BNL 994 (AS-20)

BROOKHAVEN NATIONAL LABORATORY

ANNUAL REPORT
July 1, 1966

Associated Universities, Inc.
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Annual Report

July 1, 1966

BROOKHAVEN NATIONAL LABORATORY

Upton, Long Island, New York 11973

Brookhaven National Laboratory is operated under a contract between the United States Atomic Energy Commission and Associated Universities, Inc. This, the seventeenth in a series of unclassified Annual Reports, gives an account of the progress of the Laboratory during the period July 1, 1965 – June 30, 1966, 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:

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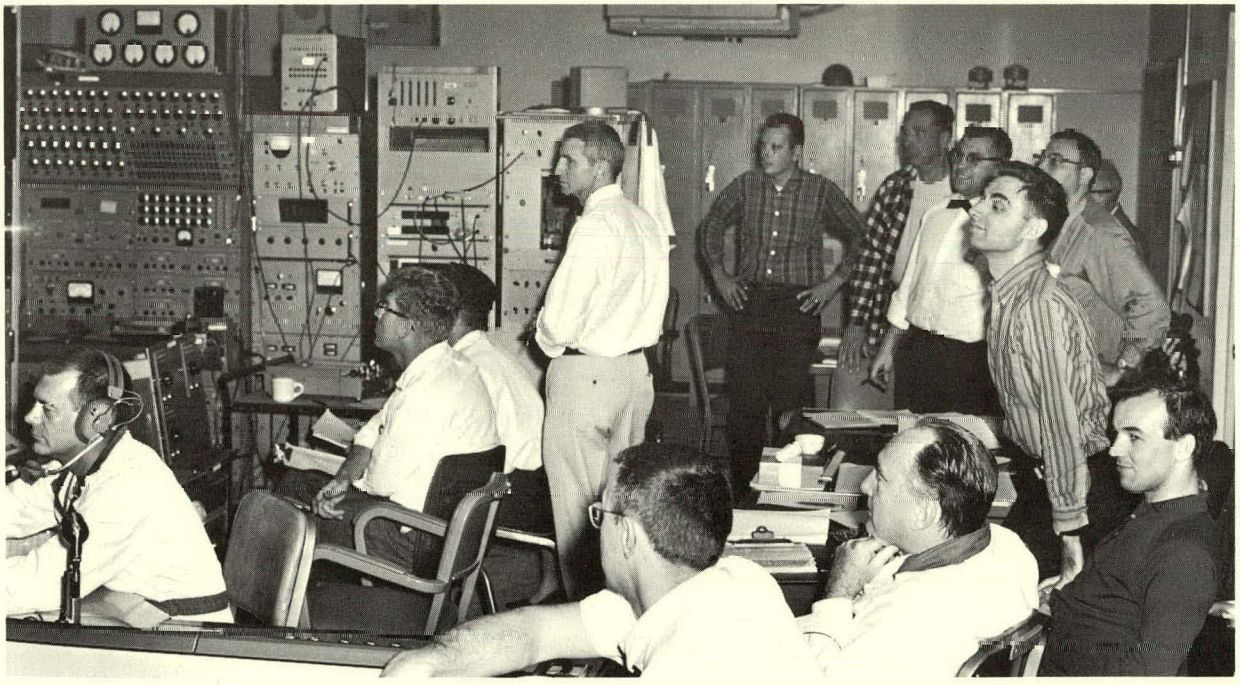
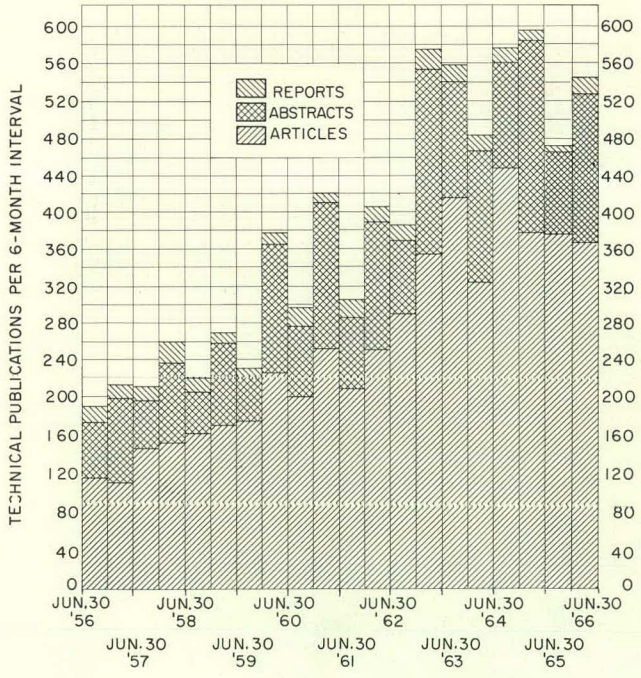


Scene in the control room of the High Flux Beam Research Reactor at 8:34 p.m. on October 31, 1965, when the first self-sustaining nuclear chain reaction was obtained.

Introduction

The program and activities of Brookhaven National Laboratory during the fiscal year 1966 are described in this annual report. The progress and trends of the research program are presented together with a description of the operational, service, and administrative activities of the Laboratory. The scientific and technical details of the many research and development activities are covered more fully in scientific and technical periodicals and special reports of the Laboratory. A list of all publications published or submitted for publication during the year may be found in Appendix A.



Technical publications.

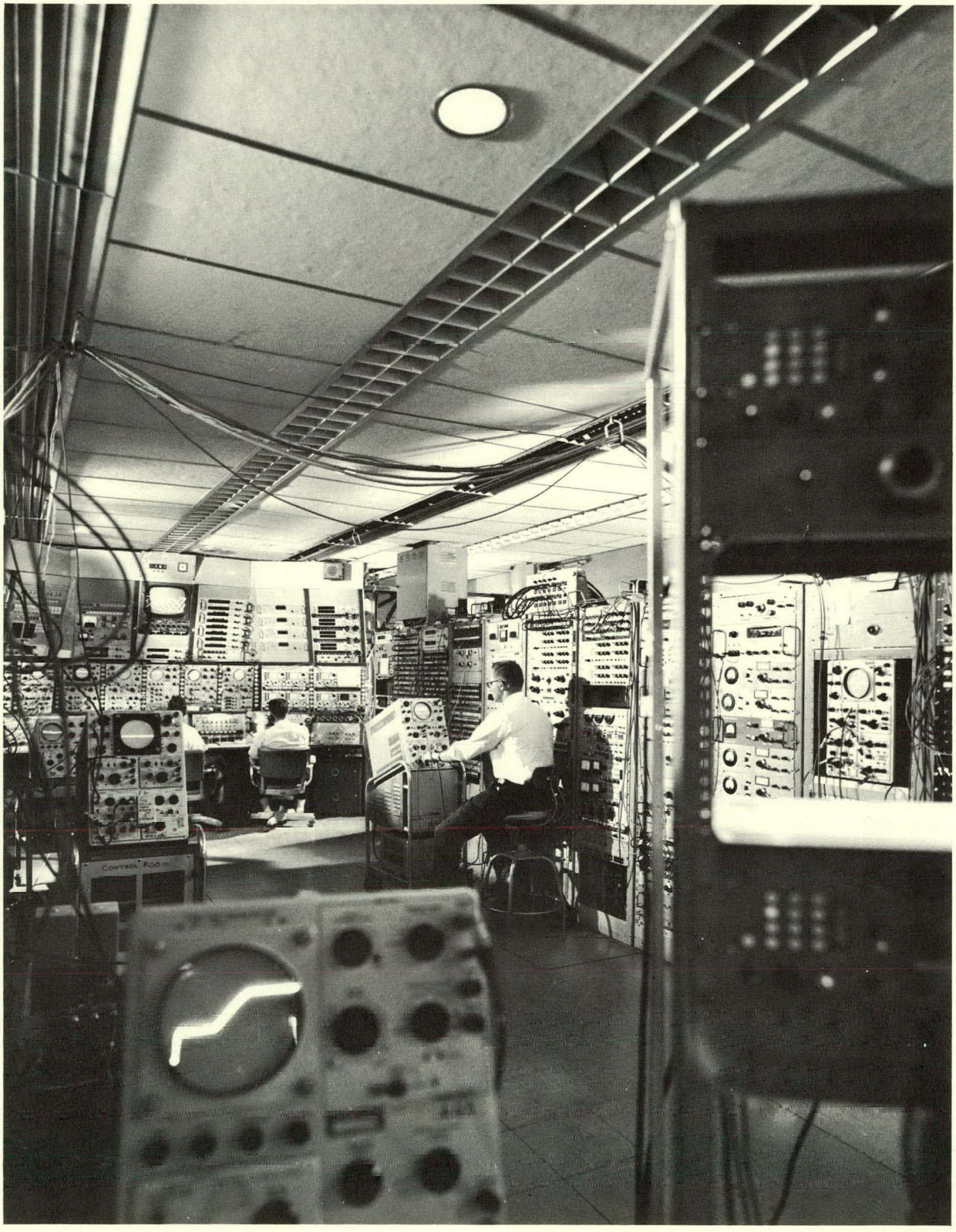
RESEARCH PROGRAM

The Brookhaven research program, which covers a wide range of subjects in the physical and biological sciences and in engineering, has as its central motif the development and exploitation of nuclear science and technology. It can be broadly described under five main headings

1. FUNDAMENTAL STUDIES OF ATOMIC NUCLEI, THE PARTICLES THAT CONSTITUTE THEM, AND THE FORCES INVOLVED IN THEIR STRUCTURE. These studies, which are basic to all nuclear science and technology, involve the use of all the major machines of the Laboratory. They range from measurements of the properties of undisturbed nuclei to study of the violent disruptions resulting from nuclear fission or from bombardment with high energy protons from the Laboratory's 3-BeV Cosmotron and 33-BeV Alternating Gradient Synchrotron (AGS).

2. STUDIES OF THE PHYSICAL, CHEMICAL, AND BIOLOGICAL EFFECTS OF NUCLEAR RADIATION. The effects of radiation are utilized to determine the characteristics of physical and chemical structures and to elucidate the more complex properties of living systems and the changes they undergo in their life and reproductive cycles. Of direct practical interest are the possible deleterious effects of radiation upon biological systems and upon various materials, for example, those involved in reactor construction. Of equal interest are the potentially beneficial effects of radiation in the treatment of diseases, in the induction of genetic changes in plants or animals, and in the improvement of manufacturing processes.

3. THE USE OF NUCLEAR TOOLS, SUCH AS NEUTRONS, CHARGED PARTICLES, GAMMA RAYS, AND ISOTOPIC TRACERS, IN ALL BRANCHES OF SCIENTIFIC RESEARCH. In this broad and diversified field, which overlaps the one just mentioned, nuclear particles and radiations are used as tools in studying physical, chemical, and biological systems in their undisturbed states. Neutrons and other particles are used as probes: by observing their penetration and scattering, minute details of physical and chemical structure can be studied. Wide use is made of isotopic tracers in many fields to yield information on such matters as the mechanisms and rates of chemical reactions and biological processes.



The control room of the Alternating Gradient Synchrotron.

4. RESEARCH AND DEVELOPMENT, NOT NECESSARILY ITSELF OF A NUCLEAR NATURE, DIRECTED TOWARD SOLVING THE PROBLEMS OF ATOMIC ENERGY DEVELOPMENT. The more basic aspects of this category include the chemistry of elements and compounds of special interest, isotope effects, the metallurgy of materials used in nuclear reactors and other devices of importance in the atomic energy program, the neutron scattering and absorbing properties of substances used in reactors and other nuclear devices, and similar subjects. Among its applications are the development of reactor components such as fuels, structures, and shields, the development of components and processes for the chemical processing and useful recovery of reactor products, and theoretical and experimental studies in the field of reactor physics.

5. THE DEVELOPMENT OF SPECIFIC DEVICES FOR USE AS RESEARCH TOOLS OR IN PRACTICAL APPLICATIONS OF ATOMIC ENERGY. This category includes both the design and development of special research tools, such as accelerators, reactors, and other technical equipment, and the development of devices for practical applications of atomic energy, such as the preparation of special isotopes, the development and packaging of high intensity radiation sources, and basic development work on power reactor systems.

The involvement of the various scientific disciplines in these areas of study and development results in a coherence and mutuality of interest that enhance the entire program of the Laboratory in both tangible and intangible ways. Specific research projects are described in those sections of this report devoted to the particular discipline or organizational unit in which the work is being carried out. It will be noted that research interests overlap from one department to another, and similar problems are being attacked from different points of view.

