was completed on longer term effects of I¹³¹ on rats. No tumors of the thyroid were observed in 42 rats treated with 400 mC I¹³¹ 18 mo previously. Among 18 similar animals treated with propylthiouracil over the same interval, about one half showed thyroid glands that were grossly tumorous, whereas in the control group only one of 31 animals showed enlargement of one lobe of its thyroid gland. Three of the pituitary glands from each of the treated groups were observed to be grossly enlarged, al-

though the average weight of the pituitary glands for the I¹³¹ treated animals lay between that for the propylthiouracil treated animals and the controls, but closer to the former.

Another program deals with the intercalibration of radiation sources and dosimeters to improve correlations on the several x-ray and gamma-ray sources available at Brookhaven. The program at present has been limited to use of instruments of the ionization chamber type. Measurements have begun of the 125-mC Sr⁹⁰-Y⁹⁰ source. The average surface dose was determined to be 1500 rep/min, and the half-value thickness in tissue equivalent polystyrene had an average value of 0.13 cm.

A careful evaluation of the theoretical considerations of the radiation from tritium-labeled thymidine in cell nuclei indicated by calculation that a single tritium disintegration gives an average of 53 rad to the 0.5- μ -radius sphere about the site of disintegration. It is thus indicated that tritium-labeled thymidine which now can be prepared may be used to deliver significant doses selectively to cell nuclei.

Biological effects of radiation were studied with the toxicity of irradiated intestine used as a measure in one instance, and the cancerogenic effects of whole-body radiation in another. In the intestinal study mice were used. After 10,000 rad of x-radiation mice were sacrificed at 1, 2, and 3 days after exposure. Mucosal scrapings were obtained, suspended, and centrifuged. Addition of antibiotics markedly reduced the toxic effect of the sedimentable portion of the preparation, but the clear sterile supernatant fraction was found to kill normal mice in 5 to 10 min when injected intravenously if the mucosal scrapings had come from an irradiated animal. Doses over twice as large from nonirradiated animals did not prove to be toxic. The toxicity was not due to sepsis, but ultimately was shown to be due to potassium. The significance of these experiments is not yet clear.

Cancerogenic effects of x-rays were and are being studied in a group of female rats given from 50 to 600 r whole-body radiation. Suitable groups of animals were given additional local beta radiation over the mammary region. Mammary tumors have developed in a very large percentage of animals, in some groups 56% of the exposed population. Surgical removal of very large tumors

has been resorted to in order to preserve the animal's life. Various types of shielding have been employed, and ovariectomized untreated animals and animals ovariectomized and then implanted with nonirradiated ovaries have been studied. It appears that induction requires functioning ovaries, but irradiation of breast, ovary, or pituitary is not necessary as indicated by appropriate shielding and surgical procedures. Local radiation with a beta source affected neither incidence nor location in animals receiving whole-body radiation. The histological types have included adenocarcinoma, fibroadenoma, adenofibroma, and fibrosarcoma. Further studies are in progress concerning the role played by the ovary in the genesis of these tumors and the dose-response relationship. Transplantation studies are also in progress to determine whether the neoplasms are autonomous or hormonal dependent.

A quite different assay of radiation effects has been the study of the effects of x-radiation on the maturation of rat tails. This is part of the study of radiation effects on collagen. In a mature animal the disperse collagen of the young animal has changed to a more highly organized structure. This change is reflected in the degree of contraction when the tail tendon is immersed in hot water. In the older animal thermal contraction exerts considerably more force. Although radiation has been asserted to cause aging, the rat tail tendons showed no change after 1000 or 2000 r of 250-kvp x-ray. Despite marked inhibition of growth, the properties of the irradiated tail tendon corresponded to those of the tail tendon of an animal of the same chronological age.

Hemorrhage is one complication of heavy radiation. Control of hemorrhage requires replacement of the blood platelets which disappear following radiation. Clinical tests in this hospital have shown striking control achieved in thrombocytopenic states when platelet transfusions were given. The fate of a platelet is not clearly known; therefore, it is of interest to label platelets and thus follow their course. Platelets were successfully labeled with sulfate containing S35 without causing loss of their physiological qualities. Labeled platelets disappeared when tranfused into normal animals. However, when the labeled platelets were transfused into a postradiation thrombocytopenic rat, autoradiographs of tissues showed a distribution of activity about capillary walls throughout the body. By use of various time intervals for sacrifice and histoautoradiography it is seen that, while the capillary bed is well outlined 1 hr after transfusion, it is not well outlined after 24 hr nor after a 4-day interval. From studies on the specific activity of labeled platelets it appears that over an initial 4-day period the animal made thrombocytopenic by radiation does not manufacture any platelets.

For the second successive year the Department has accepted the responsibility for planning and executing the medical checkup of the natives of the Marshall Islands who were exposed to significant fallout in 1953. A number of associates from other institutions assisted in this work. Perhaps the most significant finding this year was the apparent good health of all the exposed persons. Skin lesions have healed completely, and thus far no disturbances or disease attributable to radiation have developed. Another examination of these people is planned for 1958. In another study advantage has been taken of tests in Nevada to measure in man-sized phantoms the depth dose distribution of the initial gamma radiation from a fission weapon. Fast neutron distribution measurements were also obtained. It is hoped that the data thus obtained will help bridge the gap between the monitored dose measured free in air and the absorbed tissue dose, the parameter of importance for prediction of biological effects.

ACTIVATION ANALYSIS

The great usefulness of activation analysis for certain elemental studies, particularly of metals, has been shown in a number of preliminary projects. A serious attempt has now been instituted to develop a system of activation analysis which will include elements of primary interest to medical scientists. Complex instrumentation is required, but at this time the basic outlines are fairly clear. It is hoped that by this means rapid and more accurate studies can be carried out which will more conclusively demonstrate the locus of the compound studied and will do this in relation to all other compounds of interest.

HOSPITAL

It is gratifying to report a striking increase in the use of the hospital facilities for research studies.

The total patient days for this fiscal year were 7327 compared with 4814 for the previous year. During the past year 99 persons were admitted to the hospital; of these 5 were employees and 94 research patients. The work in the hospital has been augmented by an ambulatory service for patients who could be followed up satisfactorily in this manner in order to reduce their terms of actual hospitalization, and by completion of diagnostic and therapeutic tests on others for the same reason. The total number of research patients seen during the year on this service not accounted for elsewhere was 121, of whom 62 were new patients. In many instances it was thus possible to treat patients with radioactive isotopes without their prolonged absence from home or work. Radioactive isotopes of 12 different elements were used in diagnosis and therapy of 91 patients during the year. The major disease states studied and treated in the hospital were glioblastoma multiforme, leukemia, polycythemia vera, rheumatoid arthritis, hypertension, visceral cancer, paralysis agitans, diabetes mellitus, and disorders of the thyroid. No services are maintained for specific disease states, since the clinical investigations are basic; each admission, following referral by his own physician, is individually selected both for disease and stage of disease, and is admitted because study or treatment of the disorder at that time is thought to be beneficial to both patient and physician. In general, the medical profession has been most cooperative in referral of patients to the hospital and in the necessary follow-up studies.

The organization of the hospital has continued to develop, and at the present time it is believed that we have solved all the major problems relating to use of our hospital facilities in a collaborative effort by qualified clinicians from other institutions who are interested in investigational studies.

INDUSTRIAL MEDICINE CLINIC

During the past year the steady increase in visits to the clinic continued, the total being 10,692 compared with 9711 in the previous fiscal year. There has not been any commensurate increase in employees of the Laboratory. The clinic staff now consists of two full-time physicians, which permits all examinations to be kept current.

One major accident occurred during the year, which resulted in some 50 persons reporting to the clinic. Fortunately, in most cases the injuries were not widespread, and only one employee required hospitalization for burns. These healed satisfactorily and there was no loss of vision. The accident tested certain aspects of our emergency program; and after study and evaluation a few changes have been instituted in procedures for handling employee emergencies which we believe will facilitate care if the need again arises. The number of x-ray examinations increased from 1595 to 1780. All roentgenological examinations are carefully controlled so that a minimum of exposure is given. Efforts are being made to develop for our employees a satisfactory record of x-ray exposure for medical purposes whether it be done here or elsewhere. In general, the state of physical fitness of our employees has been excellent in relation to the tasks they are called upon to perform.

GENERAL ACTIVITIES OF THE MEDICAL DEPARTMENT

During the fiscal year a total of 41 staff scientists carried on the work of the Department with an average of 100 technical assistants and 15 administrative and clerical assistants. The program includes work with 47 Research Collaborators coming from 30 institutions and, in addition, 11 students from 10 institutions. This year saw our most extensive use of Research Collaborators; by this means it is possible to amplify and intensify various aspects of the Department's activities. During the year 32 different members of the Department gave a total of 141 lectures or informative talks to groups or societies outside the Laboratory, which ranged from highly technical lectures to broadly informative talks. A very significant educational effort is represented by this activity. In addition 342 professional visitors from 35 countries participated in personal conferences with members of the Department. This total does not include visitors in groups larger than four members, and the great majority were visiting as single individuals. A great deal of time and effort was consequently needed to meet this demand; this has been estimated as requiring at least an amount of time equal to one man-year. In addition to the individual visitors, 15 groups have required a program presentation. Among these were physicians completing the radioactive isotopes courses at Columbia University and Queens Hospital; the Suffolk County Medical Society; naval officers in the Medical Corps and Medical Service Corps participating in a two-week seminar; various nursing groups, pharmacy groups, and national clergy groups; delegates to the Inter-American Symposium on Nuclear Energy; and others. Various members of the Department gave testimony before the Joint Congressional Committee on Atomic Energy both on medical uses and on problems of

health raised by radioactive fallout. Members of the Department continue to serve on various committees of the National Research Council as invited to do so. The development of the Atoms for Peace Program is reflected by an increase in the number of scientists from abroad who have term appointments in the Department to gain training and experience of value in further development of the atomic energy programs in their home countries. These scientists are making a significant contribution to the Department's efforts and we are glad to number them among our staff.



		ž.
		i.
	•	
		1
	•	
	•	
	•	
		*
		2
		A CONTRACTOR OF THE CONTRACTOR
		2
	_	
	•	:
		ŀ
	_	
	•	1
		ŧ.
		į.
		di via
		1
		1

Technical Operations and Services

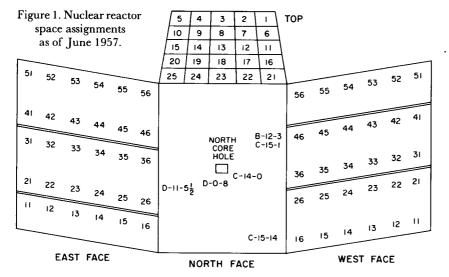
A number of organizational units in the Laboratory provide the technical services and facilities essential to the research programs. Descriptions of their operations follow under appropriate headings.

REACTOR OPERATION

The BNL research reactor has continued in its role as a major research tool. Its in-pile and beam facilities have been used in varied programs by all the scientific departments of Brookhaven as well as by many outside industrial, academic, and governmental institutions. Figure 1 shows the assignment and utilization of experimental space as of June 1957, which are typical for this report period.

There have been numerous visitors from all parts of the world. Some have come merely to view the reactor and acquaint themselves with the kind of research it supports, some to work with its facilities, and some to be trained in its operation. The outside organizations that have rented reactor space for research projects during the past fiscal year are listed below:

American Bosch Arma Corporation **Atlantic Refining Company** Bell Telephone Laboratories, Inc. California Research Corporation Columbia University Esso Research and Development Company Ford Instrument Company General Electric Company General Dynamics Corporation Glenco Corporation Mine Safety Appliances Company P.R. Mallory and Company, Inc. Pennsylvania State University Radio Corporation of America



TOP

- THERMAL COLUMN (BIOLOGY)

- LOW ENERGY NEUTRON FACILITY (PHYSICS)
 NEUTRON THERAPY FACILITY (MEDICAL)
 EXPONENTIAL FACILITY (NUCLEAR ENGINEERING)
 SHIELDING TANK (AIR FORCE)

EAST FACE

- GRAPHITE OXIDATION STUDY (PHYSICS)
- REACTOR CONTROL
- U-BI LOOP (NUCLEAR ENGINEERING)
 CROSS SECTION STUDIES
- NEUTRON SPECTROMETER (PHYSICS)

- CROSS SECTION STUDIES
 NEUTRON SPECTROMETER (PHYSICS)
- RADIATION DAMAGE ON STEELS (NAVAL RESEARCH LABORATORY)
- NEUTRON DIFFRACTION SPECTROMETER
- (GENERAL ELECTRIC)
 U-BI CORROSION LOOP (NUCLEAR ENGINEERING)
 U-BI STUDIES (NUCLEAR ENGINEERING)
- U-BI STUDIES (NUCLEAR ENGINEERING)
 RADIATION DAMAGE ON STEELS (WAPD)
- COLD NEUTRON SPECTROMETER (PHYSICS)
- LIQUID NITROGEN FACILITY (PHYSICS)
- MAGNETIC PROPERTIES OF MATERIALS
 NEUTRON SPECTROMETER (PENN. STATE UNIV.)

- GRAPHITE OXIDATION STUDY (PHYSICS) SLOW CHOPPER (PHYSICS) PHASE CHANGE IN URANIUM BASE ALLOYS (WAPD)

WEST FACE

- ION CHAMBER EVALUATION (PHYSICS)
- FOIL SLOT
- GAMMA-RAY SPECTROMETER (AIR FORCE)
- CROSS SECTION STUDIES
 NEUTRON SPECTROMETER (PHYSICS)
- NEUTRON DIFFRACTION SPECTROMETER (BELL TELEPHONE LABORATORIES) 30°C CONTROLLED TEMPERATURE IRRADIATION
- FACILITY (CHEMISTRY)
 FAST RABBIT (PHYSICS)

- CROSS SECTION MEASUREMENT
 NEUTRON SPECTROMETER (COLUMBIA UNIV.)
 NEUTRON DIFFRACTION SPECTROMETER (CHEMISTRY)
 NEUTRON DIFFRACTION SPECTROMETER (CHEMISTRY)
 NEUTRON DIFFRACTION SPECTROMETER (CHEMISTRY)
 MAGNETIC PROPERTIES OF MATERIALS

- NEUTRON SPECTROMETER (PHYSICS)
 ISOTOPE PRODUCTION TARGET CONVEYOR
- CONDITION CONTROLLED HYDROCARBON
- IRRADIATION (ESSO)
- 30°C CONTROLLED TEMPERATURE IRRADIATION FACILITY
 NEUTRON DIFFRACTION SPECTROMETER (WESTINGHOUSE)
- NEUTRON DIFFRACTION SPECTROMETER
- (GENERAL ATOMICS)
 NEUTRON DIFFRACTION SPECTROMETER (PHYSICS) GAMMA-RAY CAPTURE SPECTROMETER (PHYSICS)

NORTH FACE

- B-12-3, C-15-1. DEVELOPMENT OF FUEL ELEMENTS FOR GAS COOLED REACTOR (FORD INSTRUMENT)
- C-14-0. FISSION NEUTRON (RRADIATION (PHYSICS) C-15-14. FISSION GAS DIFFUSION STUDY (WAPD) D-0-8. IODINE PRODUCTION FACILITY
- (NUCLEAR ENGINEERING)
 D-11-5½. GAS IRRADIATION FACILITY
 NORTH CORE HOLE. FAST CHOPPER (PHYSICS)

Sperry Gyroscope Corporation University of Pennsylvania United States Air Force

Except for a major shutdown in January to permit the fuel enrichment described below and the normal routine shutdowns for maintenance and rearrangement of research apparatus, the reactor has been continuously operated at an average power level of 23 Mw per hour of operation. A total of 7295 Mw days were accumulated during the year, bringing the total Mw days of operation to 46,318. The normal preventative maintenance shutdowns were scheduled at 10-day intervals until February, when this interval was lengthened to 14 days. Although less frequent, these shutdowns every two weeks are of longer duration by 16 hr. The higher thermal neutron flux resulting from the reloading of the 36 central core fuel channels with highly enriched uranium induced more activity, which necessitated the longer "cooling off" period. The shutdown time for the entire year averaged 12.4%.

Reactor Enrichment Progress

During 1955 a proposal was made by the Reactor Department to replace the reactor's natural uranium fuel elements with enriched fuel (>90% U^{235}), with several objectives in view:

- 1) Enrichment of the fuel (removal of U^{238}) would enhance the thermal flux because of the lower nonfission neutron capture in the core. The increase in thermal flux was estimated as sixfold $(5\times10^{12} \text{ to } 3\times10^{13} \text{ n/cm}^2\text{-sec}$ at a 20-Mw power level; present level is 24 Mw).
- 2) The aerodynamic characteristics of the proposed fuel element and other associated circumstances were expected to result in substantial savings in electric costs.
- 3) The propsed alloy type of fuel element based on well developed technology (MTR type plates) would be inherently less subject to element rupture by oxidation, canal contamination, and coolant contamination, difficulties invariably associated with canned natural uranium fuel.

Detailed reactor physics and fuel element development studies, including in-pile tests, were completed and reported to the AEC, and in December 1956 approval to proceed with the enrichment was granted. The initial phase of the enrichment, completed in January 1956, consisted of replacing 35 central channels of normal uranium fuel with

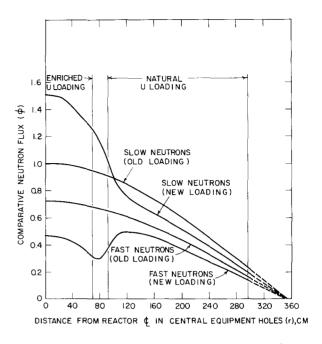


Figure 2. Effect of partial enrichment on neutron flux.

enriched fuel. This enriched zone was separated from the normal uranium zone by an 8-in.-thick buffer ring which contained no fuel.

The effect of this partial enrichment is shown graphically in Figure 2. Beams emerging from the central enriched zone are used in four neutron diffraction experiments located in Holes W-31, W-34, W-35, and W-36. In-pile U-Bi experiments located in E-34 and E-35, as well as high temperature metallurgy experiments located in E-36 (conducted by WAPD), are within this enriched zone.

The maximum thermal flux has been measured to be 1.2×10¹³ n/cm²-sec. A reduction of the fast neutron flux in the enriched zone (indicated on the graph) proved to be a disadvantage for the fast chopper group whose resonance neutrons emerge from the center of the enriched zone. This situation was corrected by increasing the U235 content in seven channels surrounding the fast chopper beam hole; the resulting local increase in fast neutron flux is not indicated on the graph. The general reduction of fast neutron flux in the enriched zone is temporary and will be improved as the zone is enlarged. During September 1957 the enriched zone will be increased to approximately 120 channels, after which the fast neutron flux in the enriched zone should be greater than that provided by the natural uranium loading.

Other Improvements

The following improvements have provided either for better protection against radiation or for more effective maintenance: an alarm system installed in the canal that indicates high level activities; provision for faster processing of the canal water which has resulted in lowered activity; a deep pit grappling device provided for the canal facility; a new control rod drive unit which operates the control rods at low speeds electrically (the hydraulic units will still be used for quick shutdowns); special instrumentation required in connection with the reloading of the reactor with highly enriched uranium.

Distribution of Isotopes and Irradiated Materials

The number of shipments of isotopes and other materials irradiated in the reactor or in the 60-in.

cyclotron increased over that for fiscal year 1956. Since 1951 over 64,000 shipments have been made to about 200 different customers (Figure 3). The present rate is about 30 shipments per week. Al-

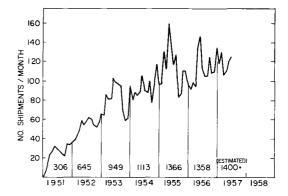


Figure 3. Isotope distribution and special materials group monthly shipments.

Table 1

Three-Year Summary of Shipments to Users Outside BNL

urce of irradiation or materia	l	1957		1956		1955
Target conveyor - Unit	574	\$ 27,019.30	673	\$ 31,231.28	894	\$ 42,907.00
Target conveyor - S.I.	210	8,458.00	175	7,488.10		_
Pneumatic tubes	138	5,848.51	39	2,928.06	57	2,990.00
Air-cooled holes	88	7,177.05	39	2,061.00	49	5,914.00
Water-cooled holes	32	2,642.35	77	6,191.00	48	3,591.00
Thermal column	6	508.00	3	100.00	12	456.00
Tunnels	7	578.77	8	783.13	2	604.00
Experimental holes	68	6,486.35	71	8,222.42	76	13,011.00
Liquid nitrogen hole	_	-	_	_	4	1,032.00
South core hole	3	510.00	1	158.00	1	925.00
Gas facility		_	1	n/c	2	
Fuel channels	_	-	1	98.00		
Iodine-132	69	7,665.00	52	5,925.00	27	1,768.00
Fluorine-18	4	185.00	10	682.50	7	315.00
Iodine-133	38	1,913.20				
Magnesium-28	74	6,187.40	21	537.50		
Yttrium-90		_	1	50.00	4	200.00
Cesium-134	_		1	70.00		
Special irradiations	49	1,595.20	83	1,200.86	105	1,872.00
Subtotal	1360	76,774.13	1256	67,726.85	1288	75,585.00
Millicurie Co ⁶⁰ sources	13	93,282.00	7	33,560.00	10	50,025.00
Rentals at reactor	_	200,981.35		192,489.04	_	71,615.00
Subtotal	1373	371,037.48	1263	293,775.89	1298	197,225.00
Cyclotron	18	3,046.80	16	3,222.50	27	4,762.00
Biology thermal column	_	_	6	1,231.60	1	249.00
Total	1391	\$374,084.28	1285	\$298,229.99	1326	\$202,236.00

though the industrial recipients of these shipments outnumbered the hospitals six to one, each group received 35% of the shipments made. In general, the medical research programs use short-lived radioisotopes of high specific activity so that routine repetitive shipments are required. Universities received 20% of the shipments, and government laboratories, 10%. Table 1 summarizes these activities during the last three fiscal years. Exclusive of the sale of Co⁶⁰ sources and reactor facility rentals, the Laboratory is grossing about \$80,000 a year through its isotope shipments and irradiation services. Of the isotope shipments, 407 were made under the radioisotope research support program, involving a subsidy of \$10,800.