In addition, the international aspects of the research program should be pointed out. Besides providing research opportunities for many scientists and students from other countries, Brookhaven has a general program of international cooperation which includes cooperative agreements with nuclear centers in Turkey and Puerto Rico and participation in the "Atoms for Peace" traveling AEC nuclear energy exhibits in Europe, Asia, and South America.

RESEARCH FACILITIES

Research at Brookhaven is centered on, although not confined to, the use of several large machines and other special facilities, some of which are described below.

Alternating Gradient Synchrotron

The AGS, Brookhaven's 33-BeV proton synchrotron (the world's most powerful particle accelerator), continues to be one of the major centers for research in high energy physics. The machine, which is operated on a schedule of 21 8-hr shifts per week, was available for operation for a total of 7050 hr during fiscal 1966. Of this time, 66% was used for research. Machine improvements resulted in increased beam intensity, and during the last half of the fiscal year the average beam intensity was $>10^{12}$ protons/pulse.

During the year design work proceeded on the AGS conversion program, which will increase the AGS beam intensity to 10^{13} protons/pulse. Congress has authorized the full $47.8 million for the project, but these funds have not yet been appropriated. The additions and modifications to the machine will include construction of a 200-MeV proton linac injector to double the capacity of the main magnet power supply and allow an increase in the machine operating rate to 1 cycle/sec, extensive modifications of the various machine components to minimize radiation damage and exposure of personnel to residual radiation, and construction of additional experimental facilities, including a 50,000-sq-ft addition to the East Experimental Area and a 25,000-sq-ft building to the west of the Target Building.

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

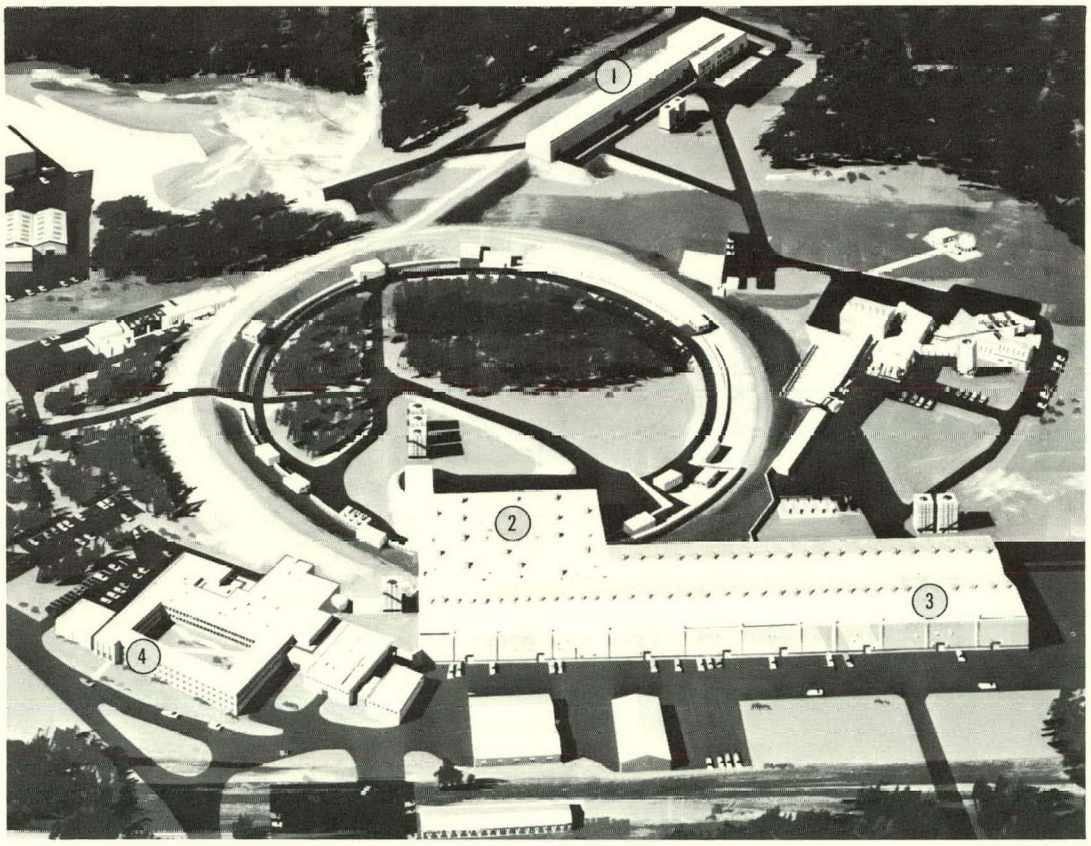
Cosmotron

In March 1965 the AEC announced its decision to terminate operation of the Cosmotron, a 3-BeV proton synchrotron, because of funding limitations and the needs for new facilities. The Cosmotron, the first accelerator to produce particles of energies >1 BeV, was started in 1952. The operating schedule was reduced from 21 to 15 8-hr shifts per week on July 1, 1966, and the machine was scheduled to be shut down permanently by the end of the calendar year. During fiscal 1966, $\approx$6600 hr of operating time were provided, of which 68%

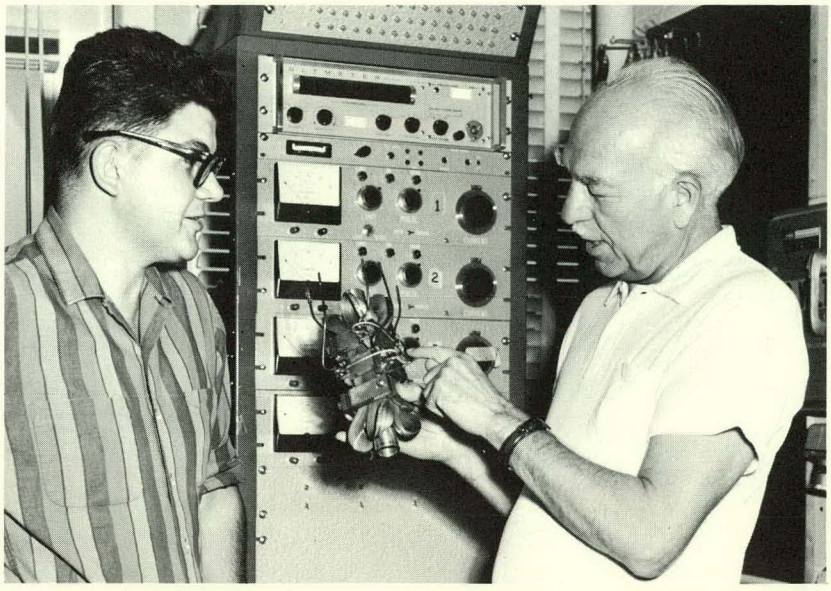
were used for research. Additional information on the Cosmotron is given in the section on High Energy Accelerators.

60-in. Cyclotron

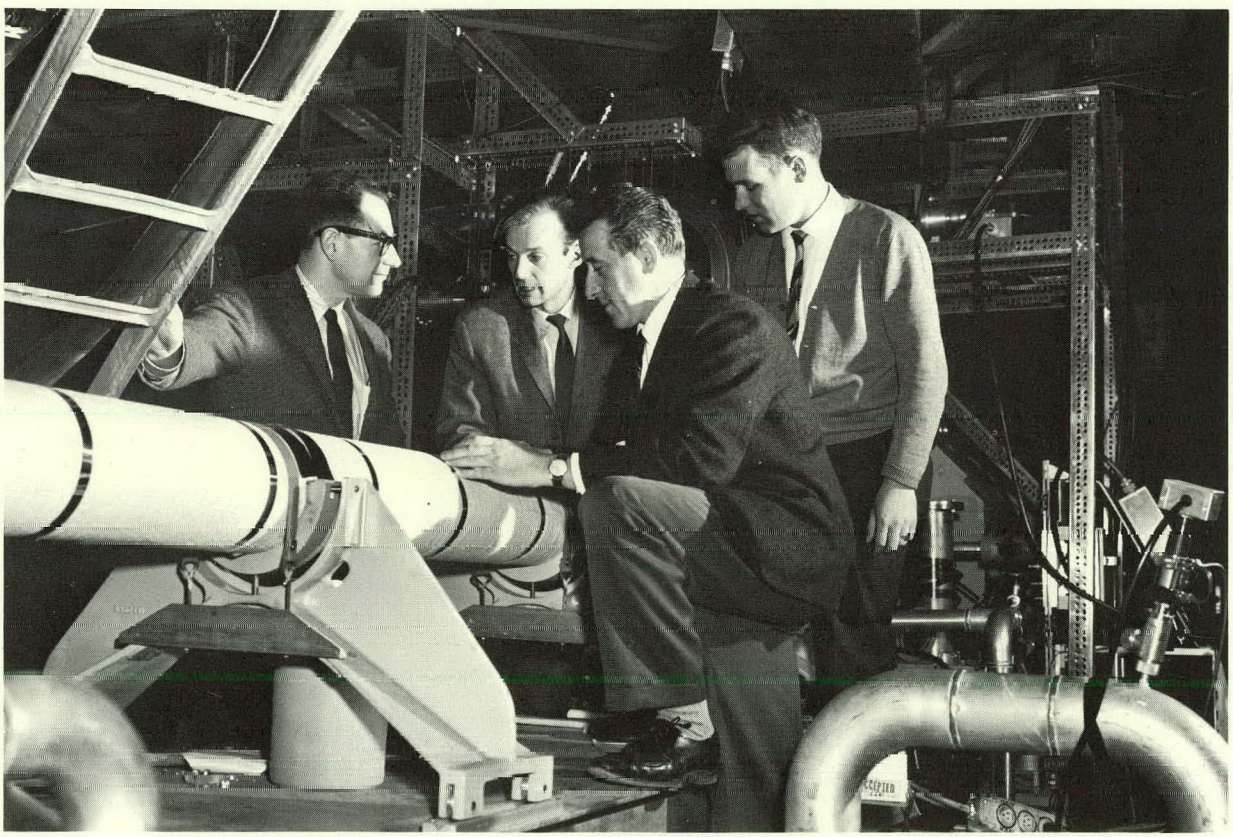
On October 1, 1965, the 60-in. cyclotron was shut down for conversion to sector-focusing, variable-energy operation. The maximum beam energy will be increased from 10 to 40 MeV for protons and from 30 to 56 MeV for He^3 ions, with the maximum deuteron and He^4 energies remaining unchanged at 20 and 40 MeV respectively. The energy of all particles will be variable from the maximum energy to between ⅓ and 1/10 of maximum. It will be possible, when an appropriate ion source is developed, to accelerate heavier ions, such as carbon and nitrogen. In addition to the advantages to be gained from these new capabilities for nuclear reaction studies and isotope production, the increased range (from 2 to 15 mm) of the proton beam will be of particular significance in medical and biological experiments. All major new components of the converted machine have been fabricated and are being installed. The cyclotron is expected to go into limited operation in the autumn of 1966 for a period of reinstrumentation and shakedown, and then resume a full operating schedule. New target facilities are planned to accommodate the expected wider use of and increased demand for machine time by scientists from Brookhaven and from outside institutions. Several beam pipes with switching and focusing magnets will provide for the rapid transfer of the beam from one experiment to another with a minimum of downtime. Also planned is the installation of a "gamma cave," a well-shielded area intended for studies of particle–gamma-ray correlations in which background both from the cyclotron beams and from external sources will be minimized.



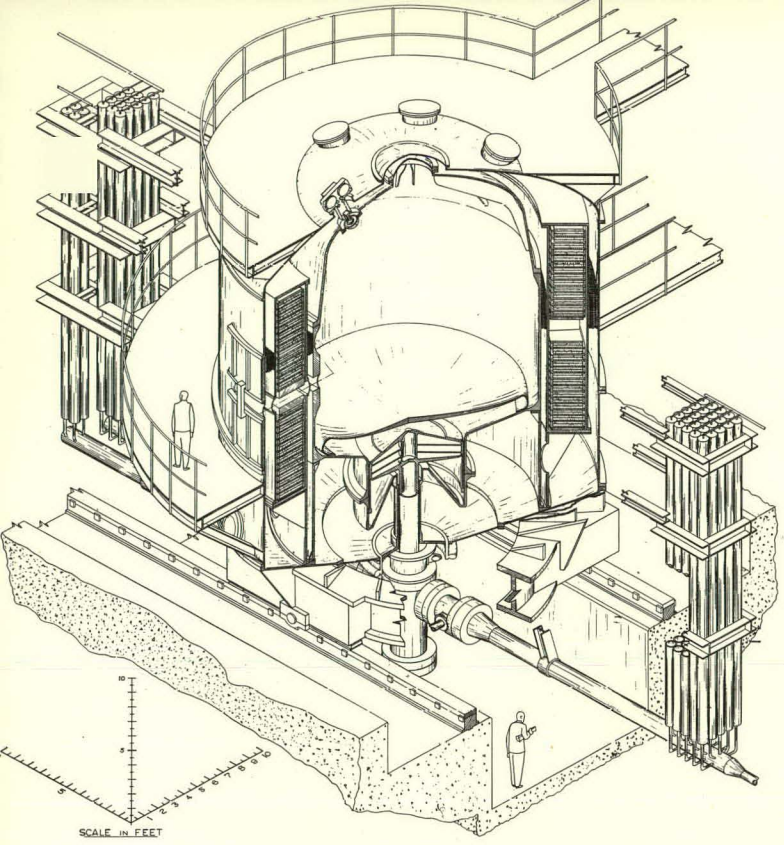
Drawing of the Alternating Gradient Synchrotron as it will appear after conversion is completed. (1) The 200-MeV linear accelerator, which will replace the present 50-MeV injector. (2) Addition to the Target Building. (3) Addition to the East Experimental Building. (4) Addition to the Service Building.



Two members of the High Field Superconductivity Group examining the world's first superconducting quadrupole magnetic lens, designed and constructed by the group during fiscal 1966. Although only 6 in. long with a 1-in. bore, the lens produces magnetic field gradients of 10,000 gauss/cm, about five times the gradients obtained with conventional iron quadrupoles. These higher gradients enable superconducting quadrupoles to focus highly energetic charged particles in much shorter distances than heretofore. Superconducting quadrupoles have already been used in beam transport systems at the Alternating Gradient Synchrotron, and applications will undoubtedly be found for them in the main assemblies of future high energy accelerators.



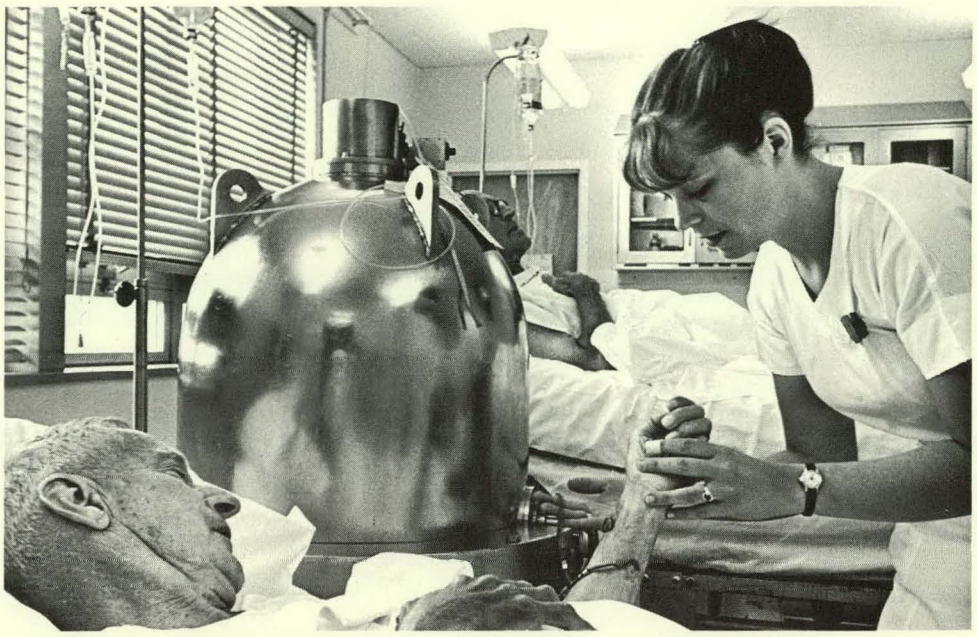
A 3-meter-long deflector (a special radio-frequency waveguide similar to a section of electron linear accelerator) in the new radio-frequency separated beam to the 80-in. bubble chamber, shown in place at the Alternating Gradient Synchrotron. A second, identical deflector is located 40 meters to the left, along the line of the beam in the direction of the AGS. This new beam system, a joint BNL–Yale University project, provides pure beams of K mesons, antiprotons, and pi mesons at selected momenta between 7 and 18 BeV/c – the highest momentum yet obtained with separated beams.



Conceptual sketch of the proposed 14-ft cryogenic bubble chamber. A volume of 13,000 gallons of liquid hydrogen, deuterium, or neon-hydrogen mixture is visible to the cameras located at the top. This volume is made sensitive for bubble track formation by actuating the piston mechanism at the bottom. The chamber is surrounded by magnetic field coils made of superconducting materials combined with normal conductors at liquid helium temperature. Beams of particles from the high energy accelerator enter the chamber through the gap between the two coil sections.

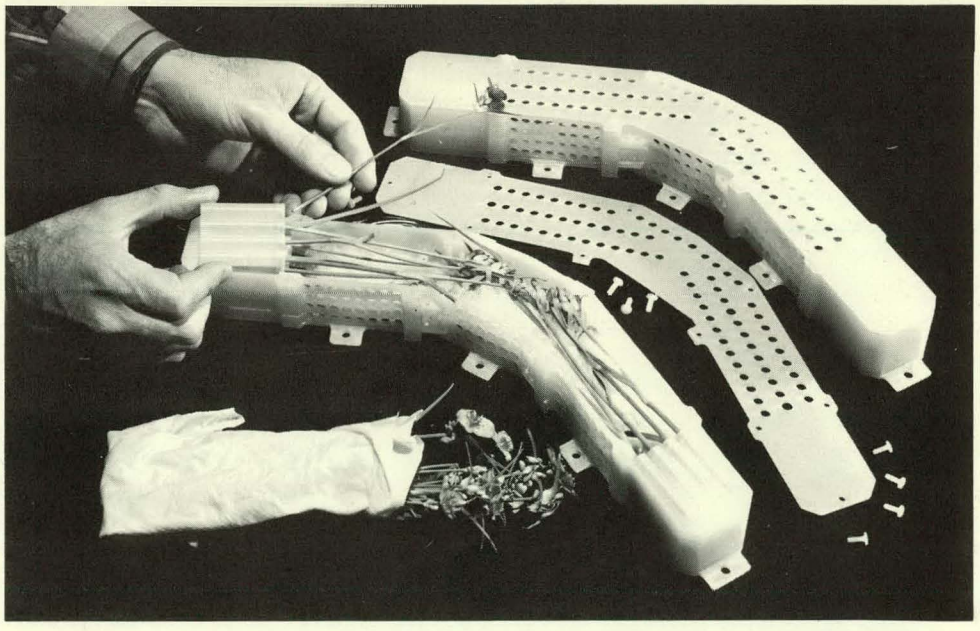
Part of 15 tons of bacon irradiated during June 1966 at the High Intensity Radiation Development Laboratory. The bacon is being loaded into a conveyor that will lower it into the irradiation cell for sterilization by exposure to 850,000 curies of Co^{60} gamma radiation. The sterilized bacon, sealed in 1-lb tins, will need no refrigeration. It was processed for the U.S. Army in the first large-scale field test of the use of gamma radiation for the preservation of perishable foods.

Left to right: AEC Chairman Glenn T. Seaborg, Commissioner John G. Palfrey, Dr. John P. Blewett, Deputy Chairman of the BNL Accelerator Department, and Dr. Maurice Goldhaber, BNL Director, on the occasion of the visit of several top-level AEC officials to Brookhaven on April 16, 1966, to inspect the Laboratory site and discuss its suitability as a location for the proposed 200-BeV proton accelerator.



Two patients at the Brookhaven Medical Research Center undergoing treatment for leukemia by extracorporeal irradiation of their blood. Arterial blood is propelled by the action of the heart through plastic tubing (connected to a semipermanent arteriovenous shunt inserted in the forearm) into the shielded container and past an intense source of gamma rays, and back into the patient's arm. The relatively sensitive white blood cells are destroyed without damage to the radiation-resistant red cells. The improved irradiator shown, which was designed and fabricated here during fiscal 1966, allows the radiation exposure to be varied mechanically and makes possible the treatment of two patients simultaneously.

Young *Tradescantia* cuttings in the holder in which similar cuttings will be flown in the first NASA biosatellite, which is expected to be put into orbit during 1966. During the 65-hr free-flight phase the flower buds will be exposed to gamma radiation from a small source on board the satellite. After recovery the flowers that open will be scored for somatic mutations and the mutation rate compared with that of similarly irradiated ground-based plants in an attempt to determine whether the mutation rate is affected by weightlessness or other conditions existing in an orbiting satellite.



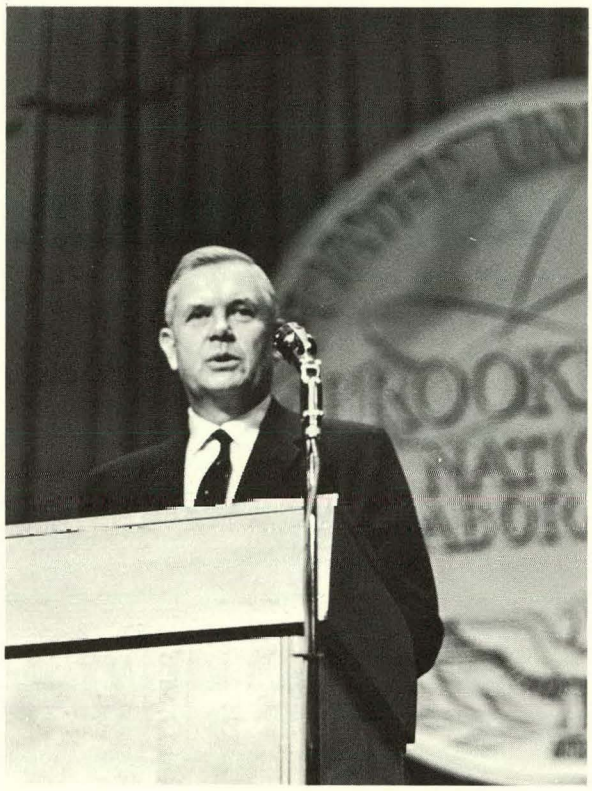
Electrostatic Generator

The electrostatic generator accelerates protons, deuterons, and He^3 and He^4 ions with beam currents up to 75 μA and energies up to 4 MeV. Modifications to the machine currently in progress will permit, in addition, the acceleration of tritium (He^3) ions. Further improvements in progress include a completely new and more versatile beam transport system and a new terminal-beam analyzing system which will provide doubly charged helium ions of substantially improved purity and intensity. With these improvements and recent advances in particle and gamma-ray detection systems and in data-handling systems, this accelerator is expected to continue as a source of new data on the properties of light- and medium-weight nuclei for a number of years to come. During the past year the machine was operated for research during 772½ 8-hr shifts. Fast neutron irradiations for a university group performing collaborative research with the Brookhaven Medical Department accounted for 1.2% of the time. The remainder was used for physics research carried out by scientists from Brookhaven and several outside institutions.

High Flux Beam Research Reactor

On October 31, 1965, a self-sustaining nuclear chain reaction was achieved for the first time with the Brookhaven High Flux Beam Research Reactor (HFBR). This noteworthy event was followed by a series of lengthy and exhaustive tests and measurements under various operating conditions before the reactor was brought to its full design power of 40 MW on February 6, 1966, and became available for experimental use. On April 22 the HFBR was formally dedicated, with AEC Commissioner Gerald F. Tape giving the dedication address.

This reactor, designed to meet experimenters' needs for higher neutron fluxes, has a compact core of 28 ETR-type enriched-uranium fuel elements cooled, moderated, and reflected by heavy water. Sixteen experimental facilities have been provided in the HFBR; nine convey beams of neutrons outside the reactor, and seven allow materials to be irradiated inside the reactor. The maximum neutron flux in the core will be $\simeq 1.6 \times 10^{15}$ neutrons/cm^2-sec. The HFBR is housed in a three-story, hemispherical, gas-tight, steel dome. The bottom floor houses the operating machinery for the reactor; the second (ground) floor is reserved for beam experiments and laboratories; and the top floor accommodates the control room, irradiation experiments, and fuel-handling facilities.