Brookhaven has also activated annually about 15,000 curies of Co⁶⁰ in the form of special kilocurie gamma-ray sources. Since 1955, 30 such sources have been sold totalling about 34,000 curies and valued at more than \$175,000. The largest single source, 4800 curies of Co⁶⁰ valued at \$25,000, was shipped recently. The demand for these Co⁶⁰ sources has, up to the present, exceeded the Laboratory's supply. The replacement of natural uranium with highly enriched uranium fuel elements in the reactor should have a favorable effect on this situation. The higher fluxes available will also provide higher specific activities and will make it possible for the Laboratory to handle irradiation projects that have hitherto been impracticable. Reactor rentals topped \$200,000 last year for the first time.

HOT LABORATORY OPERATIONS

Gamma Irradiation and Radiography Services

The gamma irradiation laboratory had to be closed down for a period of about three months during the past year, because in October it was discovered that corrosion of a number of Co⁶⁰ sources in the water facility had caused a rapid build-up of activity in the water. It was necessary to remove all sources from the pool, pump out the water, and scrub and decontaminate the walls and floor of the facility. The walls were then painted with Amercoat, and the floor and sides of the pool to a distance of about one foot from the floor were lined with stainless steel. The installation of an Elgin water purifying system has assured maintenance of the water at megohm purity, which will inhibit the corrosion of materials used under

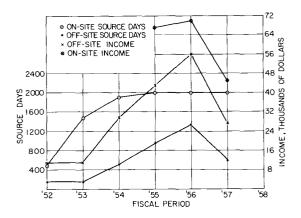


Figure 4. Income and use of gamma irradiation services by fiscal years.

water. Fifteen of the sources were shipped to Oak Ridge for recanning.

Source days and income for the gamma irradiation facility for fiscal 1957 compared with those for former years are shown in Figure 4. The income from off-site users totaled about \$27,000, representing 600 source days; and from on-site users amounted to \$44,000, representing about 2000 source days.

The gamma irradiation facility was used by the following companies and universities during the past year:

E.I. du Pont de Nemours and Company The B.F. Goodrich Company The Ford Motor Company New York Naval Shipyard Rohm and Haas Company The Kurth Malting Company H. Cuttica The Denver and Rio Grande Western Railroad Company North Carolina State College Charles Pfizer and Company, Inc. Picatinny Arsenal Ruskin Research Institute General Electric Corporation Atomic Energy Establishment, Government of India U.S. Naval Powder Factory (Indian Head, Md.) Procter and Gamble Company North Carolina School of Textiles Air Reduction Corporation Aeroprojects, Inc. The Texas Company

Temple University Technical Research Group Carbide and Carbon Chemicals Company Royal Potato Chip Corporation Minnesota Mining and Manufacturing Company Vitene Manufacturing Company General Foods Corporation R. Del Castillo and Company Glenco Corporation Socony Mobil Oil Company, Inc. Thiokol Chemical Corporation Westvaco Chlor-Alkali Division of Food Machinery and **Chemical Corporation Curtiss-Wright Corporation** Frankford Arsenal Mellon Institute Radio Corporation of America Olin Mathieson Chemical Corporation Fairchild Camera and **Instrument Corporation**

A hot cave of concrete blocks has been constructed around a low level Co⁶⁰ source that will be used in studies of the effects of gamma irradiation on crystalline materials.

A total of more than 1500 radiographs were made during the year. Most of these were made in the field, i.e., in buildings other than the Hot Laboratory. Special radiographs were made of the heads of hamsters for the Biology Department and of the hydrogen liquefier at the Cosmotron. Autoradiographs were made to show the distribution of U in a U-Bi alloy and the distribution of F¹⁸-tagged soldering flux in soldered joints.

Radiochemical Analysis

Chemical analyses of radioactive materials were performed during the year; and, in addition, the following procedures were developed or modified.

- 1) Separation (for subsequent determination) of traces of uranium from large excesses of bismuth via solvent extraction with ether and xylene solutions of various trialkylphosphine oxides.
- 2) Polarographic determination of uranium in the presence of bismuth, complexed by diaminocyclohexyltetraacetic acid.
- 3) Colorimetric methods of analysis for certain corrosion products of interest in the LMFR program developed as alternates to determination by emission spectroscopy.

- 4) Volumetric determination of bismuth by adding excess EDTA and back-titrating with standard Bi*** in the presence of buffered KI.
- 5) Volumetric determination of iodide by titration with ceric ammonium sulfate in the presence of ferrous *σ*-phenanthroline indicator.
- 6) Spectrophotometric determination of iodide and of magnesium.
- 7) Separation of polonium (by carrying on Bi₂S₃) from plutonium prior to determination of the latter.
- 8) Extraction of zirconium with thenoyltrifluoroacetone (TTA) prior to radiometric determination of Zr.
- 9) Analysis for fluoride by distilling fluorosilicic acid away from interfering elements and then titrating with thorium.
- 10) Extraction of cesium from potassium and other interfering elements by an organic solution of tetraphenylboron prior to radiometric Cs¹³⁷ determination.

Other Services

A pumping system was designed and built for the Medical Department whereby boron containing solution can be injected into a patient undergoing neutron capture therapy. The system is remotely operated, and its flow-rate is continuously variable over a wide range and is dependable and accurate to within 1%. Another system is under development that will measure and record continuously the boron concentration in the blood of the patient; its intended use is to control the pump of the first system.

The gamma irradiation cave built several years ago for use by the Medical Department has been rebuilt to accommodate new sources giving about 5 times the previous radiation level.

The following items have also been designed and built: 1) a beta source for the controlled irradiation of hamsters, 2) equipment for loading hollow needles with radioactive clay, and 3) filter assemblies to permit spectrography and flame spectrophotometry to be performed on radioactive samples.

Liquid Waste Operations

The figures in Table 2 indicate the magnitude of the liquid waste operations of the past year as compared to those of the previous year. While the total volume of radioactive wastes discharged to

 $\label{eq:Table 2}$ "F" Waste Discharged to the Sewer

Period	Volume, gal	Average activity level, C/ml	Total activity, mC
Fiscal 1956	3,731,620	2.46×10 ⁻¹¹	324.5
Fiscal 1957	4,978,335	1.77×10^{-11}	352.6
	Waste Cond	centration	

Feed, gal	396,615
Average volume reduction	121
Drummed concentrate, gal	121 3,175
Waste Inventory in G	allons
Fiscal 1956	Fiscal 1957

	Fiscal	Fiscal 1956		Fiscal 1957	
	"D" waste	"A" waste	"D" waste	"A" waste	
Volume on hand					
at beginning of	05.405	2224	00.010		
fiscal year	95,105	2201	99,310	2927	
Volume received					
during year	337,880	726	463,795	665	
Volume to	·				
evaporator	333,675		404,560		
Volume on hand at end of fiscal	000,0.0		101,000		
	00.010	0007	150545	2500	
year	99,310	2927	158,545	3592	

the sewer has increased by one-third, the activity discharged increased by less than 10%. The efficiency of the concentration operation was about the same as in the previous year; the volume handled was greater by about 20%. The status of the waste inventory for the past two years is also given in Table 2.

HEALTH PHYSICS

The staff of the Health Physics Division has remained stationary at 42 persons, of whom 11 are professional health physicists on the scientific staff and 31 are technical specialists or technicians. As in the past, exposure control at the pile and Cosmotron, disposal of radioactive wastes, and contamination control at the pile and waste processing area have been the major concerns. Other problems include the evaluation of neutron hazards at the 18-in. cyclotron, rupture of a 200-mC

P³² source, removal of LMFR Loop B from the pile, increased use of tritium in various parts of the Laboratory, grinding of uranium rods at the hot shop, maintenance or repair work at the 60-in. cyclotron, and rupture of a pile fuel element.

The bio-assay laboratory carried out a total of 362 urinalyses for personnel possibly exposed to radioisotopes internally. Gross fission product elimination is determined in most cases, but Sr activity eliminated is determined in cases in which a significant gross activity is observed. Results for gross analyses ranged from 0 to 740 dis/min/day and for Sr analyses from 0 to 720 dis/min/day. In no case was an individual overexposed, all high values being transitory and due to specific incidents.

The training activities of the Health Physics Division have continued to expand both in regard to the number of visitors and the length of time that they stay. The 1957 group of AEC Fellows in Radiological Physics, numbering 25, is the largest yet and will be in residence at BNL for 11 weeks. Foreign visitors have shown a very active interest in radiation safety in general, while an unusually large number of domestic visitors have been interested in our waste disposal procedures.

During its period of operation prior to the long shutdown for repairs, the Cosmotron presented an increasing problem in regard to exposure control. Levels in the control room averaged 200 mrem/week (rbe=10) with much higher values in some other areas. For special modes of operation control room levels as high as 150 mrem/hr were noted, and objectionable levels were encountered in areas outside the building. Improvements in shielding and operating procedures are being planned by the Cosmotron Department to cope with even higher levels predicted for next year.

Waste Disposal and Reclamation

Four members of the Health Physics Division are now assigned full time to this activity, and much additional work is performed by personnel of the Maintenance Division. The effectiveness of this group has been greatly increased by completion, last fall, of a waste disposal building at the waste area located near the southeast corner of the site. This building contains sanitary facilities, locker space, an office, two hoods for small decontamination jobs, and a large works area where solid waste is sorted and baled.

Table 3
Summary of Liquid Waste Data

	1956-57	1955-56
Input to filter beds,		
gal/day	427,500	362,000
Output from filter beds,		
gal/day	332,000	306,000
Net loss in filter beds, %	21.4	15.5
Stream above discharge point,		
gal/day	315,000	999,000
Stream at site boundary,		
gal/day	778,500	1,525,000
Rainfall, in./mo	2.9	4.5
Activity concentration at input		
to filter beds, C/cc	3.9×10^{-13}	3.5×10^{-13}
Activity concentration at output		
from filter beds, C/cc	1.6×10^{-13}	1.3×10^{-13}
Reduction in activity		
concentration, %	58	63
Activity at input to filter beds,		
mC/mo	17.5	14.2
Activity at output from filter		
beds, mC/mo	6.0	4.6
Percent of permissible	12.5	11.7
•		

Figures are averages for each fiscal year.

Considerable reclamation work has been done with temporary facilities, but it cannot be adequately handled until the proposed reclamation building has been constructed. Reclamation of contaminated equipment is important, since it not only saves the cost of the equipment but avoids the necessity for disposing of it as waste, often a costly process.

The liquid waste system has been operated as in the past, and a summary of data is shown in Table 3. Two shipments of 55-gal drums containing radioactive waste and loaded with concrete for sea disposal were dumped at sea by the Navy. This sea disposal procedure was started in 1952 with a shipment of 55 barrels. The last shipment was 704 barrels, and the total to date is 2719 barrels. The total activity disposed of in this way amounts to about 2000 curies or somewhat less than 1 curie per barrel.

Personnel Monitoring

The new punch card system for processing of personnel exposure data has proved to be satisfactory. Of the 1515 individuals monitored, 1374

Table 4

Use of Personnel Monitoring Equipment

	1956-57	1955-56
Pairs of pocket chambers	919	963
Regular film badges	734	1006
Visitors' film badges - on-site	96	113
Visitors' film badges - off-site	198	176
Total film badges	1029	1294
Neutron films used	762	461
Neutron films read	280	321

Figures are weekly averages for each fiscal year.

had total exposures for the year of less than 1.0 rem, while 18 had totals greater than 5.0. The highest total was 9.9 rem. Analysis of integrated exposures for all individuals monitored shows that only 6 have averages over 5.0 rem/year during their employment at Brookhaven, the specific values being 8.2, 6.4, 5.8, 5.5, 5.4, and 5.4. In all cases the average exposure since age 18 is well below the prescribed limit of 5.0 rem/year.

Breakdown of the records by work location shows that the great bulk of exposures, in terms of both number and average value, occur at the nuclear reactor, the Cosmotron, and the waste disposal area. Of the Laboratory-wide exposure total, 32% is due to beta radiation, 18% to neutrons or other particles, and 50% to x- or gamma radiation.

Table 4 gives a breakdown of the work done by the Personnel Monitoring Group, which has functioned very much as in previous years. The off-site neutron monitoring service provided for contractors of the New York Office of the AEC for the past 5 years was terminated June 30, 1957, since competent commercial suppliers of this service are now available. The workload of this service, not included in Table 4, averaged 286 badges per week.

Research and Development

The energy response of the NTA film system of neutron personnel monitoring was studied with monoenergetic neutron fluxes from the Van de Graaff generator. The exposures were standardized by means of a long counter. It was found that neutrons with energies of less than 0.5 Mev, and greater than thermal, are not detected at all, and

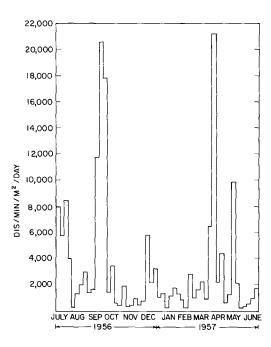


Figure 5. Weekly averages of the daily rate of fallout of radioactivity at BNL.

that the sensitivity of detection is dropping rapidly in the 0.5 to 0.8-Mev region. This result emphasizes the difficulty of monitoring low energy neutrons, since most fast neutron survey meters are insensitive to neutrons below a few hundred kilovolts in energy.

As in the past, various dose rate measurements were made at the Co⁶⁰ irradition field, in the Biology greenhouse, and in connection with experiments at the Cosmotron. Dosage rates from a Sr⁹⁰ plaque were investigated with photographic film, and a cadmium sulfide crystal dosimeter for internal use in small animals was built and calibrated. The degree of internal contamination was evaluated in two individuals, one exposed to dust containing radioactive phosphorus and the other to fumes containing natural uranium.

Routine measurements were continued of the radioactive fallout in rain or settled dust. The results are shown in Figure 5. Considerable additional data concerning the time sequence of arrival and the chemical composition of the activity were collected last summer. Similar measurements are being carried out during the current series of continental weapons tests with greatly improved equipment and techniques.

The exposure and contamination control problems associated with operation of a decontamination laundry were studied by accumulating a variety of measurements during repeated processing of 10 batches of 35 coveralls used at the pile and waste disposal areas. The problems associated with mildly contaminated garments were found to be very minor. For grossly contaminated garments (up to 50 $\mu \rm C$ mixed fission products per garment) however, proper techniques must be employed if airborne and surface contamination are to be held to acceptable levels.

METEOROLOGY

Research and development are the primary objectives of the Meteorology Group, but service functions continue to occupy a significant place in the program. The major part of these activities comprises a series of short-term projects and studies - such as special forecasts for various Laboratory activities, including construction planning, and the loan and repair of meteorological instruments - often involving the direct measurement of meteorological variables by Group personnel. Larger projects have included the development of a set of simplified nomographs for the location of the reactor cooling air plume under any combination of operating and meteorological conditions, and the preparation of special climatological data for site evaluation in connection with the location of the Liquid Metal Fuel Reactor Experiment.

APPLIED MATHEMATICS

Formation of the Applied Mathematics Division in February represents a major advance in providing guidance and technical assistance for the continually expanding mathematical and computational activities of the research programs at the Laboratory.

As the Division grows, the present assistance in programming services to Laboratory users of computing machinery is expected to expand, and increased training activities will raise the level of awareness of modern computational methods within the Laboratory. The Division will also continue to assist the engineering group engaged in the construction of the new computer on problems related to logical design of the machine. As the staff is enlarged, emphasis will be placed upon activities aimed at making this computer an effec-

Table 5

Distribution of 409 Facility Time by BNL Departments

Department	Computer use, %	Auxiliary machine use, %
Reactor	12	11
Nuclear Engineering	28	37
Medical	13	7
Cosmotron	15	14
Physics	24	18
Health Physics	1	7
Biology	5	5
Chemistry	2	1

Table 6

Distribution of Univac Time by BNL Departments

Department	Usage, %
ADD	48
Nuclear Engineering	46
Chemistry	3
Reactor	2
Physics	1
1 Hysics	-

tive operational tool as soon as possible after its completion. These will include initiation of the design of a programming system, development of a serviceable library of subroutines, and writing final operation manuals for the computer.

Some research activity is expected to be started this summer, aimed partially at mathematical problems of general interest to other areas of Laboratory activity and partially at problems having a more direct bearing upon the mathematical interests of the Division itself.

During this past year the use of the on-site punch card computing facility increased to the saturation point. Some 1253 hr of computer time were used in calculation, and 3308 hr of auxiliary machine time were expended to support the computer operation. Table 5 shows the distribution of computer and auxiliary machine time among the various Laboratory departments.

Usage of the Univac at the AEC Computing Facility at New York University increased over that during the previous year to reach a total of 832 hr. The distribution of this time is shown in Table 6. The addition of an IBM 704 can be ex-

pected to provide for increased Laboratory usage of this facility in the coming year.

MECHANICAL ENGINEERING DESIGN AND CONSTRUCTION

The activities of the Mechanical Engineering Division constituted for the most part a continuation of work that was in progress in 1956. Most of them have been described in preceding sections of this report. Equipment has been designed and constructed, and components for the major Laboratory facilities have been evaluated and tested. Table 7 is indicative of the areas of major concentration.

While the organization within this Division has been flexible, the construction of the Alternating Gradient Synchrotron is currently absorbing the full time of half the engineering staff. The Cosmotron has been undergoing repairs and modifications for the past five months because of a fracture in one of the main exciting coils. The analysis of the cause of the coil failure and the redesign and installation of new coil clamps on all four quadrants were materially aided by the temporary transfer of three engineers to the Cosmotron facility. During this repair period, the floor in the Cosmotron building was reinforced by pressure grouting to permit installation of a complete shielding enclosure around the machine at some future date. Four of the staff are working with the Physics shop, where the large hydrogen bubble chamber is the major project. Nuclear engineering equipment is being built at an acceler-

Table 7

Localities Where Mechanical Engineering Staff is Currently Working

	Engi- neers	Designers and Draftsmen	Secre- taries and Clerical
Accelerator Development	11	13	2
Nuclear Engineering	3	9	1
Cosmotron	4	4	
Central Design	1	7	1
Physics	1	5	
Reactor		2	
Total	20	40	4

ated pace to provide data for the construction of the Liquid Metal Fuel Reactor Experiment. The Central Design Group has devoted its major efforts to the design of equipment and component parts for the research reactor and the new medical reactor.

Machine Shops

There has been a continued slow improvement in both the operations and the equipment of the Central Shops. The study of equipment needs initiated in the prior fiscal year has been completed, and the indicated program of changes has been started. This program includes not only the repair or replacement of certain equipment now in use but also the retirement of equipment in excess of present needs and the acquisition of certain additional equipment that would enable the Division to broaden the scope of work that it can offer.

The production record system initiated during fiscal year 1956 has proved satisfactory. Certain indicated modifications dealing chiefly with inprocess control procedures and forms have been introduced. An attempt at closer association between scientists and craftsmen has led to the establishment of a Technical Consulting Group which provides three types of service: 1) advisory service to the scientific staff on questions of fabrication feasibilities; 2) engineering design service to bridge the gap between informal sketch and detailed formal design, which benefits both the scientific staff and the Division; and 3) advisory service to the production staff of a general nature concerning methods, materials, and design changes for fabrication feasibility.

The relative contribution of the several departments to the work-load of the Shops Division is shown in Table 8. The division between major and minor users remains the same as in previous years, although there is considerable change in use by individual departments. The increased workload from the Reactor, Physics, and Cosmotron Departments more than offsets the decreased workload placed by the Nuclear Engineering and Accelerator Development Departments during this past year. The amount of short-order work requested constitutes 7.3% of the total workload, and shows little change from that in fiscal year 1956. The backlog of work has continued to fluctuate, as it did last year, around a level which

Table 8

Departmental Contributions to Shop Workload

	% Man-hours fiscal year 1956	% Man-hours fiscal year 1957
Major users		
Nuclear Engineering	44.2	36.2
Reactor	13.4	15.5
ADD	4.9	2.9
Physics	15.7	22.2
Cosmotron	6.3	9.5
Percent of workload	84.5	86.3
Minor users		
Chemistry	6.6	2.1
Biology	2.7	2.6
Medical	2.5	4.3
Instrumentation and		
Health Physics	0.5	0.8
Miscellaneous	3.2	3.9
Percent of workload	15.5	13.7

has been found appropriate: 15,000 man-hours, or about 8 weeks' work.

There appears to be a marked trend toward the construction of equipment of increasingly larger size. While the facilities of the Shops Division are still capable of handling most of the work called for, the capacities of some machines are being taxed; if this trend continues, larger equipment will be required to handle future projects.

TECHNICAL INFORMATION

The shift in emphasis from classified to unclassified research in the nuclear sciences, which has been gaining momentum for the past several years, has resulted in a major change in the Laboratory's technical information functions. This change has been brought about mainly by the two AEC "crash" review programs of the past two years, under which many thousands of classified reports were reviewed under the new liberalized classification policies and found declassifiable. This made it possible to transfer a major proportion of the Laboratory's document holdings from the Classified Library to the Research Library, with consequent shifts in the staff and in the cataloguing and reference functions of these two units. After the final results of the AEC's most

recent review program have gone into effect here, a further adjustment in the staff will be possible.

As an extension of the current declassification program, two members of the AEC's Declassification Branch spent two weeks here in the summer of 1956 to review classified Brookhaven originated drawings, photographs, notebooks, memoranda, and letters. It was possible to declassify most of this material. The AEC's latest declassification guide has opened up additional areas of information, and it is hoped that another review of this type of unpublished material will be possible in the near future, with a further extensive decrease in classified holdings.

In March 1957 declassification of the Nuclear Engineering Building, in which the Classified Library is located, left the Classified Library as the only permanent exclusion area on the site. Before the building could be declassified, all classified documents held individually within the building had to be returned to the Classified Library. This change resulted in a noticeable increase in the demands upon the Library's facilities, in spite of the lesser volume of classified holdings. The number of classified reports originating here has decreased sharply; in fact, unless the scope of the Laboratory's research programs changes drastically, it is doubtful that many more classified reports will be published under Brookhaven's auspices.