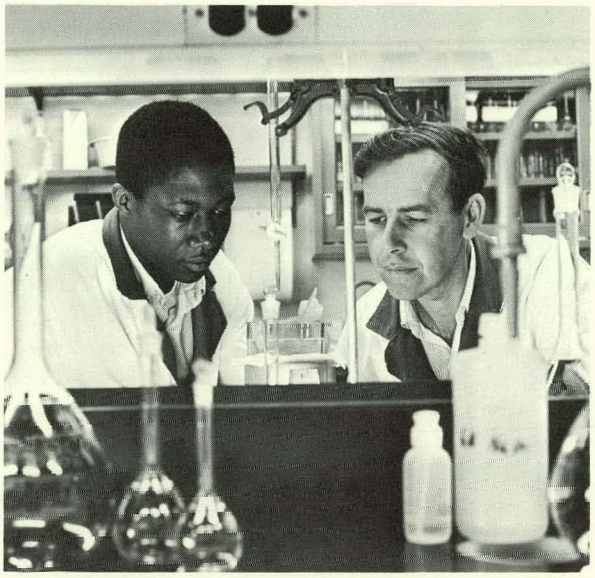
Commissioner Gerald F. Tape of the US AEC, making the principal address at the dedication of the High Flux Beam Research Reactor on April 22, 1966.

Additional information on the HFBR may be found in the section on Technical Operations and Services.

Graphite Research Reactor

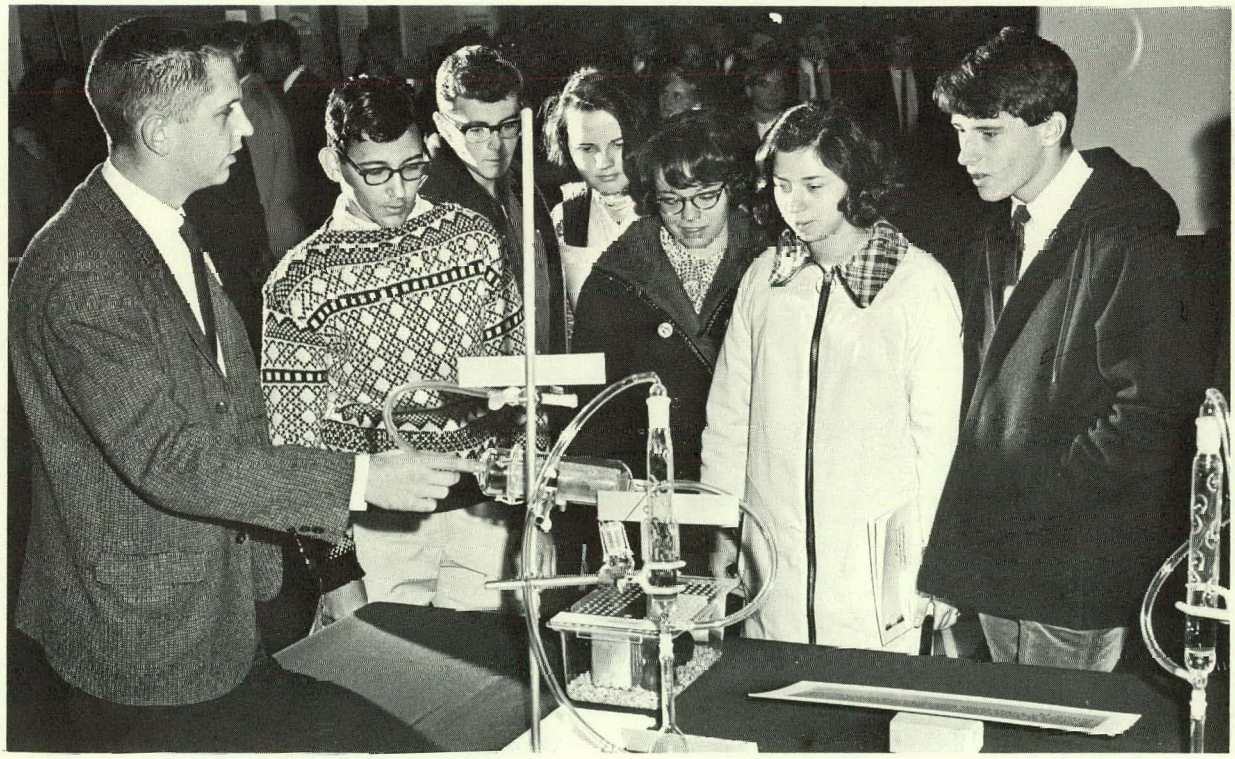
The in-pile and beam facilities of the 20-MW Brookhaven Graphite Research Reactor (BGRR), which has been in almost continuous operation since 1950, are used in a variety of programs by Brookhaven personnel and by visiting scientists and engineers from other institutions. The maximum thermal neutron flux available is $\simeq 2 \times 10^{13}$ neutrons/cm^2-sec. The reactor loading remained at 615 channels during fiscal 1966. The graphite annealing procedure to repair graphite radiation damage was carried out 11 times during the year. Approximately 30 reactor holes are assigned to

A member of the Physics Department describing the High Flux Beam Research Reactor to some of the 138 students from 33 Suffolk County high schools who visited Brookhaven on Science Youth Day, February 11, 1966, as part of the International Edison Birthday Celebration in which all AEC installations take part.



One of the 161 students taking part in the 1966 Brookhaven summer student program, shown working with a member of the Chemistry Department (right) in studies of the thiocyanate complexes of mercury.

Some of about 5000 high school students who attended the 12th BNL High School Visitors' Day on October 30, 1965, listening to an explanation of a Medical Department exhibit illustrating the technique of using C^{14}-labeled sugar to study the metabolism of sugar in mice.



BNL research departments and outside users. The five outside organizations using the reactor's facilities (for other than routine irradiation services) under various cooperative arrangements accounted for 3.7% of the total reactor usage. A complete report on the BGRR is given in the section on Technical Operations and Services.

Medical Research Reactor

The Medical Research Reactor (MRR) was constructed for the sole purpose of exploring the possible applications of nuclear reactors to the study of man and his diseases. Each salient feature of the reactor was designed in relation to its use for therapy and diagnosis or in the advancement of basic medical science. Operation is on an intermittent basis because of the nature of the research program. Operating power levels up to 3 MW have been approved for continuous operation, and levels up to 5 MW are permitted for intermittent periods not to exceed 10 minutes. The MRR was operated 240 times during the year for a total of 738 MWh. Further details on the MRR are included in the section on Technical Operations and Services.

Hot Laboratory

The Hot Laboratory, which is adjacent to the BGRR, contains extensive facilities for the analysis and processing of highly radioactive materials. It includes three hot cells in which chemical operations can be performed remotely while under observation by periscope, and a larger hot cell of the cave type for the physical examination of materials, especially metals of high radioactivity.

Critical Assembly Laboratory

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

High Intensity Radiation Development Laboratory

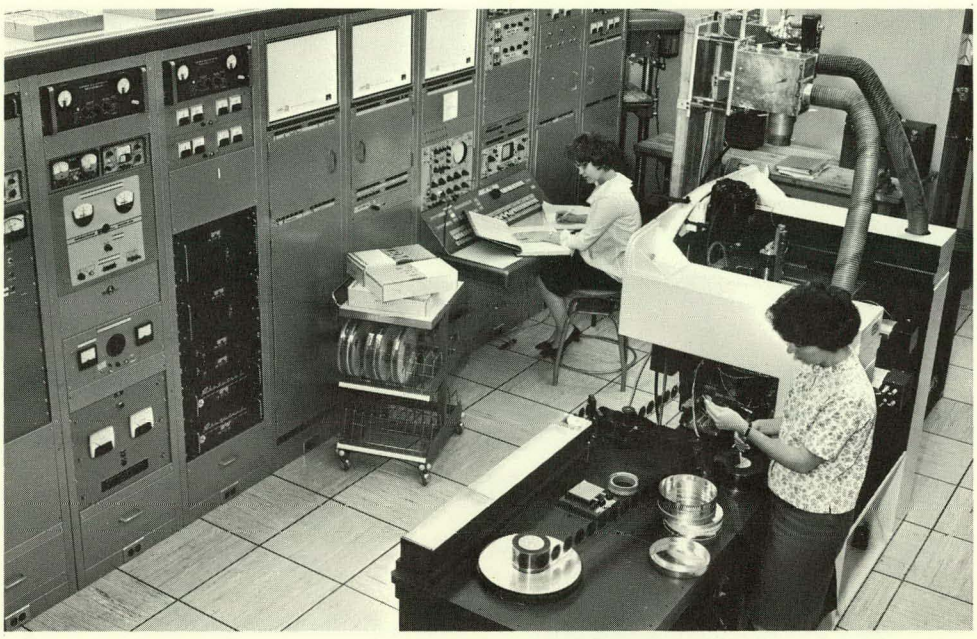
The function of the High Intensity Radiation Development Laboratory (HIRDL) is to obtain engineering data on a variety of radiation sources in the million-curie range and to develop more efficient techniques for handling large-scale radiation sources. This information is essential for the design of future irradiation facilities needed for a wide range of applications of radiation energy. The main design features of the HIRDL are two unique cells, one an irradiation cell for the experimental work with radiation sources, and the other a work preparation cell in which various types of sources are prepared. This laboratory is equipped to handle up to 2 million curies of radiation sources at one time. During the past year almost one million curies of Co^{60} were encapsulated and made available for research at Brookhaven and elsewhere. In addition, $\approx$60,000 curies of ETR Co^{60} were installed in two shipboard irradiators. Additional information on the HIRDL is given in the section on Nuclear Engineering.

80-in. Liquid Hydrogen Bubble Chamber

During the year the 80-in. liquid hydrogen bubble chamber, located in the North Experimental Area of the AGS, produced slightly more than 1,200,000 photographs in $\approx$900 hr of operation. This bubble chamber, the largest in the world, has an effective volume of 850 liters. It is positioned inside a vacuum chamber; a magnet capable of producing magnetic fields as high as 20,000 gauss with its 280-ton steel yoke completes the assembly, which is constructed in two units that separate to give access to the chamber. The entire 450-ton chamber and magnet assembly rides on an undercarriage and can be translated, rotated, and elevated as required by the experimental program. More information on the 80-in. bubble chamber may be found in the section on Physics.