Activity in the Research Library continued to increase, particularly in the reference section, where for the second year an unusually large number of reports, most of them declassified, were added to the collection. To keep the report files current, an additional staff member was acquired to assist in report processing and catalog card filing. An increasing space problem was temporarily alleviated by storing these reports in a nearby building. The reference section has continued to prepare bibliographies and to do literature searches. Members of the Biology Department and the library staff worked together in the compilation of an extensive bibliography on the biological effects of ionizing radiations.

Subscriptions to many of the translated Soviet scientific periodicals were important additions to the Library's current journal files. The staff has participated in the translation program now under way at the AEC's Technical Information Service by arranging for the review of Soviet

monographs and by providing the project with material received here and judged to be of sufficient general interest for translation and distribution.

The use of the Library continues to grow, both in demands upon the reference staff and in borrowing from the collection. The growing participation of industry in nuclear science and technology has caused an increase in published literature, resulting in a greater annual acquisition of books.

The work level of the publication group appears to have reached a peak which has remained fairly constant during the past three years, with approximately 50 major technical reports edited and otherwise processed for publication as Brookhaven documents. However, instead of about one-third of these reports being classified as in previous years, only two classified reports were published during the past year, both of which have since been declassified.

The number of technical manuscripts originating from Brookhaven research and published in scientific and technical periodicals also appears to have reached a near plateau. During the year 401 such papers (including published abstracts of speeches) have been processed, as compared with 393 for fiscal 1956 and 418 for fiscal 1955.

A technical information display was prepared for the Inter-American Symposium on the Peaceful Application of Nuclear Energy. Over 150 samples of books, reports, brochures, and pamphlets covering various aspects of atomic energy were assembled from the Latin American countries, the AEC, U.S. industry, and the national laboratories, copies of which were available, without cost, to the Latin American visitors. Included in this material was the eight-volume set of Selected Reference Material prepared for the 1955 Geneva Conference by the AEC. After the Symposium Brookhaven arranged for the publications selected by the visitors to be shipped to them directly from the originating sources. In addition to this service, the Library assembled and displayed a collection of books and journals to familiarize the visitors with recently published material they might wish to procure under the \$25 book allowance granted to each individual by the International Cooperation Administration.

The distribution lists for the Laboratory's unclassified reports continue to grow. During the year a number of exchange arrangements were made with research institutions both in the United States and abroad. Many countries embarking upon their own national nuclear research programs are eager to benefit from the technical information available here, and in turn are only too pleased to furnish the results of their own work to cooperating sites. The advantages of such exchanges are very apparent, both from the technical viewpoint and from that of the international goodwill and cooperative spirit engendered.

PHOTOGRAPHY AND DUPLICATING

The photography group continued at the level of activity shown in Table 9. A short film on aspects of the Chemistry Department was produced for use on visitors' days. The sensitometry of film processing for bubble chambers was investigated in preparation for the purchase of a continuous film processing machine. Nuclear emulsion processing was moved to a new laboratory in T-109, and equipment providing 40 ft²/week of processing area was installed. Preliminary tests were being run at the end of the report period.

The Intertype Fotosetter was received by the duplicating group, and the appropriate staff members underwent a period of training and experimentation. All indications are that the machine is highly satisfactory for our purposes, including the setting of equations. The composition in this report is an example of its use. A saddle gang stitcher, a mechanized collating and binding device, was purchased to aid in report production. A

Table 9				
	Fiscal '55	Fiscal '56	Fiscal '57	
Photographs	4,218	4,552	6,322	
Photomicrographs	1,837	1,770	1,306	
Lantern slides	5,788	6,283	6,251	
Prints	36,008	36,351	41,583	
Photostats, Xerox	18,969	19,925	23,627	
Ozalid prints	276,968	332,451	295,517	
Recording film processed	13.6 mi.	14.6 mi.	22.5 mi.	

	Table 10		
	Fiscal '55	Fiscal '56	Fiscal '57
Offset pages	4,036,991	4,574,215	5,163,705
Offset negatives	5,035	5,479	7,034
Offset plates	1,066	1,677	2,310
Mimeo impressions	1,850,795	1,517,156	1,633,468
Stencils cut	1,992	1,497	1,011
Stencils run	10,168	10,084	11,266
Sheets collated			
and bound	1,377,050	1,637,145	1,951,525
Report copies issued	40,304	67,155	71,075

Stenafax, which scans copy and cuts a stencil, and replacements for an obsolete paper cutter and a mimeograph machine were received.

Production figures for the period are shown in Table 10.

The illustration section prepared 2615 drawings for publication or for slides, and was active in designing material for the Inter-American Symposium.

Administration and Operations

Included in this section are reports on the personnel, business, and other operational activities of the Laboratory.

PERSONNEL

Scientific Staff

For the past three years the size of the regular scientific staff of the Laboratory has remained almost constant, in spite of the characteristic high turnover promoted by policy. During the period from June 1, 1956 through May 31, 1957 there were 47 additions to the regular staff and 45 terminations. The composition of the scientific staff on May 31, 1957 is set forth in Table 1 and compared with that on the same date a year ago. The major changes in the regular staff were a reduction in the number of Associate Scientists from 129

to 103 and an increase in the number of Assistant Scientists from 20 to 40. The latter category was created only two years ago following a review of the appointment policy.

By contrast, the number of scientific staff visitors and collaborators, Research Associates, and graduate students has once again shown a marked increase. The number of salaried visitors increased by more than 10%. This increase is traceable to the growing number of Research Associates, who are listed for statistical purposes under the heading of visitors. Including both salaried and nonsalaried Research Associates, their number has nearly doubled in the past two years, having increased from 22 in 1955 to 33 in 1956, and to 43 on May 31 of this year. It is significant that of the present number, 12 are foreign scientists. These appointments are similar to postdoctoral research

Table 1
Scientific Staff on May 31, 1956 and 1957

				Vi	sitors	
	Regular staff		Sala	aried	No compensation	
	1956	1957	1956	1957	1956	1957
By appointment category						
Senior Scientist	37	39	2	2	12	12
Scientist	76	82	4	2	82	89
Associate Scientist	129	103	4	2	53	65
Assistant Scientist	20	40	1	1	12	24
Research Associate	_	_	27	38	6	5
Junior Scientist	17	19	_	1	4	9
Junior Research Associate		_	13	10	27	28
Research Assistant	2	0	_	1	7	8
Total	281	283	51	57	203*	240**
By academic degree						
PhD or MD	178	174	37	44	133	155
Master	34	35	13	6	50	35
Bachelor	63	71	1	7	18	45
No degree	6	3	_		2	5

^{*134} of these appointees worked intermittently at BNL.

^{**177} of these appointees worked intermittently at BNL.

Table 2

Classification of Visiting Scientists Participating in BNL Program for Period of One Month or More, June 1, 1956 – May 31, 1957

	Regular visitors and guests				10566	-		
	More than 3 months		Less than	3 months	1956 Summer program		Total	
	Salaried	Guest	Salaried	Guest	Salaried	Guest	Individuals	Institutions
University Staff	10	20	7	13	39	67*	156	73
Thesis students	15	11	3	5	1	2	37	14
Student Research Assistants	; 1	_	1		85	23	110	51
Total	26	31	11	18	125	92	303	101 different
Industry	1	32	_	6	_		39	29
Other institutions	2	26	1	15	3	7	54	34
Total	29	89	12	39	128	99	396	164 different

^{*}Includes 30 individuals participating in Summer Institute in Nuclear Science and Engineering.

fellowships and are limited in duration. Twenty-two Research Associates were appointed and 12 completed their work and terminated during the year. Nonsalaried visitors increased in number from 203 in 1956 to 240 in 1957. This increase is entirely in the category of visitors who work at the Laboratory for one or more days at intermittent intervals. The date May 31 was selected to eliminate from Table 1 individuals at the Laboratory only for the summer. Similarly, the dates used for Table 2 were selected in order to include participants in one summer program only – that of 1956. Dates coincident with the fiscal year would, on the other hand, span portions of two summer programs.

Table 2 indicates the number of scientists who worked at the Laboratory for a period of one month or more between June 1, 1956 and May 31, 1957. Such individuals from 101 different colleges and universities participating in the Laboratory program totaled 303. This compares with 280 individuals from 86 institutions last year, and 238 individuals from 69 institutions for the similar period two years ago. There were 93 individuals from industrial and other organizations, such as hospitals and government agencies, as compared with 85 last year and 52 two years age. The number of graduate students engaged in doctoral investigations was 37 as compared with 34 last year and 27 two years ago. Seventeen students

completed the research required for their degrees during the year.

In previous annual reports, the summer participants were not listed separately but were included with other visitors here for less than or more than three months. However, the number of summer appointees has steadily increased so that the present total represents a significant fraction of all visitors here for more than one month. Exclusive of students, participants in the 1956 summer program constituted about 40% of the year's total visitors; on the basis of visitors from colleges and universities only, this percentage is even greater.

Scientists who worked at the Laboratory on a continuous or an intermittent basis for less than one month are not included in Table 2. There were 90 such individuals here this year as compared to 85 last year and 72 two years ago.

The number of foreign scientists here during the past year was 86, which is 43% more than that for the previous year (Table 3). Not only do these scientists come from many different countries (24), but they work in almost every department of the Laboratory. In most instances, foreign visitors receive their financial support from their own institutions or govenments; a few receive grants-in-aid from philanthropic organizations or U.S. Government agencies other than the Atomic Energy Commission; and about 25 are salaried, including 12 Research Associates. The presence of foreign scien-

Table 3

Foreign Visitors,* July 1, 1956 – June 30, 1957,
Appointed to Staff for Various Periods (Weeks to a Year)

				Field					
Country	High Energy and Theoretical Physics	Other Physics	Chemistry	Biology	Engineering	Medicine	Total	Total for previous year (7/1/55-6/30/56)	
Germany	1	3	4	3		1	12	5	
Britain		4	2	2		2	10	7	
Japan	3	2	1	2		1	9	6	
Belgium		1	1		4	1	7	6	
China	5	1		1			7	5	
Canada		1		3		1	5	4	
France	1		4				5	3	
India	1	1	1	1			4	5	
Israel		1	2	1			4	1	
Italy	1			1		1	3	3	
Netherlands			1	2			3	1	
Egypt		1	1				2	2	
Norway		2					2	2	
South Africa			2				2	2	
Spain		2					2		
Argentina					1		1	1	
Australia				1			1	1	
Chile				1			1		
Greece						1	1		
Pakistan		1					1	_	
Sweden			1				1		
Thailand				1			1	_	
Turkey	1					•	1	1	
Yugoslavia		1					1	_	
Austria							0	1	
Denmark							0	1	
Peru							0	1	
Total	13	21	20	19	5	8	86	60	

^{*}This table does not include 24 foreign visitors here during the summer of 1957.

tists working cooperatively with others at the Laboratory is not only stimulating to all individuals concerned, but also plays an important role in integrating the scientists of the free world and promoting mutual understanding.

Table 4 lists the man-days of service rendered by consultants. Comparisons are made between the year covered by this report and the two previous fiscal years.

Summer Program for 1957

Arrangements have been made for 130 faculty members from 70 different educational institu-

Table 4							
Consultants' Services							
	1955	1956	1957				
Total contracts in effect June 30	81	72	80				
No. consultants used	52	41	35				
No. man-days of service	535	443	358				

tions to work at the Laboratory for up to three months during the summer of 1957. Of this number, 30 faculty members will participate in an 8week Summer Institute in Nuclear Science and Enginering. In addition, 20 individuals from 15 industrial and other organizations will work at the Laboratory for up to three months.

The formal summer student program has been continued for the sixth consecutive year. In January, announcements were sent to about 135 schools, most of which are located in the northeastern region of the United States. Applications were received from 90 graduate and 336 undergraduate students from 122 different colleges and universities. Appointments were offered to 104 applicants. Of these appointments, 80 have been accepted by 45 undergraduate and 35 graduate students representing 40 different institutions.

Also here for a portion of the summer are 24 Radiological Physics Fellows who have completed the first part of their training at the University of Rochester, 17 additional graduate students brought to the Laboratory by faculty members to work as their research assistants, and 9 Junior Research Associates working on their doctoral theses. The scientific staff will thus be increased by 280 additional workers.

Personnel Management

The total number of employees on June 30, 1957 was 1696, excluding temporary appointees, research collaborators, and guests. This represents a net increase of 98 staff members during the year. As of the end of this fiscal year, the ratio of 1 scientist to 4.0 nonscientists compares with the figure of 3.8 for a year ago. Employment statistics for

fiscal 1957 compared with those for fiscal 1956 are shown in Table 5.

In addition to the normal personnel management activities carried on during the year, there was special emphasis in the following areas: the negotiation of three union contracts, the initiation of a position evaluation and salary administration plan covering administrative and technical personnel on the monthly payroll, and improvement in employee benefit plans.

Labor Relations. During the year each of the three union contracts came up for renegotiation, and every effort was made during the negotiations to obtain contracts which would provide a sound basis for productive and harmonious relationships between the unions and the Laboratory.

A contract was signed with the Federal Labor Union, AFL-CIO (which has changed its name to Directly Affiliated Local Union No. 24426, AFL-CIO) covering maintenance, shop, warehousing, and firefighting employees. The contract became effective in December 1956 and covers a period of two years, with a "wage reopener" provision for limited negotiations at the end of one year.

The International Guards Union contract became effective in March 1957 and covers a period of two years.

For the first time a contract was negotiated between the Laboratory and the Oil, Chemical and Atomic Workers International Union AFL-CIO representing a newly organized group of 17 wage employees (pile operators). The contract, being

Table 5
Employment Statistics

		Fiscal 1956			Fiscal 1957			
Number of employees on June 30 Turnover data		1598*			1696**			
	Number	Annual rate (%)	Average monthly rate (%)	Number	Annual rate (%)	Average monthly rate (%)		
Accessions	285	18.20	1.52	348	21.17	1.76		
Separations (turnover)	220	14.05	1.17	250	15.26	1.27		
Net accessions	65	5.69	0.47	98	5.93	0.49		
Replacements (net turnover)	196	12.51	1.04	233	14.20	1.18		

^{*}Not including 147 temporary appointees.

^{**}Not including 144 temporary appointees.

new to both groups, was limited to one year and was made effective in November 1956.

Position Evaluation and Salary Administration. A staff member was added to the Office of Personnel in order that additional attention might be given to the matter of position evaluation and salary administration within the Laboratory. A comprehensive survey was carried out covering wages paid by other organizations within the area; as a result, revisions were made in the salary ranges of a number of categories within the Laboratory.

There has been a continuing effort to maintain comparable jobs at comparable rates of pay regardless of whether the positions were in a technical, clerical, bargaining-unit or other general category. In carrying out this policy, it became evident that a thorough job evaluation of middle-level and high-level positions outside the scientific staff was neded. A Laboratory-wide evaluation of such positions has been initiated with the objective of grouping the various positions into appropriate categories and adjusting the salary ranges accordingly.

Improvement in Employee Benefit Plans. Group life insurance available to those employees at the higher salary levels was previously limited in the amount of the coverage. This limitation has been lifted, and the coverages now may approximate twice the employee's annual salary. Employees on the weekly payroll are being canvassed to determine their interest in taking out a supplemental amount of life insurance now available to employees on the monthly payroll. If a sufficient number are interested, it is intended to arrange for them to participate on the same basis as employees paid on a monthly basis.

The benefits provided in the case of work-connected dismemberment or accidental death were increased, in the latter event from \$10,000 to \$12,500.

The major medical coverage (previously referred to as Medical Catastrophe coverage) was also improved. Total disability is no longer a prerequisite for this coverage and 80% of allowable expenses of over \$100 incurred within any 90-day period are reimbursed by the insurance carrier.

A thorough review of the Retirement Plan was initiated toward the end of 1956. The review revealed the desirability of providing for an increase in the annuity available at the time of retirement due to changes in the economy. In March 1957

an improved Retirement Plan was offered to employees which provided for the following changes: 1) the Laboratory's contribution was increased from 5% to 71/2% of an employee's total base salary; 2) the employee's contribution was increased from 5% to 7½% on that portion of his salary in excess of \$4200 per year (there was no change in the employee's contribution of 2\\% on the first \$3000 of salary and 5% on the salary between \$3000 and \$4200); and, 3) participation was made compulsory after July 1, 1958 for all employees who are 30 years old or older and have completed 3 months of service. The increase in total contributions to the retirement fund will provide employees with an annuity which, when supplemented by their social security benefits, will more adequately meet their needs upon retirement.

As an added service to employees, arrangements were completed to provide a special personal loan service and savings plan, with the convenience of payroll deductions, in lieu of a credit union.

Employee Activities. The Brookhaven Employees Recreation Association (BERA) continued to sponsor recreational activities for the benefit of the employees. The Concert Group, Theatre Group, Ceramics Group, and Camera Club were all active and well supported. Bowling attracted the greatest number of participants with 32 teams competing for the annual championships. Tennis proved increasingly popular and a beginner's class for girls was provided. The swimming pool was open two nights a week throughout the fall, winter, and spring. A program of supervised play, including swimming lessons, was organized, primarily for the children of visiting scientists residing on the Laboratory site.

SECURITY AND PLANT PROTECTION

The Security and Plant Protection Division functions as both a security and a service organization. As a security organization, it administers and enforces the AEC and Laboratory regulations concerned with the safeguarding of restricted data and the clearance of Laboratory personnel and visitors. As a service organization, it provides for protection of life and property through the activities of the Police and Fire Groups.

During the past fiscal year the scope of the security program has been further reduced. A major step in this direction was the declassification

Table 6

Admissions to the Site

	Fiscal 1955	Fiscal 1956	Fiscal 1957
Regular visitors*	19,893	22,507	28,287
Conference visitors	2,498	2,452	2,760
Alien visitors	832	1,179	1,969
Subcontractor employees	16,362	17,610	20,747
Total	39,585	43,748	53,763

^{*}Includes visitors during open house days.

of most of the last major restricted area, the nuclear engineering building. Only a small repository of classified documents now remains restricted. The easing of this phase of the security program, however, was offset by the clearance services required by the large increase in the number of visitors, both citizens and aliens. An indication of the growth in these activities during the past fiscal year may be gained by reference to Table 6, which shows the number of site admissions of nonstaff personnel.

Although the total number of on-site responses by the Fire Group increased in this fiscal year, only one fire of any consequence occurred, and this was effectively controlled within the experimental laboratory in which it started. The activity of the Fire Group is shown in the table below.

FIRE GROUP	1955	1956	1957
Responses on site	65	80	109
Responses off site	9	5	2
No response-investigation	12	11	14
Total	86	96	125

ARCHITECTURAL PLANNING

The Architectural Planning Division continued its collaborative efforts with the Brookhaven Area Manager's Office and their Architect-Engineers in connection with construction projects, particularly the Medical Research Center. The works area building was completed and turned over to the Laboratory late in the fiscal year. Early in FY 1958, bids for construction of two new facilities will be invited by the Area Manager's Office; namely, an addition to the cyclotron–Van de

Graaff building to house the 18-in. cyclotron, and the hot laundry and reclamation facility. Both in the preliminary design stages and during the preparation of contract drawings and specifications, this Division has assisted the Area Manager's Office and their Architect-Engineers.

Another aspect of construction progress was the work of extending the underground electric power and communication lines to serve the Medical Research Center. The design and supervision of this work, with a value of about \$100,000, was entirely the responsibility of this Division. The work was essentially completed during the past fiscal year; final completion is anticipated well in advance of the need for these utilities by the Medical Research Center.

During the year many other jobs, with a total value of about \$420,000, were undertaken which required working drawings and specifications, contract administration, and field supervision by this Division. The principal projects under this heading included

Source reactor facility	\$ 57,000
Building modifications for housing	
of electronic digital computer	36,000
Extension of underground site fire	
alarm network	42,000
Cafeteria modifications and	
improvements	45,000
Cosmotron projects including leak	
test panels, injector modifications,	
shielding foundations, cooling water	
waste lines, etc.	74,000
Reactor refueling, 2 projects	27,000
Modifications and additions to the	
Chemistry, Biology, and Hot	
Laboratories	44,000
Site utilities improvements	23,000

PLANT MAINTENANCE

The activities of the Plant Maintenance Division include the operation of all plant utilities, the maintenance of all buildings and plant equipment, and the provision of staff services and special services for other departments. The staff services include all Laboratory communications and transportation services. In October 1956 Laboratory controlled housing and official travel were added to these services to provide for their centralized control along with transportation. The

Table 7

Manpower Utilization

Type of work	Productive man-years	Percent of total work
Plant utilities operation	51	22
Building janitor service	24	10
Decontamination and hot laundr	у 9	4
Total plant operations	84	36
Communications service Transportation, housing,	14	6
and staff services	20	9
Total staff services	34	15
Special services for others	34	15
Facility improvements	3	1
Total special services	37	16
General repairs and maintenance	e 60	26
Special long-term maintenance	16	7
Total maintenance	76	33

housing facilities on the site – apartments, guest houses, and dormitories – have been operated at reasonably full occupancy during the past fiscal year. More than 40 off-site summer rentals have been procured for families of visiting scientists who will be working at the Laboratory this summer.

A breakdown of the utilization of manpower within the Plant Maintenance Division is shown in Table 7. It may be noted that $\frac{2}{3}$ of the total effort of this Division is devoted to the operation of plant facilities and to the provision of various services, and only $\frac{1}{3}$ to the maintenance of the buildings and the site. A breakdown of major costs involved in the operations and maintenance of the plant utilities and services provided by this Division is shown in Table 8. No costs, however, are included in this table for services to the scientific departments.

During the past year special maintenance work continued with the restoration of both permanent and semipermanent buildings. Among the major projects included in this program was the rehabilitation of both interior and exterior of four on-site housing buildings. Other special maintenance projects included exterior waterproofing and painting of six permanent buildings and the interior painting of seven permanent and semiper-

Table 8

Costs of Supplies, Materials, and Purchased Labor

Plant utilities operation	
Coal and fuel oil	\$256,365
Electricity	752,879
General supplies	23,680
Building janitor supplies	13,086
Decontamination and hot laundry supplies	24,132
Total plant operations	1,070,142
Staff services	
Telephone, teletype, and mail	160,117
Transportation (gasoline)	14,678
Housing and cafeteria supplies	36,334
Total staff services	211,129
Maintenance	
General materials and purchased labor	109,603
Special materials and purchased labor	219,339
Total maintenance	328,942
Total Plant Maintenance Division	\$1,610,213

manent buildings. Roofing or roofing repairs were made on thirteen buildings, and asbestos shingles were installed on three semipermanent buildings.

A survey is being made in conjunction with the Architectural Planning Division on the feasibility of distributing natural gas on the site to reduce both the cost of fuel and the maintenance cost of gas producing and heating plants now in use.

BUSINESS OPERATIONS

Supply, Materiel, and Inventory Management

The Supply and Materiel Division is responsible for the warehousing of approximately 22,000 items of inventory, of which 16,000 items are issued only by signed requisitions and are subject to daily machine records control. The remaining 6000 items of low unit price, classified as "common usage items," are issued without formal papers.

The task of keeping inventory adequate and in balance at a minimum level has been greatly aided by the advisory committees of Laboratory users. This cooperation between users and inventory management has helped to effect a further decrease in active inventory investment in terms of number of months' requirements on hand, even though the total dollar value has risen – in part

Table 9

Inventory Changes

		Fiscal year	
Type of inventory	1957	1956	1955
Active inventory			
Opening active inventory July 1	\$261,146	\$274,574	\$396,564
Net of purchases, stores issues,			
adjustments, additions to inventory,			
and transfers to excess	+31,910	-13,428	-121,990
Closing active inventory June 30	293,056	261,146	274,574
No. of months' investment in			
active inventory June 30	3.3	3.8	4.1
Stand-by inventory			
Opening stand-by inventory July 1	0		
Net of purchases, issues to active, and adjustments	3,402		
Closing stand-by inventory June 30	3,402		
Excess inventory			
Opening excess inventory July 1	4,327	45,026	0
Net of transfers from active inventory,	,	,	
dispositions, and adjustments	-4,327	-40,699	45,026
Closing excess inventory June 30	0	4,327	45,026
Total inventory			
Opening total inventory July 1	265,473	319,600	396,564
Net of purchases, stores issues, adjustments,	,	,	, .
transfers to excess, and dispositions	+30,984	-54,127	-76,964
Closing total inventory June 30	\$ 296,458	\$265,473	\$319,600

because of unit cost increases, and in part to satisfy larger demands (see Table 9). Regular screening of stock and closer liaison between the stores section and the Purchasing Division has improved the inventory in both quality and usefulness. Excess inventory was reduced to zero.

During the year the Laboratory had an opportunity to acquire a quantity of steel plate from a dismantled building of another AEC installation, which will be of great value as shielding for the Cosmotron and the AGS. It is being delivered at Brookhaven for about 50% of current market value for comparable material. In order not to distort the normal metals inventory, the Laboratory has elected to place these steel plates in a standby inventory until required for use. As these plates are received during fiscal 1958, this feature of the Laboratory's inventory will increase several-fold.

This Division is also responsible for office machines, equipment, and furniture. An inventory by classification of all furniture and office machines was completed during the fiscal year. A program of rehabilitating and refinishing old furniture was instituted which has shown substantial savings over salvage and replacement costs and will be continued.

The reclamation section has returned a total of \$35,000 of used material, no longer required by some departments, back to service for other departments.

Purchasing

During this fiscal year the Central Purchasing Group was consolidated with the Stores Buying Group in a location adjacent to the Stores Inventory Control Group. This arrangement maintains the close liaison between inventory control and stores buying yet permits the expanded use of commodity buying by the combined group. The consolidation of the Purchasing Catalog Library with that of the Supply and Materiel Division has eliminated some duplication of files and clerical effort.

The use of both petty cash purchases and blanket orders was greatly expanded in order to expedite further the procurement of low cost items, which constitute about one third of all purchase transactions. This procedure has markedly reduced the number of complete purchase orders required, the time required for processing an order, and specific cost per purchase transaction.

During the past fiscal year the total dollar volume of purchasing, not including contracts, increased from \$3,384,268 during fiscal year 1956 to \$4,666,372 for fiscal year 1957, an increase of 37.5%. At the same time the specific purchasing costs decreased by 20%, from 3.5% in FY 1956 to 2.8% in FY 1957.

During the year 30 purchase transactions were made from government lists of excess material and equipment at a cost of \$96,202 on which the original acquisition cost was \$646,444. There were 15 sales to dispose of Laboratory excess material and equipment, producing gross return of \$11,332.

PUBLIC INFORMATION

The activities of the Public Information Office continued to grow during the fiscal year, mainly for two reasons: the heightened general interest in the peaceful applications of atomic energy, and the everwidening areas of unclassified research at Brookhaven brought about by AEC declassification of many topics previously not available to the public for security reasons.

The recent development of nuclear energy programs in many foreign countries was reflected

here in the increasing number of foreign press representatives who visited the site and requested photographs and stories of interest to their own reading public. This resulted, moreover, in a number of loans of Brookhaven exhibit material to international trade fairs and expositions in Europe, in addition to the Laboratory's usual response to requests from this country. Preparations are already under way at Brookhaven for contributions of exhibits and technical films to the 1958 International Atoms for Peace Conference.

The most extensive single public information operation of the year was in connection with the Inter-American Symposium on the Peaceful Application of Nuclear Energy, held here May 13-17. Since it was considered desirable that the symposium achieve the maximum public impact both in this country and in Latin America, an elaborate program for press coverage was worked out with the AEC. Press digests of the papers to be presented were prepared in advance, and daily releases and news conferences with the speakers and discussants were arranged during the course of the symposium. On-site press rooms and other facilities were provided for representatives of the news media that accepted the general invitation to attend.

A number of U.S. television and radio programs featured Brookhaven personnel in interviews explaining to the lay public the research programs of the Laboratory and nuclear science in general. An increase over previous years was noted in the volume of requests for general information, interviews by representatives of the news media, and the use of photographs for publication in the popular press.

		5- - - - -
		₩ ₩
		•
		6
		; ; ;
		:
		# 4
		• s
		•
		:
		ă
		- 1 -
		# 69 69 69 69 69 69 69 69 69 69 69 69 69
		• 4
		(S. V. A. S. V.
		Fig.
		e de la companya de l
		ed orden

Appendix A

UNCLASSIFIED PUBLICATIONS, JULY 1, 1956 - JUNE 30, 1957

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, 1956. BNL 426 (AS-10).

Quarterly Progress Reports:

July 1 – September 30, 1956. BNL 419 (S-31).

October 1 - December 31, 1956. BNL 430 (S-33).

January 1 - March 31, 1957. BNL 439 (S-35).

April 1 – June 30, 1957. BNL 455 (S-36).

Conference Reports:

Brookhaven Symposia in Biology No. 9. Genetics in Plant Breeding. BNL 396 (C-23).

Proceedings of the Brookhaven Conference on Resonance Absorption of Neutrons in Nuclear Reactors. BNL 433 (C-24). Weekly Bulletin 9, No. 50-52: 10, No. 1-49.

Weekly Selected Reading List 9, No. 18-52; 10, No. 1-17. Miscellaneous:

Study for an Asian Regional Nuclear Center, November 15, 1956. Prepared for the International Cooperation Administration.

Appended Material to the Study for a Colombo Plan Nuclear Center, September 24, 1956. Prepared for the International Cooperation Administration.

STAFF PUBLICATIONS AND ABSTRACTS

Accelerator Development Department

COURANT, E.D. Orbit stability in particle accelerators.

Presented at Am. Math. Soc. Meeting, New York,
April 1957.

Palmer, J.P. and Phillips, R.H. Correction of remanent field effects in an alternating gradient synchrotron magnet by demagnetization. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 187 (1957).

PHILLIPS, R.H. (See Palmer, J.P.)

PLOTKIN, M. Ferrite accelerating cavities for a 25 billion electron volt proton synchrotron. Presented at Conf. on Magnetism and Magnetic Materials, Boston, Oct. 1957.

Biology Department

Anderson, I.C. (See Fuller, R.C.)

Anderson, I.C. and Fuller, R.C. Photophosphorylation in purple sulfur bacteria. (A) *Plant Physiol. Suppl.* 32, 16 (1957).

Anderson, I.C. (See Bergeron, J.A.)

ANDERSON, L. (See Steffensen, D.)

Augenstine, L. Discussion of a proposed mechanism of protein inactivation. Chapter in *Information Theory in Biology*, Pergamon Press, New York (In press).

Augenstine, L. Evidence for two modes of protein inactivation due to irradiation in dilute solution. (A) Radiation Research 7, 301 (1957).

Augenstine, L. A method for the estimation of the surface area occupied by active enzyme sites. Abstracts Natl. Biophys. Conf., 1957, pp. 4-5.

Bergeron, J.A., Anderson, I.C. and Fuller, R.C. Studies on the chromatophores of the purple sulfur bacteria. (A) *Plant Physiol. Suppl.* 32, 16 (1957).

BJERKNES, C. (See Steele, R.)

Brewbaker, J.L. Pollen anatomy and self-incompatibility in plants. (A) *Records Genetics Soc. Am.* 26, 361-2 (1957).

Buch, F.G., Charipper, H.A. and Edelmann, A. The effects of whole-body x-irradiation on peritoneal fluid cells and peripheral blood leukocytes in pollen-sensitized rats. *Radiation Research* 7, 129-38 (1957).

CALDECOTT, R.S. (See Konzak, C.F.)

CALDECOTT, R.S. (See Curtis, H. J.)

CALDECOTT, R.S., KONZAK, C.F. AND JOHNSON, E.B. Post treatment modification of x-ray induced injury in barley by aerobic and anaerobic hydration. (A) Radiation Research 7, 308 (1957).

^{*}Also included are those listings from the last Annual Report [BNL 426 (AS-10)] for which complete reference information was not then available.

CALDECOTT, R.S. AND CURTIS, H. J. The stability of x-ray induced chromosome breaks in dormant seeds of barley. (A) Abstracts Natl. Biophys. Conf., 1957, pp. 17-18.

CUANY, R.L. (See Sparrow, A.H.)

Curtis, H. J. and Delihas, N. The Design and Calibration of the Instrument Tunnel for Irradiation of Biological Material. BNL 425 (T-83), Dec. 1956.

Curtis, H. J. and Healey, R. Effects of radiation on aging. *Proc. 5th Intern. Radiobiol. Congr.* (In press).

Curtis, H. J. (See Konzak, C.F.)

Curtis, H. J., Delihas, N., Caldecott, R.S. and Konzak, C.F. Modification of x-ray damage in dormant seeds by storage. (A) *Radiation Research* 7, 311 (1957).

Curtis, H. J. (See Delihas, N.)

Curtis, H. J. (See Caldecott, R.S.)

Curtiss, R. (See Levine, M.)

Darrow, J.B. (See King, R.C.)

DE, D.N. (See Kaufmann, B.P.)

Delihas, N. (See Curtis, H. J.)

Delihas, N. (See Konzak, C.F.)

Delihas, N. and Curtis, H. J. The relative biological effectiveness of fission neutrons for the production of an acute mortality in mice. *Radiation Research* (In press).

EDELMANN, A. (See Buch, F.G.)

ENGLBERGER, F. (See Koshland, M.E.)

ERWIN, M. J. (See Koshland, D.E. Jr.)

FINGERMAN, L. (See Steffensen, D.)

FLEISCHER, M.L., KING, R.C. AND HARNLY, M.H. The effect of 2,4-dinitrophenol upon the uptake, localization and turnover of P³² in adult *Drosophila pseudo-obscura* females. *Records Genetics Soc. Am.* **26**, 369 (1957).

FLEISCHER, M.L., KING, R.C. AND HARNLY, M.H. Oogenesis in adult *Drosophila pseudoobscura*. (A) *Records Genetics Soc. Am.* **26**, 369 (1957).

FLUKE, D. J. A radiation target study of three enzyme activities of xanthine oxidase. Abstracts Natl. Biophys. Conf., 1957, p. 29.

FLUKE, D. J. (See Serlin, I. - Medical)

FORRO, F. Jr. Distribution of radioactive phosphorus among the progeny of a single labeled bacterium. *Exptl. Cell Research* 12, 363-73 (1957).

Fuller, R.C. and Anderson, I.C. CO₂ assimilation in the photosynthetic purple sulfur bacteria. (A) *Plant Physiol. Suppl.* 32, 16 (1957).

Fuller, R.C. A modified end-window counting tube for paper chromatograms. *Science* **124**, 1253 (1956).

Fuller, R.C. (See Anderson, I.C.)

Fuller, R.C. (See Bergeron, J.A.)

Geisselsoder, J. and Nims, L.F. Carbohydrate metabolism in stress. (A) Radiation Research 7, 317 (1957).

Gennaro, J.F. Jr. The effect of continuous beta irradiation of the pituitary on growth and thyroid function in the albino rat. (A) Presented at Am. Assoc. Anatomists Meeting, Baltimore, Spring 1957.

GIBBS, M. AND KANDLER, O. Asymmetric distribution of C¹⁴ in sugars formed during photosynthesis. *Proc. Natl. Acad. Sci. U.S.* **43**, 446-51 (1957).

GIBBS, M. (See Kandler, O.)

HEALEY, R. (See Curtis, H. J.)

HERR, E.B. JR. (See Koshland, D.E. Jr.)

HERR, E.B. JR. AND KOSHLAND, D.E. JR. Kinetic studies of amidophosphate and thiophosphate. (A) Presented at Am. Chem. Soc. Meeting, Miami, April 1957.

Jansen, V. (See Speirs, R.S.)

Johnson, E.B. (See Caldecott, R.S.)

KANDLER, O. (See Gibbs, M.)

Kandler, O. and Gibbs, M. Asymmetric distribution of C¹⁴ in the glucose phosphates formed during photosynthesis. *Plant Physiol.* 31, 411-2 (1956).

KAUFMANN, B.P. AND DE, D.N. Fine structure of chromosomes. Submitted to J. Biophys. Biochem. Cytol.

KAYE, N.E. (See King, R.C.)

Kennedy, E.P. and Koshland, D.E. Jr. Properties of the phosphorylated active site of phosphoglucomutase. *J. Biol. Chem.* (In press).

King, R.C. and Rubinson, A.C. The distribution of calcium in adult *Drosophila melanogaster*. *Science* 125, 546 (1957).

King, R.C. (See Fleischer, M.L.)

King, R.C. The major inorganic constituents of adult *Drosophila melanogaster. Am. Naturalist* (In press).

King, R.C. The problem of dominant lethals in *Drosophila melanogaster* females. *Proc. Natl. Acad. Sci. U.S.* 43, 282-5 (1957).

King, R.C., Darrow, J.B. and Kaye, N.E. Studies on different classes of mutations induced by radiation of *Drosophila melanogaster* females. *Genetics* 41, 890-900 (1956).

KLEIN, J.R. Effect of competitive inhibitors on the inactivation of the D-amino acid oxidase and its protein component by oxygen. *Arch. Biochem. Biophys.* 67, 423-31 (1957).

Konzak, C.F., Caldecott, R.S., Curtis, H. J. and Delihas, N. The influence of ion density and environmental factors on the radiosensitivity of seeds. II. The relation of pre- and post-irradiation storage conditions and temperature to observed radiation damage. (A) Presented at Agronomy Soc. Meeting, Atlanta, 1957.

Konzak, C.F. The influence of oxygen on the mutagenic effects of x-rays on maize endosperm loci. *Radiation Research* **6**, 1-10 (1957).

Konzak, C.F., Caldecott, R.S., Delihas, N. and Curtis, H.J. The modification of radiation damage in dormant seeds. (A) *Radiation Research* 7, 326 (1957). Konzak, C.F. (See Curtis, H.J.)

Konzak, C.F. Mutants from Lee H.R.S. wheat. (N) 1956 Wheat Newsletter 3, 17-8 (1957).

Konzak, C.F. Possible new rust resistance in oats obtained in an irradiated population. (N) 1956 Natl. Oat Newsletter 7, 64 (1957).

Konzak, C.F. (See Caldecott, R.S.)

Konzak, C.F. (See Sparrow, A.H.)

Koshland, D.E. Jr. and Herr, E.B. Jr. Acid and base catalysis in a non-enzymatic transfer reaction. A possible enzyme model. *Biochim. et Biophys. Acta* 25, 219-20 (1957).

- Koshland, D.E. Jr. and Erwin, M. J. Enzyme catalysis and enzyme specificity sequence of amino acids at the active site of phosphoglucomutase. (L) J. Am. Chem. Soc. 79, 2657 (1957).
- Koshland, D.E. Jr. Isotopic studies of carbohydrate reactions catalyzed by enzymes. (A) Presented at Am. Chem. Soc. Meeting, Symposium on Carbohydrates, New York, Sept. 1957.

Koshland, D.E. Jr. (See Herr, E.B. Jr.)

Koshland, D.E. Jr. (See Kowalsky, A.)

Koshland, D.E. Jr. (See Kennedy, E.P.)

Koshland, D.E. Jr. and Herr, E.B. Jr. The role of water in enzymatic hydrolyses: General method and its application to myosin. J. Biol. Chem. (In press).

Koshland, M.E. Decay of different antibodies in the guinea pig. (A) Federation Proc. 16, 420 (1957).

Koshland, M.E. Mechanism of antibody formation. I. Fate of iodine-labeled diphtheria toxoid at the site of antibody formation. *J. Immunol.* (In press).

Koshland, M.E. and Englberger, F. Mechanism of antibody formation. II. Rate of diphtheria antitoxin formation in the booster response. *J. Immunol.* (In press).

Koshland, M.E. Mechanism of antibody formation. III. Decay of diphtheria antitoxin in the guinea pig. J. Immunol. (In press).

Kowalsky, A. and Koshland, D.E. Jr. The mechanism of the galactose-glucose interconversion in *Lactobacillus bulgaricus*. *Biochim. et Biophys. Acta* 22, 575-7 (1956).

LEVINE, M. AND CURTISS, R. Genetic studies with mutants of phage P22 affecting lysogenization of Salmonella typhimurium. (A) Records Genetics Soc. Am. 26, 383 (1957).

Murray, B.E. The ontogeny of adventitious stems on roots of creeping-rooted alfalfa. Can. J. Botany 35, 463-75 (1957).

Nims, L.F. (See Geisselsoder, J.)

Pond, V. (See Sparrow, A.H.)

QUASTLER, H. The complexity of biological computers. Proc. IRE Professional Group on Electronic Computers (In press).

QUASTLER, H. The domain of information theory in biology. Chapter in *Information Theory in Biology*, Pergamon Press, New York (In press).

QUASTLER, H. Labyrinth damage by x-irradiation. (A) Radiation Research 7, 444 (1957).

QUASTLER, H. Quality of radiation and selectivity of radiation effects. (A) Abstracts Natl. Biophys. Conf., 1957, p. 57.

RUBINSON, A.C. (See King, R.C.)

Sagawa, Y. (See Shapiro, S.)

SAGAWA, Y. AND MEHLQUIST, G.A.L. The effect of ionizing radiation on the carnation, *Dianthus caryophyllus*. II. The effect of x-rays on flower color. (A) Presented at Am. Inst. Biol. Sciences Meeting, Aug. 1956.

SAGAWA, Y. AND MEHLQUIST, G.A.L. The mechanism responsible for some x-ray induced changes in flower color of the carnation, *Dianthus caryophyllus*. Am. J. Botany 44, 397-403 (1957).

- SAGAWA, Y. Nitrogen as a modifying factor in the growth and flowering response of carnations to radiation. (A) Plant Physiol. Suppl. 32, 50 (1957).
- SAGAWA, Y. AND MEHLQUIST, G.A.L. Radiation A new tool in carnation breeding. *Carnation Craft* No. 37, 3-5 (1956).
- SAUNDERS, L.Z. AND MOORE, E.N. Blindness in turkeys due to granulomatous chorioretinitis. *Avian Diseases* 1, 27-36 (1957).
- Saunders, L.Z., Jubb, K.V. and Coates, H.V. The intraocular lesions of canine distemper. *J. Comp. Pathol. Therap.* **67**, 21-9 (1957).
- SAUNDERS, L.Z. The retinal lesions in some viral infections of animals. (A) Proc. 3rd Intern. Congr. Neuropathol., Brussels, July 1957, pp. 77-8.

Schairer, L. (See Sparrow, A.H.)

Schwinghamer, E.A. Effect of ionizing radiation on rust reaction on plants. *Science* 125, 23-4 (1957).

Schwinghamer, E.A. Radiation-induced mutations in race 1 of flax rust. (A) *Phytopathology* 47, 31 (1957).

Shapiro, S. and Sagawa, Y. The Brookhaven cooperative program for radiation mutation research. *Proc. 9th Oak Ridge Regional Symposium: Radiation in Plant Breeding*, pp. 11-35, Jan. 1957.

Shapiro, S. Growth of root primordia in the stem of the Lombardy poplar. (A) *Plant Physiol. Suppl.* 32, 13 (1957).

Shapiro, S. The role of light in the growth of root primordia in the stem of the Lombardy poplar. Presented at Symposium on Tree Physiol., Harvard Forest, Mass., April 1957.

SMITH, H.H. Radiation in the production of useful mutations. *Botan. Rev.* (In press).

SPARROW, A.H., STEIN, O. AND SCHAIRER, L. Abnormal proliferations in plant tissue produced by ionizing radiation. (A) Abstracts Natl. Biophys. Conf., 1957, p. 67.

Sparrow, A.H., Pond, V. and Sparrow, R.C. Evidence for time of occurrence of the tertiary split in meiotic chromosomes of *Trillium erectum*. (A) *Records Genetics Soc.* Am. 26, 397-8 (1957).

Sparrow, A. H., Cuany, R.L. and Pond, V. Genetic response of Antirrhinum majus to acute and chronic plant irradiation. Z. Induktive Abstammungs-u. Vererbungslehre (In press).

Sparrow, A.H. and Konzak, C.F. The use of ionizing radiation in plant breeding – Accomplishments and prospects. Chapter in *Camellia Culture*, Macmillan Co., London (In press).