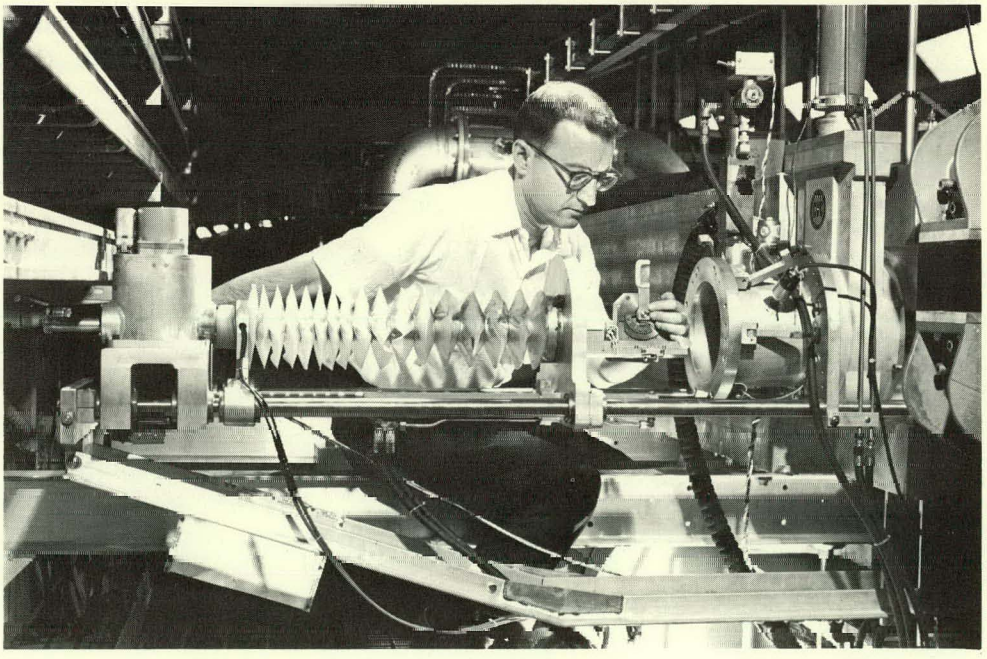
Central Scientific Computing Facility

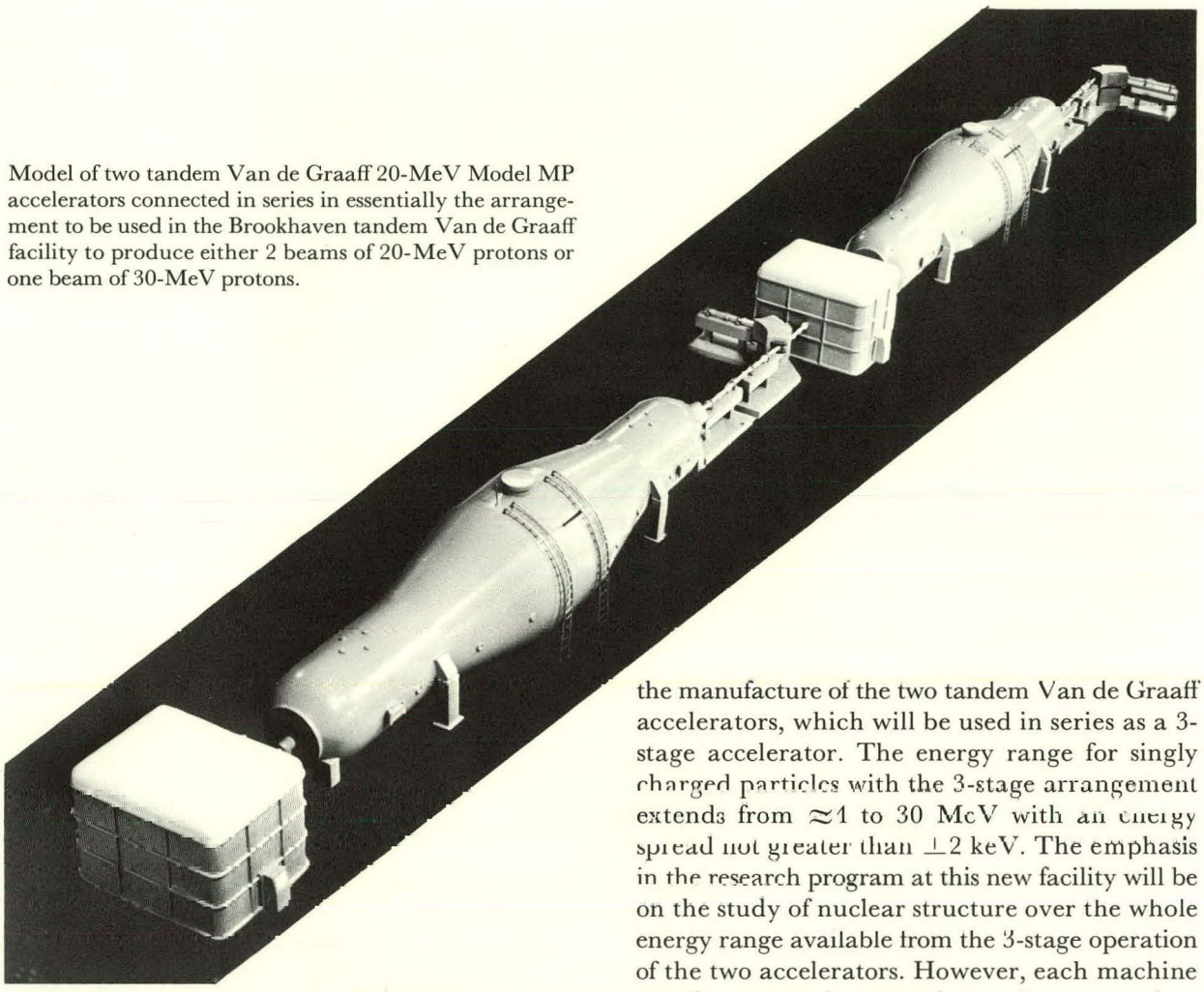
In March 1966 the Central Scientific Computing Facility moved into the newly completed Applied Mathematics Building. At the same time a CDC 6600 computer system, which significantly increases the computational capability available for the research programs of the Laboratory, was added to the facility. The IBM 7094 computer, previously the main unit of the facility, was left in the old location, where it is convenient for con-



The Flying-Spot Digitizer used in the automatic analysis of bubble chamber film. Light signals from a spot of light moving back and forth across the film are received by a photomultiplier tube behind the film. These signals, which reveal the positions of the particle tracks, are transmitted to electronic circuitry which converts the information to digital form for processing by the IBM 7094 computer. The computer is programmed to automatically analyze and identify the particles and events recorded on the bubble chamber film.

A copper target for proton bombardment being installed at the Alternating Gradient Synchrotron. The reactions between high energy protons and complex nuclei are studied as part of a program in nuclear chemistry.





Model of two tandem Van de Graaff 20-MeV Model MP accelerators connected in series in essentially the arrangement to be used in the Brookhaven tandem Van de Graaff facility to produce either 2 beams of 20-MeV protons or one beam of 30-MeV protons.

tinued on-line use with the Hough-Powell Flying-Spot Digitizer. During fiscal 1966 the IBM 7094 was again used to its full capacity, and its usage is expected to continue at a saturation level throughout fiscal 1967 despite the availability of the CDC 6600, which by the end of fiscal 1966 was already being operated two full 8-hr shifts per day. Further information on the Laboratory's computers is contained in the section on Applied Mathematics.

MAJOR RESEARCH FACILITIES UNDER DESIGN AND CONSTRUCTION

Tandem Van de Graaff

Work on the new tandem Van de Graaff facility has proceeded. The High Voltage Engineering Corporation, under a contract awarded by the AEC in March 1965, is making satisfactory progress in the manufacture of the two tandem Van de Graaff accelerators, which will be used in series as a 3-stage accelerator. The energy range for singly charged particles with the 3-stage arrangement extends from ≈ 1 to 30 MeV with an energy spread not greater than ± 2 keV. The emphasis in the research program at this new facility will be on the study of nuclear structure over the whole energy range available from the 3-stage operation of the two accelerators. However, each machine may be operated separately as a 2-stage tandem Van de Graaff accelerator with energy up to 20 or 25 MeV; this will greatly extend the research capabilities of the facility. There will be 4 experimental scattering rooms containing a total of 22 beam tubes and associated equipment. A high-resolution magnetic spectrometer, scattering chambers, and other types of experimental apparatus are being designed for use in the tandem Van de Graaff research program. A gradual expansion of existing experimental programs at the cyclotron and the small Van de Graaff is planned with the aim of carrying on a full research program at the tandem Van de Graaff as soon as it is in operation.

Because bids for the construction of the building to house the facility were higher than the amount budgeted for that purpose, some redesign was necessary, involving the reduction of some of the service area. Revised bids are being solicited, and construction of the building should be completed

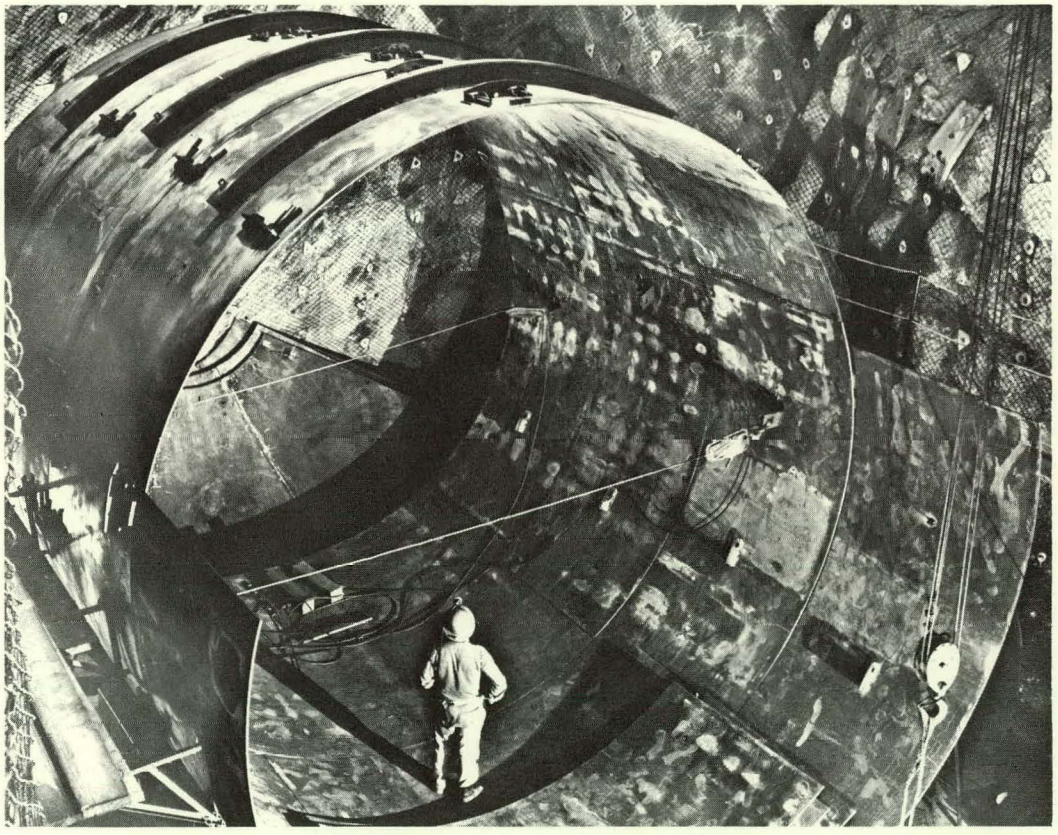
in the spring of 1968, followed by installation and testing of the accelerators. Final completion of the facility is expected early in 1970.

GENERAL CONSTRUCTION PROGRAM

In July 1965 construction began at the Medical Center on the low-level radiation counting facility for clinical research. Completion is expected before the end of 1966.

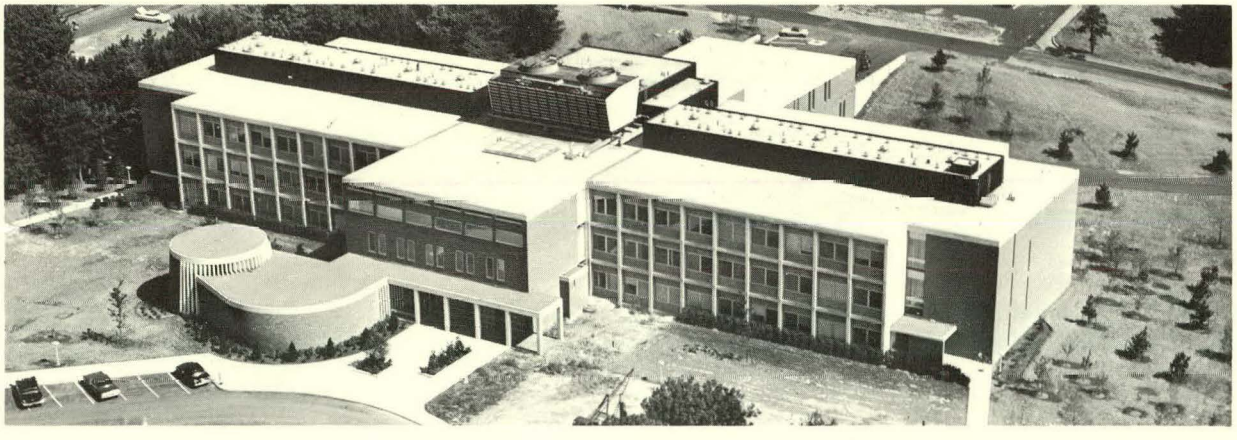
In February 1966 occupation was begun of both the new Chemistry Building and the Physics and Mathematics addition to the Physics Building. Construction was begun in May 1966 on the enlargement and modernization of the sewage treatment plant. Completion of this project is expected to take $\approx$7 months. In June 1966 the contract for construction of the Lecture Hall–Cafeteria was awarded, with construction scheduled to start in July and completion expected early in 1968. In addition, the last three 2-story barracks buildings being used as dormitories were relocated and rebuilt as a single men's residence containing 90 bedrooms and central kitchen, dining, bath and lounge facilities.

Detailed planning for the laboratories and facilities required to meet Brookhaven's needs continued. Included are the Nuclear Engineering Building (Phase II), the Metallurgy Building addition, the Technical Services Building, the Electron Accelerator, and the Molecular Biology Building. A continuation of this building program will be requested so that the Laboratory's function as a research center can be efficiently and economically fulfilled.