Sparrow, R.C. (See Sparrow, A.H.)

Speirs, E.E. (See Speirs, R.S.)

Speirs, R.S. and Wenck, U. Effect of cortisone on blood leukocytes and peritoneal fluid cells of mice. *Acta Haematol.* 17, 193-201 (1957).

Speirs, R.S. and Wenck, U. Effect of cortisone on the cellular response during allergic inflammation. *Acta Haematol.* 17, 271-9 (1957).

Speirs, R.S., Jansen, V. and Speirs, E.E. Effect of 500 r whole-body irradiation on the cellular composition of the peritoneal fluid following an intraperitoneal injection of antigen in mice. J. Immunol. 77, 437-43 (1956).

Speirs, R.S. Relation of eosinophils to antibody formation. *RES Bulletin* (In press).

STEELE, R., WALL, J.S., ALTSZULER, N. AND DEBODO, R.C. Conversion of circulating glucose to CO₂ in normal, hypophysectomized and adrenalectomized dogs. (A) Federation Proc. 16, 254 (1957).

Steele, R., Wall, J.S., DeBodo, R.C. and Altszuler, N. Effect of insulin on utilization and production of circulating glucose. *Am. J. Physiol.* **189**, 43-50 (1957).

STEELE, R., ALTSZULER, N., WALL, J.S. AND DEBODO, R.C. Effects of adrenocortical steroids on the carbohydrate metabolism of hypophysectomized dogs; studies with C¹⁴-labeled glucose. *Am. J. Physiol.* (In press).

Steele, R., Altszuler, N., Wall, J.S. and DeBodo, R.C. Effects of growth hormone on carbohydrate metabolism of hypophysectomized dogs. *Federation Proc.* 16, 2 (1957).

Steele, R., Altszuler, N., Wall, J.S., and deBodo, R.C. Increased production and utilization of circulating glucose during growth hormone regimen. *Proc. Soc. Exptl. Biol. Med.* (In press).

Steele, R., Wall, J.S., DeBodo, R.C. and Altszuler, N. Mechanism of insulin hypersensitivity in the hypophysectomized dog. *Am. J. Physiol.* **189**, 51-6 (1957).

STEELE, R., BERNSTEIN, W.AND BJERKNES, C. Single phototube liquid scintillation counting of C¹¹; application to an easily isolated derivative of blood glucose. *J. Appl. Physiol.* **10**, 319-26 (1957).

Steffensen, D. Dwarf *Drosophila* produced by ethylenediaminetetraacetic acid: a relationship to chelation of zinc. *Nature* **180**, 390-1 (1957).

Steffensen, D., Fingerman, L. and Anderson, L. Failure to increase the recessive lethal frequency in *Drosophila* with ethylenediaminetetraacetic acid. (N) *Drosophila Inform. Service* 30, 152 (1956).

STEIN, O. (See Sparrow, A.H.)

Stein, O. The effects of chronic and acute exposures of ionizing radiations on *Kalanchoe* "Brilliant Star." *Proc. Minn. Acad. Sci.* (In press).

Swanson, R.E. Distribution of renal arterial and portal fluids to proximal tubules in doubly-perfused frog kidneys. (A) *Am. J. Physiol.* **187**, 636 (1956).

Swanson, R.E. Water permeation coefficients for membranes calculated from osmotic and tracer data. (A) *Federation Proc.* 16, 126 (1957).

Taylor, J.H., Woods, P.S. and Hughes, W.L. The organization and duplication of chromosomes as revealed by autoradiographic studies using tritium-labeled thymidine. *Proc. Natl. Acad. Sci. U.S.* 43, 122-8 (1957).

Woods, P.S. A chromatographic study of hydrolysis in the Feulgen nucleal reaction. *J. Biophys. Biochem. Cytol.* 3, 71-88 (1957).

Woods, P.S. The mechanism of chromosome duplication as demonstrated by autoradiographs using tritium-labeled thymidine. (A) Presented at Histochem. Soc. Meeting, Baltimore, April 1957.

Woods, P.S. (See Hughes, W.L. - Medical)

Chemistry Department

ALLEN, A.O. AND CAFFREY, J.M. JR. On the radiolysis of pentane adsorbed on solids. Presented at Conf. on Application of Radioactive and Stable Isotopes and Radiations, Moscow, April 1957.

ALLEN, A.O. (See Schuler, R.H.)

ALLEN, A.O. (See Caffrey, J.M. Jr.)

ALLEN, A.O. AND ROTHSCHILD, W.G. Studies in the radiolysis of ferrous sulfate solutions. I. Effect of oxygen concentration in 0.8 N sulfuric acid. Radiation Research (In press).

ALLEN, A.O., HOGAN, V.D. AND ROTHSCHILD, W.G. Studies in the radiolysis of ferrous sulfate solutions. II. Effect of acid concentration in solutions containing oxygen. *Radiation Research* (In press).

ANDERSON, R.C. (See Wolf, A.P.)

Baker, E. and Katcoff, S. Heavy fragment emission in nuclear emulsions induced by 0.4, 2 and 3 Bev protons. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 222 (1957).

BARR, N.F. AND SCHULER, R.H. Dependence of radiation chemical yields on rate of energy loss: The yields of molecular and radical products from 0.8 N sulfuric acid solutions. (A) Radiation Research 7, 302 (1957).

BIGELEISEN, J. The significance of the product and sum rules to isotope fractionation processes. (A) Presented at Symposium on Isotope Separation, Netherlands Phys. Soc., Amsterdam, April 1957.

BIGELEISEN, J. AND WOLFSBERG, M. Theoretical and experimental aspects of isotope effects in chemical kinetics. Chapter in *Advances in Chemical Physics*, Vol. 1, Interscience, New York (In press).

Brodasky, T.F. (See Weston, R.E. Jr.)

CAFFREY, J.M. JR. AND ALLEN, A.O. Radiolysis of pentane adsorbed on mineral solids. *J. Phys. Chem.* (In press).

CHRISTMAN, D.R. (See Wolf, A.P.)

CHRISTMAN, D.R. Tritium counting in glass proportional counting tubes. *Chemist Analyst* 46, 5-6 (1957).

Corliss, L.M., Elliott, N. and Hastings, J. The magnetic structures of the polymorphic forms of manganous sulfide. *Phys. Rev.* **104**, 924-8 (1956).

Corliss, L.M. (See Hastings, J.M.)

CUMMING, J.B. (See Johnson, N.R.)

Dodson, R.W. (See Sayre, E.V.)

ELLIOTT, N. The magnetic structures of MnS₂, MnSe₂, and MnTe₂ below their Curie points. (A) Presented at 16th Congr. of Pure and Appl. Chem., Paris, July 1957.

ELLIOTT, N. (See Corliss, L.)

Fessenden, R.W. Jr. and Schuler, R.H. On the use of iodine as a radical detector in hydrocarbon radiolysis. J. Am. Chem. Soc. 79, 273-6 (1957).

FREED, S. Chemistry and biochemistry at low temperatures and discrimination of states and reactivities. (A)
Presented at Symposium on Information Theory in
Health Physics and Radiobiology, Gatlinburg, Tenn.,
Oct. 1956.

Freed, S. Equilibria as origin of differences in spectra of chlorophyll in different solvents. *Science* 125, 1248-9 (1957).

FREED, S. (See Sayre, E.V.)

FRIEDLANDER, G., BIVINS, R., STORM, M., METROPOLIS, N., TURKEVICH, A. AND MILLER, J.M. Nuclear cascades. I. Mechanics and low energy studies. (A) Bull. Am. Phys. Soc. Ser. II, 2, 63 (1957).

FRIEDLANDER, G., MILLER, J.M., METROPOLIS, N., BIVINS, R., STORM, M. AND TURKEVICH, A. Nuclear cascades. II. High energy results. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 63 (1957).

FRIEDLANDER, G. (See Pate, B.D.)

FRIEDMAN, L. (See Gordon, B.M.)

FRIEDMAN, L., Long, F.A. AND WOLFSBERG, M. Ionization efficiency curves and the statistical theory of mass spectra. (L) *J. Chem. Phys.* 26, 714-5 (1957).

Friedman, L. (See Irsa, A.P.)

Friedman, L. Mass spectrometer techniques for the analysis of solids. (A) Presented at Meeting of Soc. for Appl. Spectroscopy, New York, Nov. 1956.

FRIEDMAN, L. (See Wolfsberg, M.)

FRIEDMAN, L., LONG, F.A. AND WOLFSBERG, M. A study of the mass spectra of the lower aliphatic alcohols. J. Chem. Phys. 27, 613-22 (1957).

GORDON, B.M., FRIEDMAN, L. AND EDWARDS, G. Cesium in stony meteorites. (L) Geochim. et Cosmochim. Acta 12, 170-1 (1957).

GORDON, B.M. AND FRIEDMAN, L. Mass spectrometer studies of high energy nuclear reactions. (A) Presented at ASTM Meeting on Mass Spectrometry, New York, May 1957.

Hamilton, W.C. The effect of crystal shape and setting on secondary extinction. *Acta Cryst.* (In press).

Hamilton, W.C. Equivalent orbital bond moments: Applications to carbon dioxide and water. *J. Chem. Phys.* 26, 345-50 (1957).

Hamilton, W.C. A neutron crystallographic study of lead nitrate. Acta Cryst. 10, 103-7 (1957).

Hamilton, W.C. The quadrupole moment of carbon dioxide. (L) J. Chem. Phys. 25, 1283 (1956).

Hamilton, W.C. The two-center dipole moment integrals in terms of C functions. J. Chem. Phys. 26, 1018-20 (1957).

HARBOTTLE, G. (See Goldhaber, G.S. - Physics)

HARBOTTLE, G., McKEOWN, M. AND GOLDHABER, G.S. Disintegration scheme of Ra²²⁶ (1620 y). *Phys. Rev.* 103, 1776-7 (1956).

HARBOTTLE, G. AND RAUSCHER, H. The Szilard-Chalmers reaction in potassium cobalticyanide. *J. Inorg. & Nuclear Chem.* 4, 155-70 (1957).

Hastings, J.M. (See Corliss, L.M.)

Hastings, J.M. and Corliss, L.M. A neutron diffraction study of manganese ferrite. *Phys. Rev.* **104**, 328-31 (1956).

Hogan, V.D. (See Allen, A.O.)

HORNE, R.A. The ion exchange resin absorption of thallium(I) and (III). Submitted to J. Inorg. & Nuclear Chem.

Hudis, J. Production of carrier-free Mg²⁸ from aluminum. J. Inorg. & Nuclear Chem. 4, 237-8 (1957).

Hudis, J. (See Katcoff, S.)

IRSA, A.P. Electron impact studies on C₂H₅Cl, C₂H₅Br, and C₂H₅I. *J. Chem. Phys.* **26**, 18-22 (1957).

IRSA, A.P. AND FRIEDMAN, L. Mass spectra of halogen fluorides. Submitted to J. Inorg. & Nuclear Chem.

Izawa, M. (See Johnson, N.R.)

JOHNSON, N.R., CUMMING, J.B. AND IZAWA, M. Decay of Se⁷². (A) Bull. Am. Phys. Soc. Ser. II, 2, 230 (1957).

KATCOFF, S. (See Baker, E.)

KATCOFF, S. AND HUDIS, J. Search for O²⁰. J. Inorg. & Nuclear Chem. 3, 253-4 (1956).

Long, F.A. (See Friedman, L.)

Long, F.A. (See Wolfsberg, M.)

McCauley, C.E. (See Schuler, R.H.)

McCauley, C.E. and Schuler, R.H. Radical production in the radiolysis of liquid butane. *J. Am. Chem. Soc.* 79, 4008-11 (1957).

MILLER, D.G. (See Sayre, E.V.)

MILLER, J.M. (See Friedlander, G.)

MILLER, J.M. AND HOUCK, F.S. Reactions of alphaparticles with Fe⁵⁴. (A) Bull. Am. Phys. Soc. Ser. II, 2, 60 (1957).

Pate, B.D. and Friedlander, G. Reactions of uranium with 3-Bev protons. (A) Bull. Am. Phys. Soc. Ser. II, 2, 198 (1957).

PERLMAN, M.L. (See Wolfsberg, M.)

RAUSCHER, H. (See Harbottle, G.)

REDVANLY, C.S. (See Wolf, A.P.)

ROTHSCHILD, W.G. (See Allen, A.O.)

SAYRE, E.V. AND DODSON, R.W. Neutron activation study of Mediterranean potsherds. *Am. J. Archaeol.* **61**, 35-41 (1957).

SAYRE, E.V., MILLER, D.G. AND FREED, S. Symmetries of electric fields about ions in solutions. Absorption and fluorescence spectra of europic chloride in water, methanol and ethanol. *J. Chem. Phys.* **26**, 109-13 (1957).

Schuler, R.H. and McCauley, C.E. Chemical effects of nuclear activation of bromine in the propyl iodides. *J. Am. Chem. Soc.* **79**, 821 (1957).

Schuler, R.H. (See Barr, N.F.)

Schuler, R.H. The effect of solutes on the radiolysis of cyclohexane. *J. Phys. Chem.* (In press).

Schuler, R.H. The effect of solutes on the radiolysis of hydrocarbons. (A) Presented at Am. Chem. Soc. Meeting, Miami, April 1957.

Schuler, R.H. (See Fessenden, R.W. Jr.)

Schuler, R.H. and Allen, A.O. Radiation chemistry studies with cyclotron beams of variable energy: Yields in aerated ferrous sulfate solution. *J. Am. Chem. Soc.* 79, 1565-72 (1957).

SCHULER, R.H. (See McCauley, C.E.)

Schuler, R.H. AND McCauley, C.E. Recoil energy effects in the hot atom chemistry of iodine. (L) *J. Chem. Phys.* 25, 1080-1 (1956).

Schwarz, H.A. The radiation chemistry of ferrous chloride solutions. J. Am. Chem. Soc. 79, 534-6 (1957).

SLAVIN, M. Electrode for bulky samples. (N) Submitted to Appl. Spectroscopy.

Welker, J. (See Wolfsberg, M.)

Weston, R.E. Jr. Effect of pressure on the isotope effect in a unimolecular gaseous reaction: Tritium and carbon-13 effects in the isomerization of cyclopropane. J. Chem. Phys. 26, 975-83 (1957).

WESTON, R.E. Jr. AND BRODASKY, T.F. The infrared spectrum and force constants of the nitrite ion. *J. Chem.*

Phys. 27, 683-9 (1957).

Weston, R.E. Jr. The infrared spectrum of N¹⁵O₂ and force constants of NO₂. J. Chem. Phys. **26**, 1248-51 (1957).

WOLF, A.P., REDVANLY, C.S. AND ANDERSON, R.C. The chemical consequences of the N¹⁴(n,p)C¹⁴ reaction in the acetamide system and the implications of nuclear recoil as a tool for synthesis. *J. Am. Chem. Soc.* **79**, 3717 (1957).

WOLF, A.P. AND OLTMANN, A. Inexpensive equipment for studying the irradiation of organic materials in a pile under static conditions. *Intern. J. Appl. Radiation and*

Isotopes (In press).

Wolf, A.P., Bordon, B. and Redvanly, C.S. Neutron irradiation of benzene and of toluene in 2-methylpyrazine. An investigation of synthesis versus re-entry.
(A) Presented at Am. Chem. Soc. Meeting, Miami, April 1957.

Wolf, A.P., Bordon, B., Christman, D.R. and Anderson, R.C. Nuclear recoil as a new technique for labeling organic compounds with carbon-14 and tritium. Presented at Symposium on Nuclear Technology in Petroleum and Chemical Industries, April 1957.

Wolf, A.P., Redvanly, C.S., Christman, D. and Anderson, R.C. Use of recoiling carbon-14 as a new technique in labeling organic compounds. (A) *Proc. Intern. Conf. on Radioisotopes in Scientific Research* (UNESCO), Paris, Sept. 1957.

Wolfgang, R. and El Sayed, M.F.A. Chemical reaction of recoil tritium with gaseous alkanes. (L) Submitted

to J. Am. Chem. Soc.
WOLFSBERG, M. (See Friedman, L.)

Wolfsberg, M., Welker, J. and Perlman, M.L. K-capture-positron ratios for first-forbidden transitions: Sb¹²², Rb⁸⁴, I¹²⁶, As⁷⁴. (A) Bull. Am. Phys. Soc. Ser. II, 2, 24 (1957).

Wolfsberg, M., Long, F.A. and Friedman, L. Statistical theory of mass spectra – Ionization efficiency curves.

(A) Presented at ASTM Meeting on Mass Spectrometry, New York, May 1957.

Wolfsberg, M., Long, F.A. and Friedman, L. Statistical theory of mass spectra – Mass spectra of alcohols. (A) Presented at ASTM Meeting on Mass Spectrometry, New York, May 1957.

WOLFSBERG, M. (See Bigeleisen, J.)

Cosmotron Department

ABASHIAN, A., ADAIR, R.K., COOL, R., ERWIN, A., KOPP, J., LEIPUNER, L.B., MORRIS, T.W., RAHM, D.C., RAU, R.R., THORNDIKE, A.M., WHITTEMORE, W.L. AND WILLIS, W. J. Angular distributions of positrons from π^* - μ^* - e^* decays observed in a liquid hydrogen bubble chamber. (L) *Phys. Rev.* 105, 1927-8 (1957).

ABASHIAN, A., COOL, R. AND CRONIN, J. Cross sections of 970-Mev π⁻ in various elements. (A) *Bull. Am. Phys. Soc.* Ser. II, 1, 350 (1956).

ABASHIAN, A. (See Cronin, J.W. - Physics)

ABASHIAN, A., COOL, R. AND CRONIN, J.W. Neutron and proton distributions in Pb. (L) *Phys. Rev.* **104**, 855-6 (1956).

Adair, R.K. (See Abashian, A.)

Adair, R.K. and Leipuner, L.B. Piston operated liquid hydrogen bubble chamber. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 7 (1957).

Adala, R.K. (See Leipuner, L.B.)

Adair, R.K. and Leipuner, L.B. Strange particle production near threshold by π^- -mesons in a hydrogen bubble chamber. (A) Presented at Conf. on High Energy Nuclear Physics, Univ. of Rochester, April 1957.

Berley, D. (See Ridgway, S.L.)

Berley, D. and Collins, G.B. Production of unstable particles by protons on various nuclei. (A) *Bull. Am. Phys. Soc.* Ser. II, 1, 320 (1956).

BOOTH, E.T. (See Lande, K.)

Chinowsky, W. (See Lande, K.)

Collins, G.B. (See Ridgway, S.L.)

Collins, G.B. (See Berley, D.)

FOWLER, E.C. (See Willis, W. J. - Physics)

HORNYAK, W.F. (See Leipuner, L.B.)

Lande, K., Booth, E.T., Impeduglia, J., Lederman, L.M. and Chinowsky, W. Observation of long-lived neutron V-particles. (L) Phys. Rev. 103, 1901-4 (1956).

LEDERMAN, L.M. (See Lande, K.)

LEIPUNER, L.B. (See Abashian, A.)

LEIPUNER, L.B. (See Adair, R.K.)

LEIPUNER, L.B. (See Madey, R.)

LEIPUNER, L.B., ADAIR, R.K. AND HORNYAK, W.F. Strange particle production by π^- -mesons in a hydrogen bubble chamber. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 7 (1957).

Leitner, J. (See Schwartz, M.)

MADEY, R. AND LEIPUNER, L.B. Relative scintillation intensity of some Cerenkov counter media. *IRE Trans. Professional Group on Nuclear Sci.* NS-3, No. 4 (1956).

RIDGWAY, S.L., BERLEY, D. AND COLLINS, G.B. Gammarays from strange particles. *Phys. Rev.* **104**, 513-7 (1956).

Samios, N.P. (See Schwartz, M.)

Schwartz, M., Samios, N.P., Steinberger, J., Chretien, M. and Leitner, J. Elastic scattering of 1.4-Bev π -mesons on hydrogen in a propane bubble chamber. (A) *Bull. Am. Phys. Soc.* Ser. II, 1, 349 (1956).

Schwartz, M., Samios, N.P., Steinberger, J., Chretien, M. and Leitner, J. Heavy particle production by 1.4-Bev π^- -mesons in a propane bubble chamber. (A) *Bull. Am. Phys. Soc.* Ser. II, 1, 349 (1956).

STEINBERGER, J. (See Schwartz, M.)

STERNHEIMER, R.M. Effect of the atomic core on the nuclear quadrupole coupling. *Phys. Rev.* **105**, 158-69 (1957).

STERNHEIMER, R.M. Effect of the exclusion principle on the interaction of K-mesons with nuclei. *Phys. Rev.* 106, 1027-30 (1957).

STERNHEIMER, R.M. (See Lindenbaum, S. J. – Physics) STERNHEIMER, R.M. AND LINDENBAUM, S. J. Pion production in pion-nucleon collisions. (A) Bull. Am. Phys. Soc. Ser. II, 2, 176 (1957).

STERNHEIMER, R.M. (See McCormick, B.H. - Physics)
TURNER, C.M. Composite electrode positive ion acceleration tube. (A) Bull. Am. Phys. Soc. Ser. II, 2, 187 (1957).
TURNER, C.M. (See Bloom, S.D. - Physics)

YUAN, L.C.L. (See Lindenbaum, S. J. - Physics)

Instrumentation and Health Physics Department

BERNSTEIN, W. (See Weiss, J.)

BERNSTEIN, W. (See Steele, R. - Biology)

Chase, R.L. and Higinbotham, W.A. Millimicrosecond time-to-pulse-height converter using an rf vernier. *Rev. Sci. Instr.* 28, 448-51 (1957).

COWAN, F.P. (See Weiss, J.)

Cowan, F.P. Radiation safety in a research laboratory. Presented at Inter-American Symposium on the Peaceful Application of Nuclear Energy, Brookhaven National Laboratory, May 1957.

GILLIAM, O.R. (See Weiss, M.M.)

Graham, M., Higinbotham, W.A. and Rankowitz, S. Dekatron drive circuit and application. *Rev. Sci. Instr.* 27, 1059-61 (1956).

HIGINBOTHAM, W.A. (See Graham, M.)

HIGINBOTHAM, W.A. AND POLLOCK, B. Ionization chamber survey instrument. *IRE Trans. Professional Group on Nuclear Sci.* NS-4, No. 1, 1 (1957).

HIGINBOTHAM, W.A. (See Chase, R.L.)

HIGINBOTHAM, W.A. AND TILLINGER, J. Twin Channel Count Integrator (EH1-503). BNL 408 (T-79), June 1956.

Kane, J.V. and Frankel, S. Gamma-electron and electron-gamma angular correlation measurements in Pt¹⁹⁶. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 25 (1957).

KANE, J.V. High-voltage low-impedance divider for regulating photomultiplier dynodes. (L) Rev. Sci. Instr. 28, 582-4 (1957).

NEVALA, L. (See Smith, R.F. - Photography)

Рогоск, В. (See Higinbotham, W.A.)

RANKOWITZ, S. (See Graham, M.)

STONG, R.W. AND KLEIN, J.H. The removal from the Brookhaven reactor and the sectioning of the in-pile unit of a liquid metal fuel reactor loop. Presented at 5th Hot Laboratory Equipment Conf., Philadelphia, March 1957.

TILLINGER, J. (See Higinbotham, W.A.)

Weiss, J. and Bernstein, W. The current status of W, the energy to produce one ion pair in a gas. Radiation Research 6, 603-10 (1957).

Weiss, J. and Cowan, F.P. Fallout Studies at Brookhaven National Laboratory During the Summer of 1956. BNL 436 (I-18).

WEISS, M.M., WALTER, R.I., GILLIAM, O.R. AND COHEN, V.W. Paramagnetic resonance spectrum of V⁴⁹. (A) Bull. Am. Phys. Soc. Ser. II, 2, 31 (1957).

Medical Department

Basson, J.K. (See Lippincott, S.W.)

Bond, V.P., Cronkite, E.P. and Easterday, O.D. Degree to which recovery from acute alpha irradiation is possible. (A) *Radiation Research* 7, 304 (1957).

Bond, V.P. and Cronkite, E.P. Effects of radiation on mammals. *Ann. Rev. Physiol.* **19**, 299-328 (1957).

Bond, V.P., Cronkite, E.P., Sondhaus, C.A., Robertson, J.S. and Borg, D.C. The influence of exposure geometry on the pattern of radiation dose delivered to large animal phantoms. *Radiation Research* 6, 554-72 (1957).

BOND, V.P. (See Shellabarger, C.J.)

BOND, V.P. (See Robertson, J.S.)

BOND, V.P. (See Cronkite, E.P.)

BOND, V.P. (See Campo, R.D.)

Borg, D.C. (See Bond, V.P.)

CAMPO, R.D., BOND, V.P. AND CRONKITE, E.P. Studies on suspected circulating "radiotoxins" in adrenalectomized irradiated rats. (A) Federation Proc. 16, 18 (1957).

CAREY, R.W. (See Easterday, O.D.)

CHRISTIE, R.W. (See Silver, L.)

Christie, R.W. and Dahl, L.K. Dissimilarity in oxygen consumption between the thoracic and abdominal aorta in rats. *J. Exptl. Med.* 106, 357-64 (1957).

CONARD, R.A., CANNON, B., HUGGINS, C.E., RICHARDS, J.B. AND LOWREY, A. Medical Survey of Marshallese Two Years After Exposure to Fallout Radiation. BNL 412 (T-80), March 1956.

CONARD, R.A. Three-year medical survey of the Marshallese people exposed to fallout in March 1954. *Radiation Research* 7, 309 (1957).

COTZIAS, G.C. AND GREENOUGH, J. J. Concomitant analysis for oxygen uptake and ammonia evolution during the monoamine oxidase reaction. *Arch. Biochem. Biophys.* (In press).

Cotzias G.C. and Greenough, J. J. The specificity of the manganese pathway in the body. (A) Federation Proc. 16, 354 (1957).

Cotzias, G.C., (See Serlin, I.)

CRONKITE, E. P., (See Bond, V.P.)

CRONKITE, E.P. (See Willigan, D.A.)

CRONKITE, E.P. Fallout, civil defense and effects of radiation on man. Presented at Am. Vet. Med. Assoc. Meeting, Cleveland, Aug. 1957.

CRONKITE, E.P. Hemorrhagic states in neoplastic disease, platelet transfusions, and radioautographic studies on tissues of animals receiving sulphur-labeled platelet transfusions. Presented at First Pan-Am. Cancer Cytol. Congr., Miami, April 1957.

CRONKITE, E.P. Human radiation injury – diagnosis, therapy and prognosis. Presented at Intern. Congr. Hematol., Boston, Sept. 1956.

CRONKITE, E.P. The interaction of radiosulphate-labeled transfused platelets with capillary endothelium in the rat. (A) Presented at First Pan-Am. Cancer Cytol. Congr., Miami, April 1957.

CRONKITE, E.P. (See Shellabarger, C.J.)

Cronkite, E.P. (See Robertson, J.S.)

CRONKITE, E.P., SHELLABARGER, C.J., BOND, V.P. AND LIPPINCOTT, S.W. Studies on the mechanism of induction of radiation induced tumors of the breast in the rat. (A) *Radiation Research* 7, 311 (1957).

CRONKITE, E.P. (See Campo, R.D.)

Cronkite, E.P., Bond, V.P., Robertson, J.S. and Paglia, D.E. The survival, distribution and apparent interaction with capillary endothelium of transfused radiosulphate-labeled platelets in the rat. (A) J. Clin. Invest. 36, 881 (1957).

Dahl, L.K. (See Silver, L.)

DAHL, L.K. (See Christie, R.W.)

Dahl, L.K. and Love, R.A. Etiological role of sodium chloride intake in essential hypertension in humans. *J. Am. Med. Assoc.* **164**, 397-400 (1957).

Dahl, L.K. Evidence for an increased intake of sodium in hypertension based on urinary excretion of sodium. *Proc. Soc. Exptl. Biol. Med.* **94**, 23-6 (1957).

Dahl, L.K. Pressor effects of norepinephrine after drastic reduction of sodium intake. *Circulation* 15, 231-5 (1957).

DI FERRANTE, N. AND POPENOE, E.A. Hexosamine-containing proteins co-precipitated with urinary muco-polysaccharides. (A) Presented at Intern. Congr. Clin. Chem. Meeting, Stockholm, Aug. 1957.

DI FERRANTE, N. Urinary excretion of acid mucopolysaccharides by patients with rheumatoid arthritis. Federation Proc. 16, 170 (1957).

Drew, R.M. (See Popenoe, E.A.)

Drew, R.M. Induction of resistance to A-methopterin in *Diplococcus pneumoniae* by deoxyribonucleic acid. (L) *Nature* 179, 1251-2 (1957).

Drew, R.M. Isolation and propagation of rabbit kidney epithelial-like cells. *Science* 126, 747 (1957).

EASTERDAY, O.D. Comparative borax toxicity among mouse population types. (A) Presented at Animal Care Panel Meeting, Chicago, Nov. 1956.

EASTERDAY, O.D. Constant temperature apparatus for increasing the solubility of drugs for injection. *Arch. intern. pharmacodynamie* (In press).

EASTERDAY, O.D. (See Bond, V.P.)

EASTERDAY, O.D. (See Robertson, J.S.)

Easterday, O.D. and Carey, R.W. Some additional pharmacological studies with boron compounds. (A) Presented at Am. Soc. Pharmacol. Exptl. Therap. Meeting, French Lick, Ind., Nov. 1956.

FARR, L.E. Man, medicine and the atom. Gordon Wilson Lecture presented at Am. Clin. Climat. Assoc. Meeting, Sky Top, Pa., Nov. 1956.

FARR, L.E. The medical uses of nuclear reactors. Bruxelles-méd., 37, 843-58 (1957).

FARR, L.E., LIPPINCOTT, S.W., HAYMAKER, W.E. AND YAKOVLEV, P.I. Neuropathological and topographic-anatomical study of whole brains following neutron capture therapy for glioblastoma multiforme. (A) Presented at Third Intern. Congr. Neuropathol., Brussels, July 1957.

FARR, L.E. (See Stickley E.E.)

Gamble, J.L. Jr. (See Robertson, J.S.)

GIDEZ, L.I. AND EDER, H.A. The incorporation of glycerol-1,3-C¹⁺ into the triglycerides and phosphatides of human serum and serum lipoproteins. (A) *Federation Proc.* 16, 186 (1957).

GIDEZ, L.I. AND JAMES, J.A. Lipide metabolism in experimental lipemia. Presented at Conf. Biochem. Problems Lipids, Belgium, Aug. 1956.

Greenough, J. J. (See Cotzias, G.C.)

GROSSMAN, A. (See Shreeve, W.W.)

Hankes, L.V. and Stoner, R.D. Incorporation of Dityrosine-2-C¹⁴ and DL-tryptophan-2-C¹⁴ by encysted *Trichinella spiralis* larvae. *Exptl. Parasitol.* (In press).

HANKES, L.V. (See Stoner, R.D.)

HANKES, L.V. AND HENDERSON, L.M. The metabolism of carboxyl-labeled 3-hydroxyanthranilic acid in the rat. *J. Biol. Chem.* 225, 349-54 (1957).

HANKES, L.V. (See Henderson, L.M.)

HANKES, L.V. SUHADOLNIK, R.J., STEVENS, C.O. AND HENDERSON, L.M. Species variation in picolinate and quinolinate formation from 3-hydroxyanthranilate by liver extracts. (A) Federation Proc. 16, 257 (1957).

Hankes, L.V. and Segel, I.H. The synthesis and metabolism of quinolinic acid ring labeled with tritium. *Proc. Soc. Exptl. Biol. Med.* **94**, 447-9 (1957).

HENDERSON, L.M. (See Hankes, L.V.)

Henderson, L.M. and Hankes, L.V. The metabolism of DL-tryptophan-3a,7a,7-C¹⁴ and DL-tryptophan-alpha-C¹⁴ in the rat. *J. Biol. Chem.* **222**, 1069-77 (1956).

Hughes, W.L. Chemistry of iodination. Ann. N.Y. Acad. Sci. 70, 3-18 (1957).

Hughes, W.L. (See Painter, R.B.)

Hughes, W.L. (See Robertson, J.S.)

Hughes, W.L., Taylor, J.H. and Woods, P.S. The organization and duplication of chromosomes as revealed by autoradiographic studies using tritium-labeled thymidine. *Proc. Natl. Acad. Sci. U.S.* 43, 122-8 (1957).

Hughes, W.L. A physico-chemical rationale for the biological activity of mercury and its compounds. *Ann. N.Y. Acad. Sci.* **65**, 454-60 (1957).

James, J.A. and Robertson, J.S. Estimation of exchangeable water and potassium by radioisotope dilution in children. A.M.A. J. Diseases Children 93, 217-22 (1957). James, J.A. (See Gidez, L.I.)

LEWALLEN, C. (See Lippincott, S.W.)

LIPPINCOTT, S.W., SHELLABARGER, C. J. AND BASSON, J.K. Comparison of acute pathological effects of alpha and beta particle radiation of the rat thyroid gland. *A.M.A. Arch. Pathol.* **63**, 557-61 (1957).

LIPPINCOTT, S.W. (See Farr, L.E.)

LIPPINCOTT, S.W. (See Shellabarger, C.J.)

LIPPINCOTT, S.W., LEWALLEN, C. AND SHELLABARGER, C.J. Pathology of radioisotopic ablation of the thyroid in the dog. A.M.A. Arch. Pathol. 63, 540-56 (1957).

LIPPINCOTT, S.W. (See Robertson, J.S.)

LIPPINCOTT, S.W. (See Cronkite, E.P.)

LOVE, R.A. (See Dahl, L.K.)

MEYER, L.M. (See Willigan, D.A.)

PAGLIA, D.E. (See Cronkite, E.P.)

Painter, R.B. and Hughes, W.L. The distribution of tritium-labeled deoxyribonucleic acid in *Escherichia coli* during growth. (A) *Bacteriol Proc.* Abstract No. G89, 1957

Popenoe, E.A. and Drew, R.M. The action of an enzyme of *Clostridium perfringens* on orosomucoid. *J. Biol. Chem.* 228, 673-83 (1957).

POPENOE, E.A. (See Di Ferrante, N.)

ROBERTSON, J.S., TOSTESON, D.C. AND GAMBLE, J.L. JR. Determination of exchange rates in three-compartment steady-state closed systems through the use of tracers. J. Lab. Clin. Med. 49, 497-503 (1957).

ROBERTSON, J.S. (See Bond, V.P.)

ROBERTSON, J.S. (See James, J.A.)

ROBERTSON, J.S. AND HUGHES, W.L. Intra-nuclear irradiation with tritium-labeled thymidine. (A) Presented at Natl. Biophys. Conf., Columbus, Ohio, March 1957.

Robertson, J.S. (See Stickley, E.E.)

ROBERTSON, J.S., BOND, V.P., CRONKITE, E.P., EASTERDAY, O.D. AND LIPPINCOTT, S.W. Relative biological effectiveness of heavy particles from the $B^{10}(n,\alpha)Li^7$ reaction for skin lesions in swine. (A) Federation Proc. 16, 107 (1957).

ROBERTSON, J.S. (See Cronkite, E.P.)

ROBERTSON, J.S. AND HUGHES, W.L. Theoretic considerations of the radiation dose from discrete tritium sources.
(A) Presented at Radiol. Soc. North Am. Meeting, Dec. 1956.

SEGEL, I.H. (See Hankes, L.V.)

SERLIN, I. AND FLUKE, D. J. The size and shape of the radiosensitive acetylcholinesterase unit. *J. Biol. Chem.* **223**, 727-36 (1956).

SERLIN, I. AND COTZIAS, G.C. State of tissue acetylcholinesterase as determined by cobalt-60 gamma radiation inactivation. *Radiation Research* 6, 55-66 (1957).

Serlin, I. Thermal protection of choline chloride from decomposition by ionizing radiation. *Science* **126**, 261 (1957).

SHELLABARGER, C.J. (See Lippincott, S.W.)

SHELLABARGER, C.J., CRONKITE, E.P., BOND, V.P. AND LIPPINCOTT, S.W. The occurrence of mammary tumors in the rat after sublethal whole-body irradiation. *Radiation Research* 6, 501-12 (1957).

SHELLABARGER, C.J. (See Cronkite, E.P.)

Shreeve, W.W. and Grossman, A. Precursors of desoxyribose in rat liver studied with C¹⁴-labeled glycine. (A) *Federation Proc.* 16, 248 (1957).

SILVER, L., CHRISTIE, R.W. AND DAHL, L.K. Connective tissue as a major sodium reservoir. (A) Federation Proc. 16, 372 (1957).

Sinex, F.M. Aging and the lability of irreplaceable molecules. J. Gerontol. 12, 190-8 (1957).

SINEX, F.M. AND VAN SLYKE, D.D. The role of hydroxylysine in the synthesis of collagen. (A) Federation Proc. 16, 250 (1957).

SONDHAUS, C.A. (See Bond, V.P.)

STEVENS, C.O. (See Hankes, L.V.)

STICKLEY, E.E., ROBERTSON, J.S. AND FARR, L.E. The nuclear reactor as an instrument of medical research and therapy. Presented at 2nd Nuclear Eng. and Sci. Conf., Philadelphia, March 1957.

STONER, R.D. (See Hankes, L.V.)

STONER, R.D. AND HANKES, L.V. In vitro metabolism of DL-tyrosine-2-C¹⁴ and DL-tryptophan-2-C¹⁴ by Trichinella spiralis larvae. Exptl. Parasitol. (In press).

SUHADOLNIK, R.J. (See Hankes, L.V.)

Tosteson, D.C. (See Robertson, J.S.)

VAN SLYKE, D.D. Hydroxylysine. In Festschrift – Arthur Stoll, p. 211, A.G. Birkhauser, Basle, Switzerland, 1957. VAN SLYKE, D.D. (See Sinex, F.M.)

Weller, R.I. Ionization Chamber Radioisotope Comparator. BNL 429 (T-85), Nov. 1956.

WILLIGAN, D.A., MEYER, L.M. AND CRONKITE, E.P. The distribution and turnover of parenterally injected Co⁶⁰-labeled vitamin B₁₂. (A) Presented at Am. Federation Clin. Res. Annual Meeting, 1957.

Nuclear Engineering Department

Ballantine, D.S., Colombo, P., Glines, A., Manowitz, B. and Metz, D.J. Progress Report on Fission Products Utilization. IX. Studies on Radiation-Induced Graft Copolymerization and Solid State Polymerization. BNL 414 (T-81), Oct. 1956.

Ballantine, D.S. Role of radiation in graft and block copolymer synthesis. *Modern Plastics*, Sept. 1957, pp. 171-6.

BOOTH, A.K. AND SCHWEITZER, D. Accumulation of Fission Products from U²³⁵. BNL 407 (T-78), July 1956.

Bretton, R.H. (See Manowitz, B.)

Colombo, P. (See Ballantine, D.S.)

CORNGOLD, N.R. (See Cohen, V.W. - Physics)

Dropkin, D. (See Hoe, R. J.)

DWYER, O.E. (See Hoe, R.J.)

FINSTON, H.L. (See Stoner, G.A.)

FINSTON, H.L. (See Heyn, Arno H.A.)

GLINES, A. (See Ballantine, D.S.)

GURINSKY, D.H. (See Kammerer, O.F.)

Heyn, Arno H.A. and Finston, H.L. Separation of magnesium from sodium and potassium; a tracer study. *Anal. Chem.* (In press).

Hoe, R. J., Dropkin, D. and Dwyer, O.E. Heat transfer rates to cross-flowing mercury in a staggered tube bank. *Trans. Am. Soc. Mech. Engrs.* 79, 899-907 (1957).

KAMMERER, O.F., WEEKS, J.R., SADOFSKY, J., MILLER, W.E. AND GURINSKY, D.H. A mechanism by which Zr and Ti inhibit corrosion and mass transfer of steels by liquid heavy metals. J. Metals (In press).

KLEIN, J.H. (See Stong, R.W. - Instr. & Health Physics)

LAMARSH, J.R. AND FESHBACH, H. Direct interaction in neutron inelastic scattering. *Phys. Rev.* **104**, 1633-9 (1956).

LAMARSH, J.R. AND BROWNE, C.P. Inelastic scattering of protons by C12. *Phys. Rev.* 104, 1099-1102 (1956).

Manowitz, B. Chemical applications of radiation. Presented at Inter-American Symposium on the Peaceful Application of Nuclear Energy, Brookhaven National Laboratory, May 1957.

MANOWITZ, B., METZ, D.J. AND BRETTON, R.H. A design study of a megacurie source. Science 124, 814-7 (1956).

Manowitz, B. (See Ballantine, D.S.)

METZ, D. J. (See Manowitz, B.)

Metz, D. J. Irradiation of polymeric materials. Article in Encyclopedia of Chemical Technology, Interscience, New York (In press).

METZ, D. J. (See Ballantine, D.S.)

MILLER, W.E. (See Kammerer, O.F.)

OLEKSA, S. (See Muehlhause, C.O. - Physics)

OLEKSA, S. The scattering cross section of U²³³. Phys. Rev. (In press).

OLEKSA, S. The variation of α of U^{235} with energy in the intermediate-energy range. J. Nuclear Energy 5, 16-32 (1957).

RASEMAN, C. J., SUSSKIND, H. AND WAIDE, C.H. Pilot plant generation of fission products in uranium-bismuth reactor fuel. Chem. Eng. Progr. 53, 86F-92F (1957).

Sadofsky, J. (See Kammerer, O.F.)

Schweitzer, D. (See Booth, A.K.)

SPINNEY, K.T. The Determination of Power and Temperature Overshoot in the Reactor Flash Problem. BNL 421 (T-82), Nov. 1956.

STANG, L.G. JR. Radioisotope facilities associated with a research reactor. Presented at Inter-American Symposium on the Peaceful Application of Nuclear Energy, Brookhaven National Laboratory, May 1957.

STONER, G.A. AND FINSTON, H.L. Separation of bismuth and uranium using thioacetamide precipitation. (N) Anal. Chem. 29, 570-1 (1957)

Susskind, H. (See Raseman, C.J.)

Teitel, R. J. Concerning the uranium-lead system. Submitted to J. Inst. Metals.

TEITEL, R. J. The uranium-bismuth system. J. Metals 9, 131-6 (1957).

Waide, C.H. (See Raseman, C. J.)

Weeks, J.R. (See Kammerer, O.F.)

Photography and Duplicating Division

GARFIELD, J.F. The use of thick emulsions in the study of charged particles. J. Soc. Motion Picture Television Engrs. (In press).

SMITH, R.F. AND NEVALA, L. A variable output electronic point light source for photomicrography. J. Biol. Phot. Assoc. 24, 63-9 (1956).

Physics Department

ALBURGER, D.E. An intermediate-image pair spectrometer. Rev. Sci. Instr. 27, 991-1004 (1956).

ALBURGER, D.E. (See Goldhaber, G.S.)

Alburger, D.E. (See Kistner, O.C.)

ANTAL, J. J. AND DIENES, G. J. Displaced atom concentration in α -Al₂O₃ as determined by neutron scattering. (A) Bull. Am. Phys. Soc. Ser. II, 2, 151 (1957).

Antal, J. J. A spectrometer for long wavelength neutrons. (A) Presented at Annual Diffraction Conf., Pittsburgh, Nov. 1956.

BINGER, A.M. Scattering of longitudinally polarized fermions. Phys. Rev. 107, 1434-8 (1957).

BLOOM, S.D., TOPPEL, B. J. AND WILKINSON, D.H. ISOtopic spin selection rules. IX. The 9.58-Mev state of ¹⁶O. Phil. Mag. 2, 57-60 (1957).

BLOOM, S.D. (See Toppel, B. J.)

BLOOM, S.D. (See Wilkinson, D.H.)

Bloom, S.D., Turner, C.M. and Wilkinson, D.H. Lifetime of the first excited state of B10. Phys. Rev. 105, 232-4 (1957).

CARTER, R.S., HUGHES, D.J. AND PALEVSKY, H. Inelastic scattering of low energy neutrons by lattice vibrations of vanadium. (L) Phys. Rev. 104, 271-2 (1956).