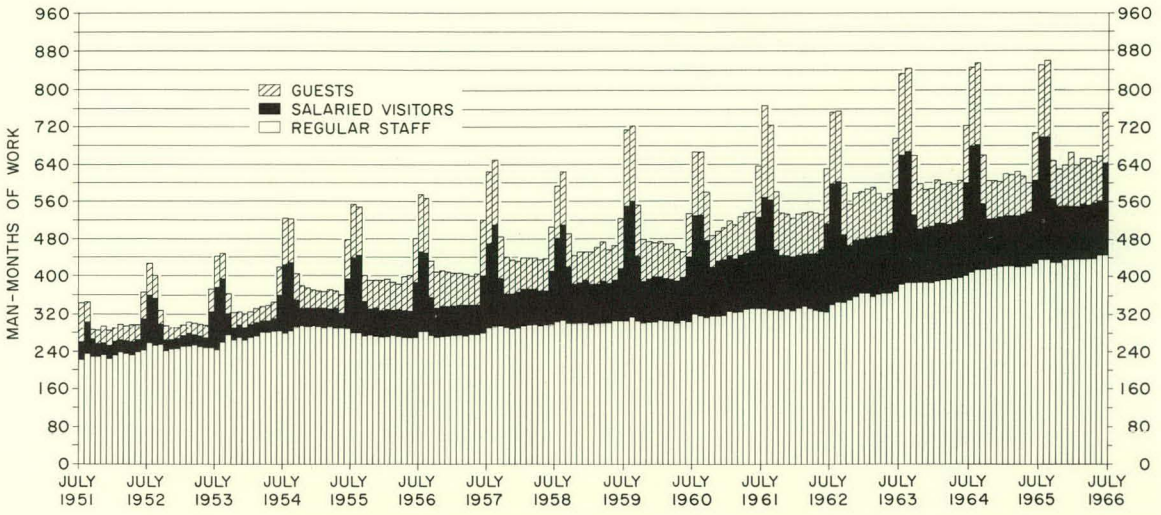


The Brookhaven solar neutrino experiment being constructed 4900 ft underground in the Homestake Gold Mine in Lead, South Dakota. The tank, 20 ft in diameter and 48 ft long, will contain 100,000 gallons of perchloroethylene. Neutrinos from the interior of the sun will be detected by observing the radioactive argon-37 produced by neutrino capture in chlorine-37, according to the reaction $\nu + Cl^{37} \rightarrow Ar^{37} + e^-$. The apparatus will be operational before the end of 1966.

Low energy gamma rays from radioactive technetium-99*m* (the *m* indicates a metastable isotope), concentrated in a patient's kidney after intravenous injection, are detected by a scintillation crystal that is moved back and forth in a precise pattern over the patient. The moving stylus of a plotter, activated by the pulses from the detector, produces a "picture" of the kidney which provides important information for diagnostic purposes. The use of Tc^{99m} is a significant advance in the field of diagnostic scanning. The gamma rays from this isotope are easily detectable outside the body, yet its short half-life (6 hr) and the absence of charged particle radiation and high energy gamma rays mean that a sufficiently large dose of Tc^{99m} can be administered to insure good detail and high contrast in the scans; at the same time the organ being scanned and the patient's whole body are subjected to a much lower dose of radiation than was possible with isotopes used earlier. The Tc^{99m} is prepared by use of a method developed in the Hot Laboratory Division of the Nuclear Engineering Department. The isotope is almost ideal for liver, spleen, and kidney scanning, has already been applied in thyroid studies, and shows promise in brain tumor localization.



The new Chemistry building, which was occupied in February 1966.



Scientific staff and students.

PERSONNEL

The total number of employees at Brookhaven National Laboratory on June 30, 1966, excluding temporary appointees, Research Collaborators, and guests, was 3343, a net increase over fiscal 1965 of 98. During the year the regular scientific staff (Ph.D. or equivalent) increased from 424 to 442, Research Associates decreased from 76 to 75,* and salaried visitors decreased from 32 to 26,* for a total increase in the salaried staff from 532 to 543. The nonsalaried scientific staff increased from 670 in 1965 to 730 in 1966 as of May 31 of these years. The latter visitors are not at Brookhaven on a full-time basis. About one-fourth to one-third of them are on site at any one time. A total of 598, as compared with 596 in 1965, visiting scientists and students worked at the Laboratory during the year; this number does not include Research Associates.

Summer visitors continue to play a significant role in the Laboratory's program. Arrangements were made for 334 visiting scientists and students to work at Brookhaven during the summer of 1966. Of this number, 145 are staff members from various educational and research institutions, and 161 are students.

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

ADMINISTRATION

The organization of the Laboratory as of July 1, 1966, is given in the Organization Chart at the front of this report. On October 1, 1965, Dr. T. Keith Glennan succeeded Mr. Theodore P. Wright as President of AUI. At its annual meeting in October 1965 the AUI Board of Trustees elected Dr. Ernest F. Johnson as Chairman of the Board, to succeed Dr. Carl F. Floe, who remains a University Trustee. Dr. Johnson is Associate Dean of Faculty at Princeton University and one of AUI's University Trustees. At the same meeting Dr. Fred T. Haddock of the University of Michigan, heretofore an Annual Trustee, was elected Trustee-at-Large for a term expiring in October 1968, and Dr. Thomas Gold of Cornell University, heretofore a Trustee-at-Large, was elected an Annual Trustee for a term ending in October 1966. In January 1966 Mr. Harold E. Manley, Business and Financial Vice-President of the University of Pennsylvania, was elected a University Trustee to fill the unexpired term of Dr. Carl C. Chambers, who resigned from the Board. In March 1966 Dr. Arthur M. Ross, Assistant to the Provost for the Sciences and Secretary of the Science Advisory Committee of Yale University, was elected a University Trustee to fill the unexpired term of Mr. C. Hamilton Sanford, who resigned from the Board.

Three changes in the Laboratory administration took effect on July 1, 1966: Dr. Rodney L. Cool was promoted to the newly created post of Associate Director for High Energy Physics; Mr. Vincent R. O'Leary succeeded Mr. H. Russell Cort, who retired after nineteen years of service, as Laboratory Budget Officer; and Mr. Bernard J. McAlary replaced Mr. Robert B. Eberbach, who was appointed Staff Assistant to the AUI Controller, as Laboratory Fiscal Officer and Head of the Fiscal Division.

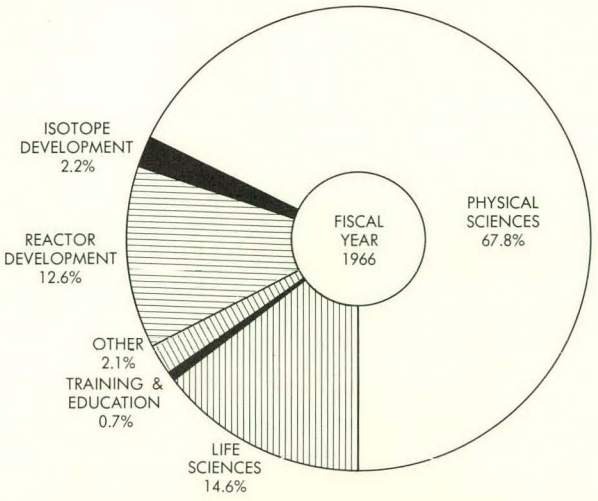
FINANCE

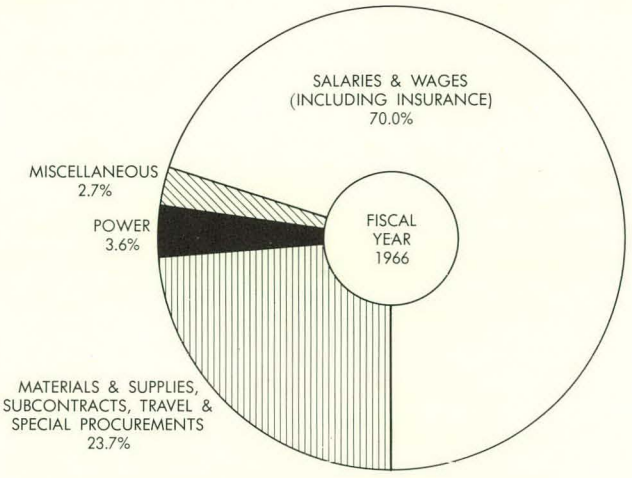
AEC-supported research at the Laboratory continued to be financed by the AEC Divisions of Reactor Development and Technology, Research (Physical Sciences), Biology and Medicine (Life Sciences), Training and Education, and Isotope Development. Operating costs for the work in each program and the major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

CONFERENCES

Five large scientific conferences were held at Brookhaven during fiscal 1966: the Conference on Inelastic Scattering of Neutrons by Condensed Systems, September 20 to 24; the Symposium on Accelerator Radiation Dosimetry and Experience, November 3 to 5; the Symposium on Structure and Function of Polypeptide Hormones – Insulin, November 8 to 10; the Joint Meeting of the Institute of Mathematical Statistics, the Biometric Society, and the American Statistical Association, April 27 to 29; and Biology Symposium No. 19, entitled "Energy Conversion by the Photosynthetic Apparatus," June 6 to 9.

A plastic phantom used in whole-body-counter calibration is wheeled into one of the five shielded rooms of the new low-level radiation counting facility for clinical research. The rooms are shielded by ⅛ in. of lead, 4 in. of steel, and 4 ft of concrete. The steel doors and their lead-glass windows are 8 in. thick. When this facility goes into operation early in fiscal 1967 it will permit detection of radioactivity in patients at levels not previously discernible because of inadequate shielding and will make possible a reduction in the amount of radioactivity used for clinical diagnostic and metabolic studies.





OPERATING COST DISTRIBUTION BY PROGRAMS

FISCAL YEAR	PHYSICAL SCIENCES	REACTOR DEVELOPMENT	LIFE SCIENCES	ISOTOPE DEVELOPMENT	TRAINING & EDUCATION	OTHER (NET)	TOTAL COST
1966	32,708,048	6,086,937	7,015,987	1,073,696	311,476	1,019,818	48,215,962
1965	30,233,277	5,718,931	6,593,700	990,596	175,167	1,137,073	44,848,744
1964	27,856,193	5,318,029	6,211,430	979,385	174,142	737,511	41,276,690

MAJOR CATEGORIES OF OPERATING EXPENDITURES

FISCAL YEAR	SALARIES & WAGES	MATERIALS & SUPPLIES SUBCONTRACTS, TRAVEL & SPECIAL PROCUREMENTS	POWER	MISCELLANEOUS (NET)	OPERATING TOTAL
1966	33,738,859	11,409,512	1,756,098	1,311,493	48,215,962
1965	30,796,939	10,999,750	1,627,532	1,424,523	44,848,744
1964	28,017,348	10,629,739	1,694,359	935,244	41,276,690

BROOKHAVEN NATIONAL LABORATORY
COMPARATIVE BALANCE SHEET

	June 30, 1966	June 30, 1965
Assets		
Cash	$ 130,816	$ 464,035
Accounts receivable	213,932	393,791
Advances, deposits, and prepaid expenses	107,425	110,885
Property, plant and equipment (less reserves of $69,860,728 at June 30, 1966, and $58,764,225 at June 30, 1965)	150,273,220	136,478,343
Research materials and supplies	16,523,161	15,176,180
Total assets	$167,248,554	$152,623,234
Liabilities		
Accounts payable	$ 6,838,073	$ 4,212,854
Accrued vacation	2,774,739	2,552,936
Accrued payroll	200,544	373,407
Atomic Energy Commission	157,435,198	145,484,037
Total liabilities	$167,248,554	$152,623,234

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

Table 1

Organizational Expenditures – Fiscal 1964, 1965, 1966

(Includes Operating, Services to Fixed Assets, and Work for Others. Direct Costs of AGS and Other Fixed Assets and Additions to Inventory Are Not Included; See Tables 3 & 4)

		Salaries, Wages, Insurance									Man-Years		
		Staff	Consultants & Temporary Employees	Travel	Material & Supplies	Sub-contracts & Special Procure-ments	Power	Miscel-laneous (Net)	Total Organi-zational Costs	% of Total	Scientific & Professional (Incl. Guests)	Others	Total
Physics & Chemistry Research	1966	12,367,282	362,908	254,588	4,985,265	262,374	1,017,826	—	19,250,243	39.9	464.5	715.0	1,179.5
	1965	11,010,475	295,793	242,426	4,683,212	538,199	913,617	—	17,683,722	39.4	451.0	695.5	1,146.5
	1964	10,054,317	302,001	224,039	4,500,694	104,392	977,705	—	16,163,148	39.2	461.5	628.5	1,090.0
Biology, Medicine & Biophysics Research	1966	3,506,238	92,791	83,864	948,628	—	—	(8,370)	4,623,151	9.6	167.0	213.0	380.0
	1965	3,265,790	100,745	72,087	817,344	(6)	—	(5,148)	4,250,812	9.5	162.5	226.0	388.5
	1964	3,046,927	116,484	64,371	775,220	—	—	(111)	4,002,891	9.7	155.5	226.0	381.5
Nuclear Engineering Research	1966	3,206,125	64,049	83,464	926,343	314,955	—	—	4,594,936	9.5	147.0	134.5	281.5
	1965	3,142,496	72,366	85,836	981,571	444,813	—	—	4,727,082	10.5	144.0	141.5	285.5
	1964	2,788,603	71,227	80,476	855,197	563,009	—	—	4,358,512	10.6	130.5	141.5	272.0
Isotope Development	1966	484,288	7,898	12,536	171,876	27,003	—	—	703,601	1.5	21.5	20.5	42.0
	1965	460,158	18,555	12,586	144,310	149	—	—	635,758	1.4	23.0	20.5	43.5
	1964	404,902	7,632	9,045	120,246	44,444	—	—	586,269	1.4	23.5	19.5	43.0
Training & Education	1966	34,688	121,977	20,089	13,199	24,082	—	—	214,035	0.4	1.0	21.5	22.5
	1965	39,343	58,643	16,342	9,127	1,219	—	—	124,674	0.3	2.0	14.5	16.5
	1964	50,093	29,561	24,079	16,475	8,504	—	—	128,712	0.3	4.0	5.0	9.0
Radiation Protection	1966	707,546	3,019	6,072	94,270	—	—	—	810,907	1.7	15.0	58.0	73.0
	1965	607,685	1,487	4,054	108,595	—	—	(745)	721,076	1.6	12.5	57.0	69.5
	1964	569,289	2,321	2,943	111,436	—	—	(13)	685,976	1.7	12.0	55.5	67.5
Supporting Scientific & Technical Services	1966	5,900,411	6,847	43,013	963,274	676,989	234,858	(4,251)	7,821,141	13.4	92.5	471.5	564.0
	1965	5,249,222	24,748	30,439	1,086,741	487,531	228,284	(126,919)	6,980,046	15.6	84.5	447.5	532.0
	1964	4,912,675	28,379	35,577	777,441	747,017	252,521	(129,001)	6,624,609	16.0	78.5	443.5	522.0
Plant Protection & Security	1966	682,006	—	2,421	15,850	—	—	3,010	703,287	1.5	—	75.5	75.5
	1965	650,329	—	1,964	15,881	—	—	3,118	671,292	1.5	—	75.0	75.0
	1964	641,497	15	1,934	18,726	—	—	2,352	664,524	1.6	—	75.0	75.0
Miscellaneous (including Lighting, T & T, Heating Fuels, Special Maintenance, etc.)	1966	—	—	582	86,357	(469)	503,414	947,754	1,537,638	3.2	—	—	—
	1965	—	—	2,228	123,025	(8,419)	435,631	938,318	1,540,783	3.4	—	—	—
	1964	—	—	2,409	94,532	(13,936)	464,133	855,968	1,403,106	3.4	—	—	—
General and Administrative	1966	6,108,462	82,324	206,312	1,041,832	144,743	—	(101,650)	7,482,023	18.3	51.0	692.5	743.5
	1965	5,704,443	66,781	187,913	851,686	—	—	140,899	6,951,722	15.5	49.5	673.0	722.5
	1964	4,907,509	57,778	150,206	1,229,515	(704)	—	(268,951)	6,075,353	14.7	42.5	624.5	667.0
Laboratory Total	1966	32,997,046	741,813	712,941	9,246,894	1,449,677	1,756,098	836,493	47,740,962	99.0	959.5	2,402.0	3,361.5
	1965	30,129,941	639,118	655,875	8,821,492	1,463,486	1,627,532	949,523	44,286,967	98.7	929.0	2,350.5	3,279.5
	1964	27,375,812	615,398	595,079	8,499,482	1,452,726	1,694,359	460,244	40,693,100	98.6	908.0	2,219.0	3,127.0
AUI Administration	1966	—	—	—	—	—	—	475,000	475,000	1.0	—	—	—
	1965	—	—	—	—	—	—	475,000	475,000	1.1	—	—	—
	1964	—	—	—	—	—	—	475,000	475,000	1.1	—	—	—
Total AUI and BNL	1966	32,997,046	741,813	712,941	9,246,894	1,449,677	1,756,098	1,311,493	48,215,962	100.0	959.5	2,402.0	3,361.5
	1965	30,129,941	639,118	655,875	8,821,492	1,463,486	1,627,532	1,424,523	44,761,967	99.8	929.0	2,350.5	3,279.5
	1964	27,375,812	615,398	595,079	8,499,482	1,452,726	1,694,359	935,244	41,168,100	99.7	908.0	2,219.0	3,127.0
Work for Others, Direct Costs Only	1966	—	—	—	—	—	—	—	—	—	—	—	—
	1965	27,868	12	1,706	31,913	25,278	—	—	86,777	0.2	2.0	5.0	7.0
	1964	26,138	—	7,206	33,033	42,213	—	—	108,590	0.3	3.0	4.0	7.0
Grand Total	1966	32,997,046	741,813	712,941	9,246,894	1,449,677	1,756,098	1,311,493	48,215,962*	100.0	959.5	2,402.0	3,361.5
	1965	30,157,809	639,130	657,581	8,853,405	1,488,764	1,627,532	1,424,523	44,848,744**	100.0	931.0	2,355.5	3,286.5
	1964	27,401,950	615,398	602,285	8,532,515	1,494,939	1,694,359	935,244	41,276,690†	100.0	911.0	2,223.0	3,134.0

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

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

†$675,186 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.

Table 2

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

	Fiscal 1966		Fiscal 1965		Fiscal 1964	
	$	%	$	%	$	%
Scientific and hospital	6,535,677	73.5	7,675,813	90.1	6,631,016	93.6
Automotive and heavy mobile	209,844	2.4	165,448	1.9	91,295	1.3
Office machines and furniture	86,366	1.0	97,854	1.1	105,019	1.5
Shop equipment	207,793	2.3	200,305	2.4	109,509	1.5
Computer acquisition	1,639,176	18.4	225,045	2.7	97,192	1.4
Miscellaneous	214,667*	2.4	150,647	1.8	49,988	0.7
Expenditures, Total	8,893,523	100.0	8,515,112	100.0	7,084,019	100.0
Proceeds from sales	(50,024)		(51,058)		(32,386)	
Expenditures, Net	8,843,499		8,464,054		7,051,633	

*Includes plant maintenance, $72.7; HFBR, $53.1; supply and materiel, $14.1.

Table 3

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

	Fiscal 1966			Fiscal 1965			Fiscal 1964		
		Man-years			Man-years			Man-years	
	Costs, $	Sci.	Others	Costs, $	Sci.	Others	Costs, $	Sci.	Others
Direct									
Salaries, wages, insurance	958,562	36.5	53.9	721,827	21.0	56.5	600,399	20.5	33.0
Materials, construction, etc.	11,314,238			11,214,871			9,364,652		
Subtotal direct	12,272,800			11,936,698			9,965,051		
Charges from organizational units	562,470			629,825			479,700		
Total	12,835,270			12,566,523			10,444,751		

*Includes AGS conversion and HFBR.

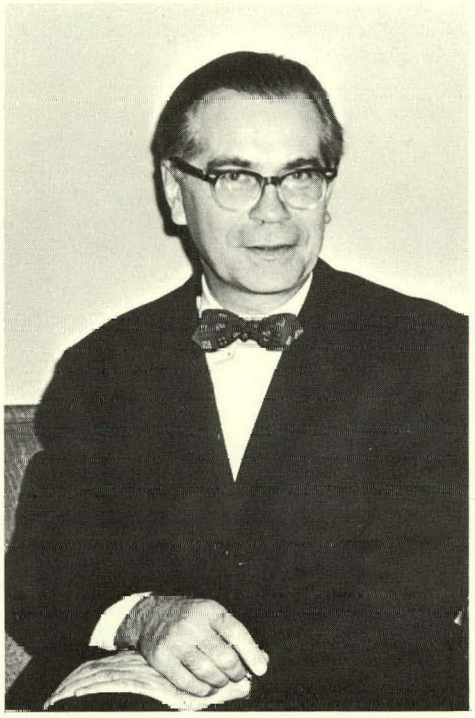
Table 4

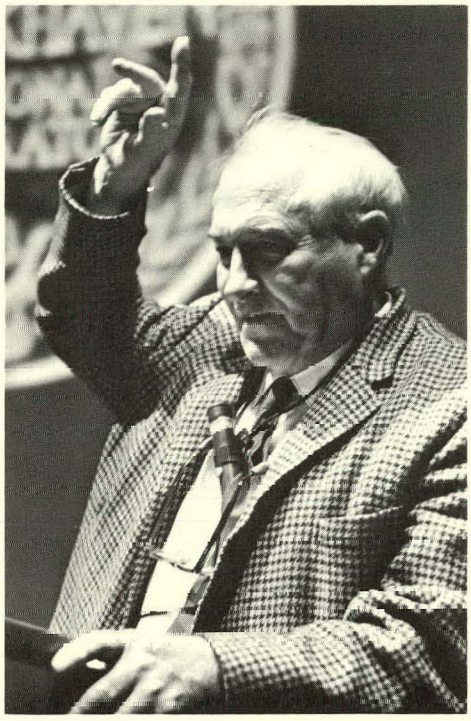
Inventory at Close of Fiscal Year

Type of inventory	Fiscal year 1966	1965	1964
General stores*	$ 907,692	$ 743,950	$ 527,612
Special process spares**	828,721	613,895	91,293
Precious metals and radium	243,452	209,124	206,089
Stable isotopes	54,071	75,217	51,962
Heavy water	657,969	750,916	753,685
Total	$2,691,905	$2,393,102	$1,630,641

*The number of months investment was 3.0 in 1966, 2.8 in 1965, and 2.2 in 1964.

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





Lecturers at BNL during fiscal 1966. Upper left: Professor Richard Hofstadter, the Seventh Pegram Lecturer. His three lectures on "Academic Freedom and the Scientific Ideal" were presented on October 25, 27, and 29, 1965. Upper right: Dr. Louis B. Leakey, the Eighth Pegram Lecturer, who presented four lectures on "A Review of Theories on Human Evolution and a Revision" on March 2, 4, 7, and 9, 1966. Lower left: Dr. Ralph J. Bunche, United Nations Undersecretary for Special Political Affairs, who gave the first lecture in a new series, the AUI Trustee Distinguished Lectures. Dr. Bunche's talk on "UN Peacekeeping: Crisis and Prospect" was given on January 13, 1966. Lower right: Dr. Bentley Glass of the State University of New York at Stony Brook, who gave the second of the AUI Trustee Distinguished Lectures on June 14, 1966. His subject was "Genetic Continuity: The History of a Scientific Concept."

PHYSICAL SCIENCES AND ENGINEERING

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Chemistry

A major event in the history of the Chemistry Department was the move to the new Chemistry Building, which took place during the first half of 1966. Open House was held on May 17 for the Laboratory staff, and dedication ceremonies are planned for the fall of 1966.

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

NUCLEAR CHEMISTRY

High Energy Nuclear Reactions

The principal emphasis in the study of nuclear reactions has been on the energy regions accessible with the proton beams of the Cosmotron and the Alternating Gradient Synchrotron (AGS).

Studies of high energy reactions yield information on reaction cross sections and their dependence on properties of the bombarding particle and target nucleus. This information can be used to investigate models and mechanisms for the reactions. In this work the high-speed computing facilities of the Applied Mathematics Department are used extensively. Cross-section measurements alone do not describe nuclear reactions in complete detail, and they are being augmented by determination of the angular distributions and energies of the product nuclei recoiling from very thin targets.

Studies of the fission of heavy elements by high energy protons were continued with use of several techniques. The experiment using semiconductor detectors for the measurement of kinetic energies of coincident fission fragments, begun last year, was greatly improved by the completion of a new 1-m-diam scattering chamber, by the addition of a time-of-flight measurement to the two energy determinations, and by the acquisition of new equipment for recording multiparameter data. Experiments on uranium and bismuth fission were begun with this new system in a well-collimated external proton beam at the Cosmotron. In another experiment, differential range and angular distribution measurements for selected uranium fission products such as Ba^{140}, Ba^{131}, Pd^{103}, and Mo^{99} were used to deduce information about the mechanisms leading to these particular products. Earlier indirect evidence for the conclusion that different mechanisms are responsible for the formation of neutron-rich and neutron-deficient species was thus confirmed.