CARTER, R.S., PALEVSKY, H. AND HUGHES, D. J. Inelastic scattering of slow neutrons by lattice vibrations in aluminum. Phys. Rev. 106, 1168-74 (1957).

Church, E.L. and Weneser, J. Effect of the finite nuclear size on internal conversion. (A) Bull. Am. Phys. Soc. Ser. II, 1, 330 (1956).

COHEN, V.W., CORNGOLD, N.R. AND RAMSEY, N.F. The magnetic moment of the neutron. Phys. Rev. 104, 283-91 (1956).

COHEN, V.W. (See Weiss, M.M. - Instr. & Health Physics)

Cool, R.L. (See Abashian, A. – Cosmotron)

Cool, R.L. (See Cronin, J.W.) COOL, R.L., MORRIS, T.W., RAU, R.R., THORNDIKE, A.M. AND WHITTEMORE, W.L. Production of V-particles by 3-Bev protons. (A) Bull Am. Phys. Soc. Ser. II 2, 222 (1957)

Cronin, J.W. (See Abashian, A. - Cosmotron)

Cronin, J.W., Cool, R.L. and Abashian, A. The cross sections of nuclei for high energy pions. Phys Rev. 107, 1121-30 (1957).

Danner, H.R. (See Shirane, G.)

DANNER, H.R., FRAZER, B.C. AND PEPINSKY, R. A singlecrystal neutron diffraction refinement of the tetragonal BaTiO₃ structure. (A) Bull. Am. Phys. Soc. Ser. II, 2,

DER MATEOSIAN, E. AND GOLDHABER, M. Rule concerning isomeric ratios following slow neutron capture. (A) Bull. Am. Phys. Soc. Ser. II, 2, 16 (1957).

DIENES, G. J. Defects in silicas. (A) Presented at Symposium on Defect Structure of Quartz and Glassy Silica, Mellon Inst., May 1957.

DIENES, G. J. Defects in solids and current concepts of radiation effects. (A) Presented at ONR-Martin Colloquium, Johns Hopkins Univ., March 1957.

DIENES, G. J. (See Antal, J. J.)

DIENES, G. J. (See Kosiba, W.L.)

Dyson, F. J. (See McVoy, K.W.)

EISENHAUER, C.M. (See Pelah, I.)

ELWYN, A. I. (See Glasoe, G.N.)

ELWYN, A. J. (See Landon, H.H.)

Erwin, A. (See Abashian, A. - Cosmotron)

Erwin, A. and Kopp, J. π^- -p interactions at 950 Mev. (A) Presented at Conf. on High Energy Nuclear Physics, Rochester, April 1957.

FIREMAN, E.L. (See Zahringer, J.)

FIREMAN, E.L. AND ZAHRINGER, J. Depth variation of tritium and argon-37 produced by high energy protons on iron. *Phys. Rev.* **107**, 1695-8 (1957).

FIREMAN, E.L. Extraterrestrial radiation from the H³, He³, and Li⁶ contents of meteorites. (A) *Bull. Am. Phys. Soc.* Ser. II, 1, 343 (1956).

Fireman, E.L. and Schwarzer, D. Measurement of Li⁶, He³ and H³ in meteorites and its relation to cosmic radiation. *Geochim. et Cosmochim. Acta* 2, 252-62 (1957).

Frazer, B.C., Langdon, F. and Pepinsky, R. An automatic control and programming system for single-crystal neutron diffractometry. (A) Presented at Annual Diffraction Conf., Pittsburgh, Nov. 1956.

Frazer, B.C. A neutron diffraction study of the magnetic structure of Fe₄N. (A) Presented at Annual Diffraction Conf., Pittsburgh, Nov. 1956.

Frazer, B.C. (See Danner, H.R.)

Fukuda, N. and Kovacs, J.S. The integral equations for the transition matrices in the static meson theory. *Phys. Rev.* 104, 1784-90 (1956).

GIBSON, J.B. The relationship between Wannier functions and the method of strong binding. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 147 (1957).

GLASOE, G.N., LANDON, H.H. AND ELWYN, A. J. Fast neutron studies by time-of-flight. (A) Presented at Intern. Conf. on Neutron Interactions with the Nucleus, Columbia Univ., Sept. 1957.

GLASOE, G.N. (See Landon, H.H.)

GOLDHABER, G.S., ALBURGER, D., HARBOTTLE, G. AND McKeown, M. Decay scheme of Os^{190m}(10 min). (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 25 (1957).

GOLDHABER, G.S. (See Harbottle, G. - Chemistry)

Goldhaber, M., Grodzins, L. and Sunyar, A.W. Evidence for circular polarization of bremsstrahlung produced by beta-rays. (L) *Phys. Rev.* 106, 826-8 (1957).

GOLDHABER, M. AND SANDWEISS, J. On the spin of K-mesons from the analysis of antiproton stars. (A) Bull. Am. Phys. Soc. Ser. II, 1, 385 (1956).

GOLDHABER, M. (See der Mateosian, E.)

GOUDSMIT, S.A. A magnetic time-of-flight spectrometer. Proc. Symposium on Precision Detn. of Nucleon Masses, Max Planck Inst., Germany (In press).

GRODZINS, L. (See Goldhaber, M.)

Grodzins, L. Lifetime of a 1⁻ level in Sm⁵². (A) Bull. Am. Phys. Soc. Ser. II, 1, 329 (1956).

HARVEY, J.A., HUGHES, D.J. AND PILCHER, V.E. Distribution of level spacings of heavy nuclei. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 42 (1957).

HORNBOSTEL, J., SALANT, E.O. AND ZORN, G.T. Mean free path and mean life of K-mesons. (A) Bull. Am. Phys. Soc. Ser. II, 2, 20 (1957).

Hughes, D. J. (See Pelah, I.)

Hughes, D. J. (See Harvey, J.A.)

Hughes, D. J. (See Schwartz, R.B.)

Hughes, D. J. (See Carter, R.S.)

HUGHES, D. J. (See Seidl, F.G.P.)

HUGHES, D. J. (See Seth, K.K.)

Hughes, D. J., Seth, K.K. and Zimmerman, R.L. Nuclear size by potential scattering cross section. (A) Bull. Am. Phys. Soc. Ser. II, 2, 225 (1957).

Hughes, D. J. (See Zimmerman, R.L.)

Igo, G. Inelastic scattering of 40.2-Mev alpha-particles. *Phys. Rev.* **106**, 256-60 (1957).

KAWAGUCHI, M. AND MORAVCSIK, M. J. Photoproduction of K-mesons from single nucleons. *Phys. Rev.* **107**, 563-9 (1957).

Kenney, V.P. Meson production in deuterium by 1.4-Bev pions. *Phys. Rev.* **104**, 784-94 (1956).

KISTNER, O.C., SCHWARZSCHILD, A. AND RUSTAD, B.M. Decay of A³⁵. *Phys. Rev.* 104, 154-8 (1956).

KISTNER, O.C., SCHWARZSCHILD, A., RUSTAD, B.M. AND ALBURGER, D.E. Positron spectrum of O¹⁵. *Phys. Rev.* **105**, 1339-41 (1957).

KLEIN, A. AND McCORMICK, B.H. Construction of the adiabatic nuclear potential. I. Formalism. *Phys. Rev.* **104**, 1747-57 (1956).

KLEIN, A. (See McCormick, B.H.)

KOPP, J. (See Abashian, A. - Cosmotron)

KOPP, J. (See Erwin, A.)

Kosiba, W.L. and Dienes, G. J. The effect of displaced atoms and ionizing radiation on the oxidation of graphite. *Advances in Catalysis* 9, 398-405 (1957).

Kosiba, W.L. (See Weed, R.C.)

LANDON, H.H., ELWYN, A. J. AND GLASOE, G.N. Measurements of neutron groups from Cu⁶⁵(p,n)Zn⁶⁵ by time-of-flight. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 233 (1957).

Landon, H.H. Radiation widths in the slow neutron resonances of Eu. (A) *Bull. Am. Phys. Soc.* Ser. II, 1, 347 (1956).

Langdon, F. (See Frazer, B.C.)

LEE, T.D. AND YANG, C.N. Possible interference phenomena between parity doublets. *Phys. Rev.* **104**, 822-7 (1956).

LEE, T.D. AND YANG, C.N. Question of parity conservation in weak interactions. *Phys. Rev.* 104, 254-8 (1956).

Levy, P.W. (See Truell, R.)

Levy, P.W. Reactor and gamma-ray induced coloring of Corning fused silica. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 150 (1957).

LINDENBAUM, S. J. AND STERNHEIMER, R.M. Isobaric nucleon model for pion production in nucleon-nucleon collisions. *Phys. Rev.* **105**, 1874-99 (1957).

LINDENBAUM, S. J. AND YUAN, L.C.L. K⁺-production in p-p collisions at 3.0 Bev. (L) Phys. Rev. 105, 1931-2 (1957).

LINDENBAUM, S. J. AND STERNHEIMER, R.M. Pion-nucleon interactions. (L) *Phys. Rev.* 106, 1107-8 (1957).

LINDENBAUM, S. J. (See Sternheimer, R.M. - Cosmotron)

McCormick, B.H. (See Klein, A.)

McCormick, B.H., Sternheimer, R.M. and Klein, A. Scattering of K⁺-mesons by protons. (A) Bull. Am. Phys. Soc. Ser. II, 2, 39 (1957).

McKeown, M. (See Goldhaber, G.S.)

McKeown, M. (See Harbottle, G. - Chemistry)

McReynolds, A.W., Shull, C.G. and Nathans, R. A polarized-beam neutron diffraction spectrometer. (A) Bull. Am. Phys. Soc. Ser II, 2, 21 (1957).

McVoy, K.W. Circular polarization of bremsstrahlung from polarized electrons in Born approximation. (L) *Phys. Rev.* **106**, 828-9 (1957).

McVoy, K.W. AND Dyson, F. J. Longitudinal polarization of bremsstrahlung and pair production at relativistic energies. (L) *Phys. Rev.* 106, 1360-1 (1957).

McVoy, K.W. Neutron scattering from nonspherical nuclei. (A) Bull. Am. Phys. Soc. Ser II, 2, 72 (1957).

MORAVCSIK, M. J. Method of analysis of charged pion photoproduction. *Phys. Rev.* 104, 1451-3 (1956).

MORAVCSIK, M. J. Negative to positive ratio from non-relativistic theories of pion photoproduction. *Phys. Rev.* 105, 267-77 (1957).

Moravcsik, M. J. (See Kawaguchi, M.)

Morris, T.W. (See Abashian, A. - Cosmotron)

Morris, T.W. (See Cool, R.L.)

Muehlhause, C.O. and Oleksa, S. The antineutrino flux from a reactor. *Phys. Rev.* 105, 1332-4 (1957).

Muehlhause, C.O. Neutron scintillation counters. IRE Trans. Professional Group on Nuclear Sci. NS-3, No. 4 (1956).

MUETHER, H.R., PALEVSKY, H. AND ZIMMERMAN, R.L. ZnS-B₂O₃ scintillation detector for slow neutrons. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 217 (1957).

Nathans, R., Riste, T., Shirane, G., and Shull, C.G. Polarization neutron studies on antiferromagnetic single crystals. (A) Bull. Am. Phys. Soc. Ser. II, 2, 21 (1957).

Nathans, R. (See McReynolds, A.W.)

PALEVSKY, H. (See Pelah, I.)

PALEVSKY, H. (See Schwartz, R.B.)

PALEVSKY, H. (See Carter, R.S.)

PALEVSKY, H. (See Seidl, F.G.P.)

PALEVSKY, H. (See Muether, H.R.)

Pelah, I., Eisenhauer, C.M., Hughes, D. J., and Palevsky, H. The Brookhaven cold neutron facility. (A) Bull. Am. Phys. Soc. Ser. II, 2, 43 (1957).

PEPINSKY, R. (See Frazer, B.C.)

PEPINSKY, R. (See Shirane, G.)

Pepinsky, R. Neutron single-crystal structure analyses and instrumentation by the Pennsylvania State University group at the Brookhaven reactor. Presented at Meeting on Research in Solid State Metallurgy, Rensselaer Polytechnic Inst., June 1957.

PEPINSKY, R. (See Danner, H.R.)

Pepinsky, R. Some new x-ray and neutron studies of hydrogen bonding. Presented at Symposium on Hydrogen Bonding, Intern. Union of Pure and Appl. Chem. and Union of Chem. Socs. of Yugoslavia, July 1957; and at Intern. Conf. on Current Problems in Crystal Physics, MIT, July 1957.

Pepinsky, R., Unterleitner, F., Shirane, G. and Jona, F. X-ray and neutron structure analysis of ferroelectric rhombohedral Pb(Zr.75, Ti.25)O₃ at room temperature. (A) Bull. Am. Phys. Soc. Ser. II, 2, 127 (1957).

PILCHER, V.E. (See Harvey, J.A.)

PILCHER, V.E. (See Seth, K.K.)

PILCHER, V.E. (See Schwartz, R.B.)

RAHM, D.C. (See Abashian, A. - Cosmotron)

RAHM, D.C. (See Willis, W.)

RAHM, D.C. A rapid beam ejector for the Cosmotron. (A) Bull. Am. Phys. Soc. Ser. II, 2, 11 (1957).

RAMSEY, N.F. (See Cohen, V.W.)

RAU, R.R. (See Abashian, A. - Cosmotron)

RAU, R.R. (See Cool, R.L.)

RISTE, T. (See Nathans, R.)

RISTE, T. (See Tenzer, L.)

SALANT, E.O. (See Hornbostel, J.)

Schwartz, R.B., Palevsky, H., Hughes, D. J. and Fox, J.D. A gas Cerenkov counter for use as a proton threshold detector. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 224 (1957).

Schwartz, R.B. (See Zimmerman, R.L.)

Schwartz, R.B., Pilcher, V.E., Hughes, D. J. and Zimmerman, R.L. The ratio of neutron widths to level spacings. *Bull. Am. Phys. Soc.* Ser. II, 1, 347 (1956).

Schwartz, R.B. Resonance parameters of U²³⁵. (A) Presented at Gatlinburg Neutron Meeting, Nov. 1956. Schwarzer, D. (See Fireman, E.L.)

Scott, M. J. A foil cooling system for high currents. Submitted to Rev. Sci. Instr.

SEIDL, F.G.P., PALEVSKY, H., HUGHES, D. J. AND ZIM-MERMAN, R.L. Modification of the Brookhaven fast chopper. Nuclear Instruments 1, 92 (1957).

SETH, K.K., HUGHES, D.J., ZIMMERMAN, R.L. AND PILCHER, V.E. Nuclear radius by potential scattering. (A) Bull. Am. Phys. Soc. Ser. II, 2, 42 (1957).

SETH, K.K. (See Hughes, D. J.)

SHIRANE, G., DANNER, H. AND PEPINSKY, R. Neutron diffraction study of BaTiO₃ near the Curie temperature. (A) Bull. Am. Phys. Soc. Ser. II, 2, 23 (1957).

SHIRANE, G., DANNER, H. AND PEPINSKY, R. Neutron diffraction study of orthorhombic BaTiO₃. *Phys. Rev.* 105, 856-60 (1957).

SHIRANE, G. (See Nathans, R.)

SHIRANE, G. (See PEPINSKY, R.)

SMITH, L.G. Measurements on some light masses with the mass synchrometer. (A) Bull. Am. Phys. Soc. Ser. II, 2, 223 (1957).

Sunyar, A.W. Delayed coincidence analyzer for short lifetime measurements. (A) Bull. Am. Phys. Soc. Ser. II, 2, 37 (1957).

Sunyar, A.W. (See Goldhaber, M.)

TENZER, L. AND RISTE, T. Temperature variation of magnetic component in neutron diffraction of magnetite. (A) Bull. Am. Phys. Soc. Ser. II, 2, 127 (1957).

TEUTONICO, L. J. (See Truell, R.)

THORNDIKE, A.M. (See Abashian, A. - Cosmotron)

THORNDIKE, A.M. (See Cool, R.L.)

TOPPEL, B. J. (See Bloom, S.D.)

TOPPEL, B. J., BLOOM, S.D. AND WILKINSON, D.H. Isotopic spin selection rules. X. The 7.18-Mev state of ²⁰Ne. *Phil. Mag.* 2, 61-2 (1957).

TRUELL, R., TEUTONICO, L. J. AND LEVY, P.W. The detection of directional neutron damage in silicon by means of ultrasonic double refraction measurements. *Phys. Rev.* 105, 1723-9 (1957).

VINEYARD, G.H. Frequency factors and isotope effects in solid state rate processes. *Phys. and Chem. Solids* (In press).

VINEYARD, G.H. Some applications of neutrons to solid state physics. (A) Presented at German Phys. Soc. Meeting, Munich, Sept. 1956.

VINEYARD, G.H. Theory and mechanism of radiation effects in metals. Nuclear Metallurgy, IMD Special Rept. Series No. 3, pp. 1-13, AIME, 1957.

Wallenmeyer, W.A. Meson production in n-p collisions at Cosmotron energies. Phys. Rev. 105, 1058-67 (1957).

Walter, R.I. Anion exchange studies of Sc(III) and V(IV). Separation of scandium, titanium, and vanadium. Submitted to J. Inorg. & Nuclear Chem.

Walter, R.I. (See Weiss, M.M. - Instr. & Health Physics) Walter, R.I. Preparation of carrier-free scandium and vanadium activities from titanium cyclotron targets. Submitted to J. Inorg. & Nuclear Chem.

Weed, R.C. and Kosiba, W.L. A method for irradiating materials at high temperatures in Co⁶⁰ sources. (A) Presented at 5th Annual Hot Lab. Conf., Philadelphia, March 1957.

Weneser, J. Antineutrino disintegration of the deuteron. *Phys. Rev.* **105**, 1335-7 (1957).

WENESER, J. (See Church, E.L.)

WHITTEMORE, W.L. (See Abashian, A. - Cosmotron)

WHITTEMORE, W.L. (See Cool, R.L.)

Wilkinson, D.H. First excited state of B¹¹: Possibility of spin-flip stripping. *Phys. Rev.* **105**, 666-71(1957).

WILKINSON, D.H. (See Bloom, S.D.)

WILKINSON, D.H. (See Toppel, B. J.)

WILKINSON, D.H. AND BLOOM, S.D. Isotopic spin selection rules. XI. The 8.06 and 6.23-Mev states of ¹⁴N. *Phil. Mag.* 2, 63-82 (1957).

WILKINSON, D.H. Isotopic spin selection rules. XII. The mirror reactions ⁶Li(d,n)⁷Be and ⁶Li(d,p)⁷Li. Phil. Mag. 2, 83-93 (1957).

WILKINSON, D.H. The low-lying states of N¹⁶. *Phys. Rev.* **105**, 686-91 (1957).

WILKINSON, D. H. AND BLOOM, S. D. The reaction $N^{15}(p,\gamma)O^{16}$. Phys. Rev. 105, 683-5 (1957).

WILLIS, W.J. (See Abashian, A. – Cosmotron)

WILLIS, W. J., RAHM, D.C. AND FOWLER, E.C. Bubble density in a propane bubble chamber. (A) Bull. Am. Phys. Soc. Ser II, 2, 6 (1957).

YANG, C.N. (See Lee, T.D.)

Zahringer, J. and Fireman, E.L. The A⁴⁰, K⁴¹, and He³ content of iron meteorites. (A) *Bull. Am. Phys. Soc.* Ser. II, 1, 344 (1956).

ZAHRINGER, J. (See Fireman, E.L.)

ZIMMERMAN, R.L. (See Seidl, F.G.P.)

ZIMMERMAN, R.L. (See Seth, K.K.)

ZIMMERMAN, R.L. (See Hughes, D. J.)

ZIMMMERMAN, R.L., SCHWARTZ, R.B. AND HUGHES, D. J. Ratio of neutron width to level spacing. (A) Bull. Am. Phys. Soc. Ser. II, 2, 218 (1957).

ZIMMERMAN, R.L. (See Schwartz, R.B.)

ZIMMERMAN, R.L. Resonance parameters of dysprosium. (A) Bull. Am. Phys. Soc. Ser. II, 2, 42 (1957).

ZIMMERMAN, R.L. (See Muether, H.R.)

ZORN, B.S. AND ZORN, G.T. The nuclear interaction of high energy K*-mesons. (A) Bull. Am. Phys. Soc. Ser. II, 2, 20 (1957).

ZORN, G.T. (See Hornbostel, J.)

ZORN, G.T. (See Zorn, B.S.)

Reactor Department

BINNS, J.E., LONES, W., PITCHER, D.G. AND MELICE, M. Safety circuit development at Brookhaven National Laboratory. (A) Elec. Eng. 76, 685 (1957).

FOOTE, H.L. JR. The neutron scattering cross section of U^{235} . Submitted to *Phys. Rev.*

Fox, J.D. (See Schwartz, R.B. - Physics)

GOULD, F., TAYLOR, T.I., RUSTAD, B.M., MELKONIAN, E. and HAVENS, W.W. Jr. The determination of the 2200-m/sec capture cross section of gold based on measurements of the total cross section from 5 to 11.5 A. (A) Bull. Am. Phys. Soc. Ser. II, 2, 42 (1957).

HAVENS, W.W. JR. (See Gould, F.)

LONES, W. (See Binns, J.E.)

MELICE, M. (See Binns, J.E.)

MELKONIAN, E. (See Gould, F.)

PITCHER, D.G. (See Binns, J.E.)

Powell, R.W. Reactor Operations Division Monthly Reports (Official Use Only):

Nov. 1956 BNL 427 (T-84)

Dec. 1956 BNL 431 (T-86)

Jan. 1957 BNL 444 (T-92)

Feb. 1957 BNL 438 (T-87)

Mar. 1957 BNL 441 (T-90)

Apr. 1957 BNL 450 (T-96)

May 1957 BNL 456 (T-99)

June 1957 BNL 460 (T-101)

Prince, E. Crystal and magnetic structure of copper chromite. Acta Cryst. 10, 554 (1957).

Prince, E. Neutron diffraction measurements on yttriumiron and yttrium-aluminum garnets. (A) Presented at Intern. Congr. Crystallography, Montreal, July 1957.

RAYNOR, G.S. AND SMITH, M.E. An analyzer and recorder for wind gustiness measurements in air pollution. *J. Air Pollution Control Assoc.* (In press).

RAYNOR, G.S. An automatic programming filter sampler. J. Air Pollution Control Assoc. 7, 122-4 (1957).

RAYNOR, G.S. (See Singer, I.)

Rustad, B.M. (See Kistner, O.C. - Physics)

Rustad, B.M. (See Gould, F.)

SAILOR, V.L. (See Shore, F. J.)

Schwarzschild, A. (See Kistner, O.C. - Physics)

SEGEL, R.E. Gamma-ray transitions in Ti⁴⁹. (A) Bull. Am. Phys. Soc. Ser. II, 2, 230 (1957).

SHORE, F. J. AND SAILOR, V.L. The fission and capture cross section of U²³⁵ for slow neutrons. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 70 (1957).

Shore, F. J. and Sailor, V.L. Problems in the analysis of resonances in the slow neutron cross section of U²³⁵. (A) *Bull. Am. Phys. Soc.* Ser. II, 2, 219 (1957).

SINGER, I. AND RAYNOR, G.S. Solar time as a meteorological classification. (A) Presented at 148th Natl. Am. Meteorol. Soc. Meeting, Asheville, N.C., Oct. 1956. SMITH, M.E. (See Raynor, G.S.)

SMITH, M.E. The location and operation of sampling stations in air pollution surveys. J. Air Pollution Control Assoc. (In press).

TAYLOR, T.I. (See Gould, F.)

Wood, R.E. Slow neutron resonance scattering in Ag, Au and Ta. *Phys. Rev.* **104**, 1425-33 (1956).

Appendix B

OFFICERS AND SCIENTIFIC STAFF

Leland J. Haworth, Director Gerald F. Tape, Deputy Director W.H. Fields, Associate Director

Robert A. Patterson, Assistant Director

R. Christian Anderson, Assistant Director

Samuel M. Tucker, Assistant to Director

Leland J. Haworth, Chairman, Accelerator Development Department
Howard J. Curtis, Chairman, Biology Department
Richard W. Dodson, Chairman, Chemistry Department
George B. Collins, Chairman, Cosmotron Department
J.B.H. Kuper, Chairman, Instrumentation and Health Physics Department
Lee E. Farr, Chairman, Medical Department
Clarke Williams, Chairman, Nuclear Engineering Department
Samuel A. Goudsmit, Chairman, Physics Department
Marvin Fox, Chairman, Reactor Department
J. Georges Peter, Director, Architectural Planning
H. Russell Cort, Budget Officer
Lewis R. Burchill, Controller
Charles F. Dunbar, Legal Counsel
Edward A. Macy, Personnel Officer
Frederick H. Williams, Security Officer

Accelerator Development Department

Leland J. Haworth, Chairman Roger R. Adams Robert D. Baldwin, Jr. Richard A. Beth John W. Bittner John P. Blewett M. Hildred Blewett Hugh N. Brown Vernon J. Buchanan Burton Z. Chertok Nicholas C. Christofilos Theodore Constant James G. Cottingham Gordon T. Danby Charles E. Falk

*Terminated before June 30, 1957.

Salvatore T. Giordano Charles L. Gould George K. Green John J. Grisoli Donald W. Huszagh David D. Jacobus Jack E. Jensen Michael B. Karelitz David A. Kassner Ralph R. Kassner John D. Kiesling Calman Lasky Walter W. Merkle Kurt F. Minati James P. Palmer Rolland Perry* (assigned from Argonne National Laboratory)

Robert J. Gerrity

Robert H. Phillips
Martin Plotkin
Irving J. Polk
Eugene C. Raka
Oliver S. Reading
Raymond H. Rheaume
Everett J. Rutan
Albert P. Schlafke, Jr.
Edward E. Shelton
Maxwell M. Small
Julius Spiro
Philip Stehle
(on leave from Univ. of Pittsburgh)
Lincoln D. Stoughton*
William G. Walker

Applied Mathematics Division

Milton E. Rose, Division Head Martin Milgram Stuart S. Rideout Yoshio Shimamoto

Biology Department

Howard J. Curtis, Chairman Irvin G. Anderson (postdoctoral appointment) Leroy G. Augenstine John A. Bergeron James L. Brewbaker Florence G. Buch* (graduate student from NYU) Phelps P. Crump Robin L. Cuany (postdoctoral appointment)

Richard DeZeew* (on leave from

California Inst. of Technology)

Harold H. Flor*

(assigned from U.S. Dept. of Agriculture)

Donald J. Fluke Rufus C. Fuller Martin Gibbs* Earl B. Herr, Jr. (postdoctoral appointment)

Otto Kandler* (on leave from

Univ. of Munich, Germany) Robert C. King*

James R. Klein Calvin F. Konzak Daniel E. Koshland, Jr.

Marian E. Koshland

Myron Levine

Harvey M. Levy (postdoctoral appointment)

Takane Matsuo

(on leave from Univ. of Tokyo)

Leslie F. Nims Lynn M. Paege*

(assigned from Frankford Arsenal)

Henry Quastler William J. Ray

(postdoctoral appointment)

George H. Reazin* (postdoctoral appointment)

Edgar Rihm

(on leave from Univ. Católica de Chile)

Yoneo Sagawa

(postdoctoral appointment)

Leon Z. Saunders

Erwin A. Schwinghamer

Seymour Shapiro

Frederick G. Sherman*

(on leave from Brown Univ.)

Oved Shifriss

(on leave from Weizmann Inst. of Science)

Harold H. Smith Arnold H. Sparrow Robert Steele Dale M. Steffensen

Otto L. Stein

(on leave from Univ. of Minnesota)

Robert E. Swanson Paul A. Swenson

(on leave from Univ. of Minnesota)

Marilyn L. Wolfsberg (graduate student from NYU)

Philip S. Woods

Chemistry Department

Richard W. Dodson, Chairman

Augustine O. Allen Elizabeth W. Baker Nathanial F. Barr* (postdoctoral appointment)

Jacob Bigeleisen James M. Caffrey, Jr. (assigned from The Texas Co.)

David R. Christman Lester M. Corliss

James B. Cumming Raymond Davis, Jr. Adolf E. DeVries

(postdoctoral appointment)

Israel Dostrovsky*

(on leave from Weizmann Inst. of Science)

Norman Elliott Arthur M. Feibush*

(graduate student from Syracuse Univ.)

Simon Freed Gerhart Friedlander Lewis Friedman Barry M. Gordon (postdoctoral appointment)

Floyd T. Gould

(graduate student from Columbia Univ.)

Walter C. Hamilton Garman Harbottle Donald S. Harmer (postdoctoral appointment) Julius M. Hastings Wolfgang Henkes

(postdoctoral appointment)

Erik H. Hogfeldt (postdoctoral appointment)

Jerome Hudis Adolph P. Irsa

Joseph Jach

(postdoctoral appointment)

Seymour Katcoff Hosaku Kawahara

(on leave from

Otaru College of Commerce, Japan)

Fritz H. Klein

(on leave from Weizmann Inst. of Science)

Alexander Kresge Esther Krikorian (postdoctoral appointment) Marie F. Maisonnier*

(graduate student from

Faculté des Sciences in Lyon, France)

Samuel Markowitz* (graduate student from RPI)

Donald G. Miller* (postdoctoral appointment) Alexander Murrenhoff (on leave from Bonn Inst. for

Physcial Chemistry, Germany)

Elinor F. Norton Brian D. Pate Morris L. Perlman Russell W. Pierce

(graduate student from Columbia Univ.)

Carol S. Redvanly Walter Rothschild J. Keith Rowley William Rubinson William Salmre Edward V. Sayre Oliver A. Schaeffer George Scholes

(postdoctoral appointment) Eric C. Schreiber

(assigned from

Charles Pfizer and Co. Inc.)

Robert H. Schuler* Harold A. Schwarz Rodman A. Sharp* (postdoctoral appointment)

Patricia R. Sisler Morris Slavin Esther L. Sprenkel

(graduate student from Univ. of Rochester)

Raymond W. Stoenner Bulusu Suryanarayana (postdoctoral appointment)

Norman Sutin (postdoctoral appointment)

Sydney O. Thompson Milton M. Wald* (postdoctoral appointment) Ralph E. Weston, Jr.

Alfred P. Wolf Richard Wolfgang* Max Wolfsberg Josef Zähringer (on leave from

Univ. of Freiburg, Germany)

Allan Zalkin*

(assigned from Univ. of California)

Colombo Project

Marvin Fox, Leader (BNL) Dennis Puleston, Deputy Leader (BNL)

^{*}Terminated before June 30, 1957.

Victor P. Bond (assigned from

Medical Department, BNL)

Solomon H. Chafkin*

(on leave from

International Cooperation Administration)

George J. Dienes (assigned from

Physics Department, BNL)

Norman Elliott (assigned from

Chemistry Department, BNL)

John F. Hogerton* (on leave from Vitro Corp.)

Harold H. Smith (assigned from

Biology Department, BNL)

Horace Smith*

(on leave from Department of State)

Ralph Strom* (on leave from

Atomic Energy Commission)

Harold B. Tukey*

(on leave from Michigan State Univ.)

Amry Vandenbosch*

(on leave from Univ. of Kentucky)

Frederick C. Vonderlage*

(on leave from

Oak Ridge National Laboratory)

Cosmotron Department

George B. Collins, Chairman

Alexander Abashian

(graduate student from

Johns Hopkins Univ.)

Robert K. Adair

David A. Barge*

(graduate student from RPI)

Mark Q. Barton

David Berley*

(postdoctoral appointment)

Henry Blumenfeld

(on leave from Duke Univ.)

Elihu Boldt

(graduate student from MIT)

Theodore Bowen

(on leave from Princeton Univ.)

Walter G. Chestnut

(postdoctoral appointment)

William Chinowsky

Forrest Cookson, Jr.*

(graduate student from Princeton Univ.)

Ernest D. Courant

Edward W. Dexter

Kenneth Lande

(graduate student from Columbia Univ.)

Christopher P. Leavitt*

Lawrence B. Leipuner

Isador J. Livant

Robert A. Loper

Richard Madey* Charles J. Maisonnier*

(on leave from Univ. of California)

William H. Moore, Jr.

Robert Motley*

(graduate student from Princeton Univ.)

Albert G. Prodell

(on leave from Barnard College)

Edwin J. Rogers

John H. Scandrett

(graduate student from Univ. of Wisconsin)

Melvin Schwartz

Lyle W. Smith

Jack Steinberger*

(on leave from Columbia Univ.)

Rudolph Sternheimer

Clifford E. Swartz

Guido Tagliaferri*

(on leave from Princeton Univ.)

Gyo Takeda*

(on leave from Kobe Univ.)

Clarence M. Turner

Albert Werbrouck

(graduate student from Princeton Univ.)

Luke C. Yuan

Instrumentation and **Health Physics Department**

J.B. Horner Kuper, Chairman

Luther C. Barcus*

Maurice R. Beebe*

William Bernstein*

Gwendolyn S. Bober Richard H. Boutelle

Robert L. Chase

Frederick P. Cowan

Emile Donneaux

(assigned from Institut Interuniversitaire)

Edward H. Foster

Lee Gemmell

Martin H. Graham John S. Handloser

Mortimer B. Heller

William A. Higinbotham

Clifford J. Konnerth Casimir Z. Nawrocki

Leigh F. Phillips

David W. Potter

Seymour Rankowitz

Francis X. Rizzo

Richard C. Roth

George E. Schwender

Robert J. Spinrad

Raymond W. Stong

Robert M. Sugarman Ierome Weiss

Max M. Weiss*

Medical Department

Howard J. Bagnall

Lee E. Farr, Chairman

(postdoctoral appointment)

Albert Bertinchamps

(postdoctoral appointment)

Victor P. Bond

Donald C. Borg

Robert D. Campo*

(graduate student from St. John's Univ.)

Robert W. Christie

Robert A. Conard

George C. Cotzias

Eugene P. Cronkite

Lewis K. Dahl

Nicola M. DiFerrante*

Ruth M. Drew

Otho D. Easterday

Conrad T.O. Fong

Lewis I. Gidez

Mary B. Hagamen Lawrence V. Hankes

Allen R. Hennes

Walter L. Hughes

Werner E. Kahle*

(postdoctoral appointment)

Hirotake Kakehi

(assigned from

Oak Ridge Inst. for Nuclear Study)

Paul G. LeFevre

Stuart W. Lippincott

Robert A. Love Myles Maxfield

Gerald McGinniss

(postdoctoral appointment)

Carleton M. Neil* (postdoctoral appointment)

Robert B. Painter

Edwin A. Popenoe

James S. Robertson

Irvin Serlin* Claire J. Shellabarger

Walton W. Shreeve

Lawrence Silver

F. Marrott Sinex

Elmer E. Stickley

Richard D. Stoner

Geronimo Terres, Jr. Donald D. Van Slyke

Richard I. Weller*

Donald Willigan (on leave from Univ. of Minnesota)

William Wolins

Nuclear Engineering Department

Clarke Williams, Chairman

George Adler

Seymour Adler

Clemens Auerbach

^{*}Terminated before June 30, 1957.

Theodore Auerbach David S. Ballantine Hampden O. Banks* Malcolm Basche Wendell E. Bent (assigned from Long Island Lighting Co.) Fritz Bloch Allan K. Booth, Jr. (assigned from American Metal Co.) Romeo G. Bourdeau Merwyn B. Brodsky Joseph S. Bryner Jack Chernick Joe G.Y. Chow Noel R. Corngold Robert F. Doering Kenneth W. Downes Orrington E. Dwyer James J. Egan Allen Eshaya Charles L. Feldman* Harmon L. Finston Joseph A. Fleck* Aaron J. Friedland (graduate student from Columbia Univ.) William S. Ginell Althea Glines Leon Green (assigned from United Engineers and Constructors Corp.) David H. Gurinsky Loranus P. Hatch Joseph M. Hendrie Frederick L. Hess* (assigned from Walter Kidde Nuclear Laboratories) Raymond J. Heus Frank B. Hill Frederick L. Horn Robert J. Isler Richard Johnson Jean Juliens* (assigned from Center of Applied Nuclear Energy, Belgium) Otto F. Kammerer Irving Kaplan William F. Kenney Carl J. Klamut George H. Knepple (graduate student from Pratt Inst.) Shirley E. Knight* (assigned from Babcock and Wilcox Co.) Herbert J. Kouts Evan C. Kovacic (assigned from

Lawrence E. Kukacka, Jr.

Otto A. Kuhl

Central Hudson Gas and Electric Co.)

John Lamarsh* Theodore M. Littman* Joseph V.A. Longcor (assigned from Stone and Webster Engineering Corp.) Walter Majkowski (assigned from Grumman Aircraft Engineering Co.) Bernard Manowitz David B. Marsland (graduate student from Cornell Univ.) Frank D. Maslan Jean Maurin (assigned from Compagnie Française de Raffinage) William E. McNulty Michel Melice* (assigned from Center of Applied Nuclear Energy, Belgium) Donald J. Metz Robert A. Meyer Francis T. Miles Daniel Milsom* (assigned from Cities Service Research and Development Co.) Donald E. Neil (graduate student from RPI) Paul J. Nicholson* Sophie Oleksa Dwight R. Patterson (assigned from TVA) James P. Phelps* (assigned from Glenn L. Martin Co.) Carl Pierce James R. Powell, Jr. Glenn A. Price Chad J. Raseman William H. Regan, Jr. David M. Richman Corwin L. Rickard* (graduate student from Cornell Univ.) Arthur E. Roswell Jerome Sadofsky Francis J. Salzano Cesar A. Sastre (postdoctoral appointment) Clifford H. Scarlett Donald G. Schweitzer Rudolph Sher John L. Speirs Kenneth T. Spinney* (assigned from Atomic Energy Research Establishment, England) Louis G. Stang, Jr.

Meyer Steinberg Graham Stoner* (assigned from Dow Chemical Co.) Gerald Strickland Herbert Susskind Walter D. Tucker

Julien Van Caeneghem (assigned from Center of Applied Nuclear Energy, Belgium) Charles H. Waide William E. Weaver* (assigned from Griscom-Russell Co.) John R. Weeks Eugene V. Weinstock Edward Wirsing, Jr. Richard H. Wiswall, Jr. Samuel A. Zwickler

Physics Department Samuel A. Goudsmit, Chairman James E. Abel* (assigned from Picatinny Arsenal) Fay Ajzenberg-Selove* (on leave from Haverford College) David E. Alburger Arne F. Andresen (assigned from Joint Establishment for Nuclear Energy Research, Norway) John J. Antal (assigned from Watertown Arsenal) Frederick Aver II Charles P. Baker Adam M. Bincer (postdoctoral appointment) Marietta E. Blau Stewart D. Bloom Ernest M. Bolze John L. Brown* (graduate student from Univ. of Michigan) Keith A. Brueckner* Robert S. Carter* Robert E. Chrien (postdoctoral appointment) Eugene L. Church (assigned from Frankford Arsenal) Victor W. Cohen Rodney L. Cool Hans W. Courant* (on leave from Yale Univ.) James W. Cronin Arthur C. Damask (assigned from Frankford Arsenal) Charles C. Damm* Horace R. Danner (on leave from Pennsylvania State Univ.) Edward der Mateosian George J. Dienes James E. Draper* Russell W. Dreyfus* (assigned from Picatinny Arsenal)

Alexander J. Elwyn

Albert R. Erwin, Jr.

Edward L. Fireman*

(postdoctoral appointment)

(graduate student from Harvard Univ.)

^{*}Terminated before June 30, 1957.

Ted B. Flanagan Simon Pasternak Raymond E. Benenson (assigned from Picatinny Arsenal) (assistant editor of The Physical Review) (assigned from John D. Fox Israel Pelah Wright Air Development Center, USAF) **B.** Chalmers Frazer (on leave from Univ. of Amsterdam) John E. Binns (assigned from Oreste Piccioni Thomas H. Broome Westinghouse Electric Corp.) Stanley J. Pickart (assigned from Glenn L. Martin Co.) John B. Gibson (assigned from United States Army) John A. Dooley Donald A. Gilbert Valter E. Pilcher* (assigned from G. Norris Glasoe Charles E. Porter, Jr. Wright Air Development Center, USAF) Allen N. Goland Lew F. Porter Anthony N. Fasano (postdoctoral appointment) (assigned from U.S. Steel Corp.) (assigned from Gertrude S. Goldhaber David C. Rahm Wright Air Development Center, USAF) Maurice Goldhaber Ralph R. Rau John J. Floyd Lee Grodzins Kurt Reibel Rudolph Haas Feza Gursey (graduate student from (on leave from (on leave from Science Univ. of Istanbul) Univ. of Pennsylvania) Technische Hochschule, Munich) Eastman N. Hatch Tormod Riste* Raymond H. Kelley (postdoctoral appointment) (assigned from Joint Establishment for (assigned from Edward L. Healey* Nuclear Energy Research, Norway) Wright Air Development Center, USAF) John W. Hess Hans-Jurgen Rose Gerald C. Kinne (assigned from Picatinny Arsenal) (on leave from Univ. of Marburg) Issai Lefkowitz John Hornbostel Edward O. Salant (assigned from Glenco Corp.) Donald J. Hughes Robert B. Schwartz Walter Lones John V. Kane Mary J. Scott Harvey Marshak Thomas A. Kaplan (graduate student from Miles J. McGoff* (on leave from Univ. of Michigan) Johns Hopkins Univ.) (assigned from David T. Keating Kamal K. Seth* Mine Safety Appliances Co.) Ottmar C. Kistner (graduate student from Lowell McLean (graduate student from Columbia Univ.) Univ. of Pittsburgh) Robert A. Meyers Joshua K. Kopp Gen Shirane* (assigned from (graduate student from Harvard Univ.) (on leave from Pennsylvania State Univ.) Walter Kidde Nuclear Laboratories) Walter L. Kosiba Ralph P. Shutt James A. Moore Saul Krasner* Joseph E. Smith (on leave from Columbia Univ.) (assigned from Picatinny Arsenal) Lincoln G. Smith Charles L. Osborne Harry H. Landon Hartland S. Snyder Jack E. Phillips Paul Levy Andrew W. Sunyar G. dePuyster Pitcher Seymour J. Lindenbaum William H. Taylor Robert W. Powell James E. Mapes (on leave from Cambridge Univ.) **Edward Prince** (assigned from Picatinny Arsenal) Leon Tenzer (assigned from Bell Telephone Co.) Marion Marcinkowski* (on Belgian-American Joseph A. Roll (graduate student from Education Foundation Fellowship) (assigned from Univ. of Pennsylvania) Alan Thorndike Westinghouse Electric Corp.) Robert S. Margulies* Bert J. Toppel Seymour N. Rottenberg (graduate student from Cornell Univ.) John C. Vander Velde* Brice M. Rustad Bruce H. McCormick* (graduate student from (on leave from Columbia Univ.) (postdoctoral appointment) Univ. of Pennsylvania) Vance L. Sailor Kirk W. McVoy, Jr. George H. Vineyard Robert D. Schamberger (postdoctoral appointment) Walter W. Wada* (assigned from Donald I. Meyer* (on leave from Wright Air Development Center, USAF) (on leave from Univ. of Michigan) National Research Laboratory) Ralph E. Segel Michael J. Moravscik Ernest K. Warburton (assigned from (postdoctoral appointment) (postdoctoral appointment) Wright Air Development Center, USAF) Thomas W. Morris Joseph Weneser Ferdinand J. Shore Henry T. Motz* William L. Whittemore Irving A. Singer Carl O. Muehlhause* (assigned from General Dynamics Corp.) Robert Nathans Maynard E. Smith Robert L. Zimmerman Ernest F. Tretow* (on leave from Univ. of Pennsylvania) Gus T. Zorn (assigned from Harry Palevsky Westinghouse Electric Corp.) **Reactor Department** Isaac Van der Hoven

(assigned from U.S. Weather Bureau)

Marvin Fox, Chairman

^{*}Terminated before June 30, 1957.