A detailed nuclear-emulsion study of the energy spectra and angular distributions of Li^8 fragments produced in the interaction of copper, silver, and gold targets with 2.2-BeV protons was completed. Comparisons of the results with nuclear cascade and evaporation calculations showed that a substantial fraction of the Li^8 fragments is emitted by a process other than evaporation.

Further tests of various nuclear models used in Monte Carlo calculations of intranuclear cascades were carried out with the IBM 7094 computer. Inclusion of classical refraction of nucleons in the calculations was shown to lead to erroneous results (too much energy deposition) at incident energies below about 150 MeV. To test the predictions of various model calculations at higher energies, where pertinent data are very sparse, copper and tantalum foils in a hydrogen bubble chamber were bombarded with 380-MeV protons. Approximately 150,000 pictures were obtained for the purpose of mapping differential energy and angle distributions of emitted protons.

Calculations of the de-excitation of highly excited nuclei, especially those with high angular momenta, were carried on and refined. For this analysis, the role of the lowest excited state at every angular momentum was found to be particularly important. One of the most interesting results of the calculations was the prediction that, in the region of these excited states, α particles of energies well below Coulomb barrier height should be emitted in competition with γ rays only, because neutron emission is strongly inhibited by centrifugal barriers.

Nuclear Spectroscopy

The detailed study of the radiations emitted by radioactive atoms gives information about the structure of nuclei in various states of excitation. In addition, a substantial part of the research in this field is relevant to studies of nuclear reactions, since the yields of certain nuclei from these reactions are often determined by measuring the radiation emitted by the nuclei.

sion, can take place by internal conversion. The results are consistent with predictions based on the rotational model.

Reports of inconsistencies and discrepancies between measurement and theory motivated an experimental investigation of the ratios of L-subshell internal conversion coefficients in electric quadrupole transitions. The cases studied, all pure $E2$, were: Dy^{160} (86.7 keV), Er^{166} (80.6 keV), Tm^{169} (130.5 keV), Yb^{170} (84.2 keV), Os^{186} (137.1 keV),

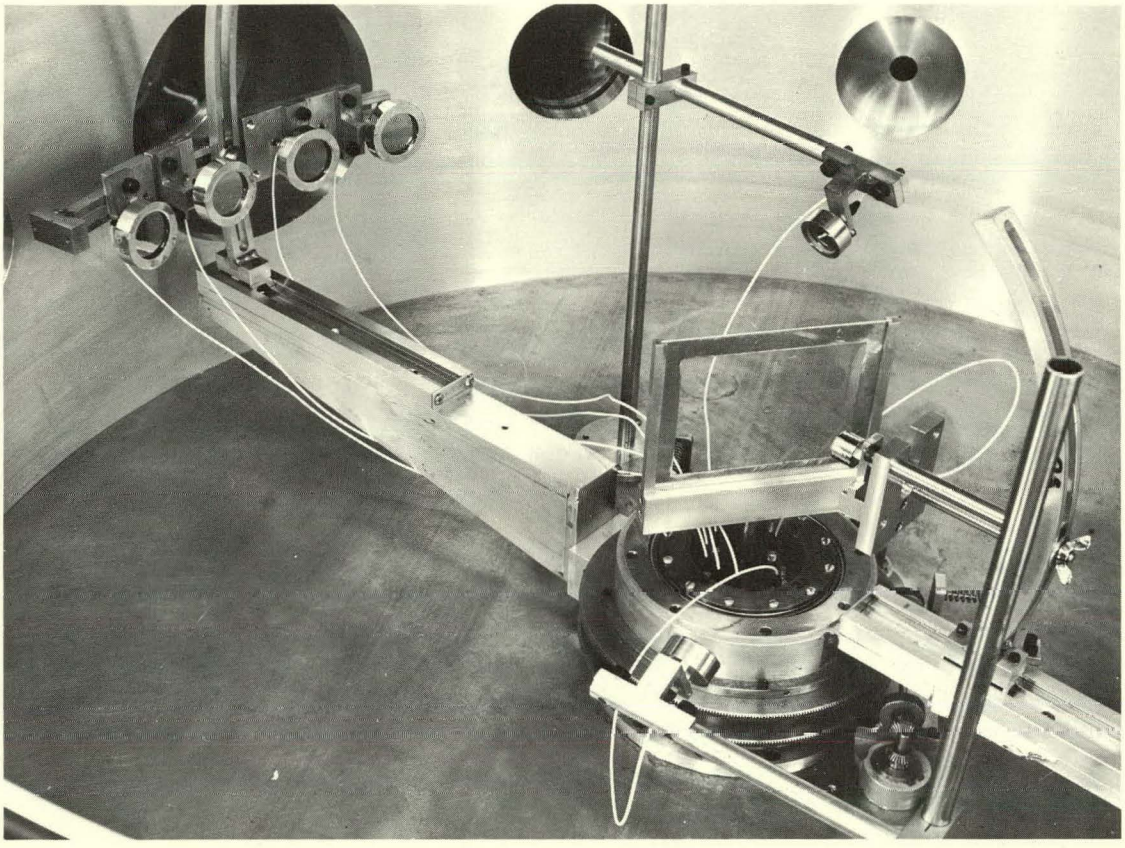


Figure 1. Interior of the 1-m-diam scattering chamber for studies of high energy proton fission of heavy elements. In this photograph the solid-state detectors and the target (in rectangular frame at center) can be seen.

In collaboration with a member of the Physics Department, State University of New York at Stony Brook, a study was made of the internal conversion of the 396-, 283-, and 145-keV transitions in Lu^{175}, which are all strongly hindered electric dipole transitions that take place between the same two rotational bands. This study provides the only test so far proposed of theoretical branching ratios in the case of nuclear transitions which, strongly forbidden with respect to photon emis-

and Os^{188} (155.0 keV). In all these cases the L_2/L_3 ratios were found to agree well with theory, but the L_1/L_3 ratios were about 4 to 7% greater than theoretical values. Reasons for the disagreement are not yet known. Similar measurements were begun on transitions of other multipole orders.

Experiments were begun in an effort to observe the effects of chemical environment on internal conversion electron spectra. Very thin sources of Sn^{119m}, prepared with the isotope separator, are being used.

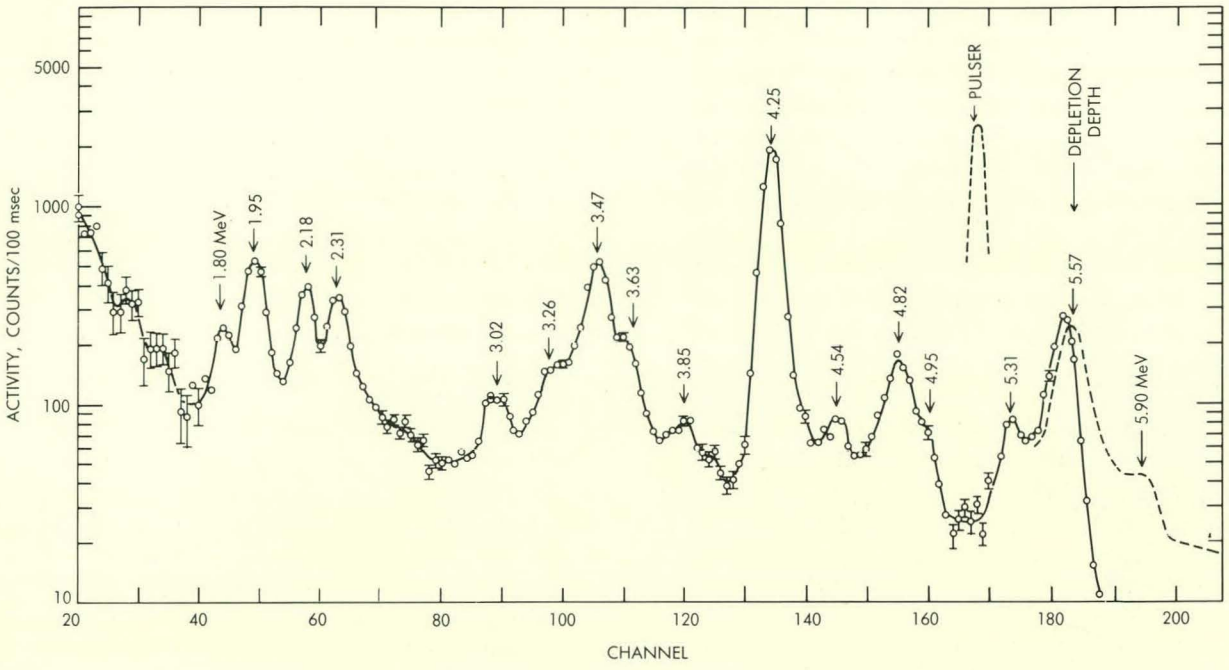


Figure 2. Spectrum of delayed protons following β^+ decay of Si^{25}, taken with a silicon semiconductor detector.

An investigation of the γ rays produced in the decay of Ir^{186} and of Ir^{185} was carried out in collaboration with a visitor from Clark University. Lithium-drifted germanium detectors were used. The measurements obtained made it possible to establish the multipole orders of a number of transitions that could not be determined in an earlier, very extensive study at BNL.

The investigation of the decay properties of the neutron-deficient nucleus Ce^{131} was continued. The observed ratio of electron capture to positron emission is in disagreement with theory, for reasons not yet apparent.

Studies were continued of delayed neutron and delayed proton emitters produced in irradiations with various accelerators at BNL. Detailed investigations were made of the delayed proton spectra of Ne^{17}, Si^{25}, Ar^{33}, Ca^{37}, and Ti^{41}, produced at the 60-in. cyclotron. O^{13}, produced at the 50-MeV linac of the AGS, was found to have a half-life of 8.7 msec, the shortest half-life of any delayed proton emitter thus far known. The existence of a new delayed neutron emitter, He^8, was established. It was produced by high energy proton bombardment of carbon and oxygen targets at the Cosmotron, and its properties were studied.

The fluorescence yield of the M x rays accompanying the α decay of Po^{210} was determined by L-M x-ray coincidence measurements with proportional counter detectors. Preliminary analysis of the data showed that the fluorescence yield is $\approx$4.5%, close to that expected for lead M x rays excited by conventional means. This indicates that the fluorescence yield is affected in only a minor way by the disruption of the outermost electron shells that occurs in the α decay process.

The Brookhaven Solar Neutrino Experiment

This experiment is designed to measure the neutrino flux produced by the radioactive decay of Be^7 in the sun. Current theoretical estimates of the rate of Be^7 production indicate the feasibility of such a measurement, in which the neutrino detection depends upon the reaction $Cl^{37}(\nu,e^-)Ar^{37}$. The detector itself is a 100,000-gal tank of perchloroethylene which will be 4900 ft below the surface in the Homestake Gold Mine at Lead, South Dakota.

Progress during the past year included construction and filling of the tank, testing of the pumps to handle the perchloroethylene, and testing of the eductors that will permit removal of the Ar^{37} from the liquid by purging with helium. The gas processing system for removal of argon from the helium stream is under construction.

Background-effect experiments were performed in order to estimate rates of Ar^{37} production by

reactions other than the one to be used as a neutrino detector. One such reaction may be initiated by α-radioactivity from uranium and thorium in the rock walls of the mine, producing fast neutrons in an (α,n) reaction. The fast neutrons yield Ar^{37} by the successive reactions $Cl^{35}(n,p)S^{35}$ and $Cl^{37}(p,n)Ar^{37}$. By means of the $Ca^{40}(n,\alpha)Ar^{37}$ reaction, it was shown that, even in the unshielded tank, this fast neutron process would produce only 1.5 to 6% of the Ar^{37} predicted from the expected neutrino flux. Ar^{37} production by the $S^{34}(\alpha,n)Ar^{37}$ process involving trace amounts of sulfur in the perchloroethylene, and by the successive reactions $Cl^{35}(\alpha,p)Ar^{38}$ and $Cl^{37}(p,n)Ar^{37}$, was shown to be at least two orders of magnitude below that from solar neutrinos.

Low-level counter development has been continued, and a system has been built to photograph each counter pulse so that noise pulses can be separated from signal pulses.

Nuclear Cosmochemistry and Geochemistry

Much attention has been focused on neutron activation analysis for trace elements in both meteorites and terrestrial rocks. In this work the recently developed lithium-drifted germanium semiconductor detectors have been extensively used. The increased resolution of these detectors permits the detection of several elements by direct γ-counting, without any chemical separation.

γ Rays from the elements Co, Cu, As, Au, Ir, and Ga were measured in 33 samples from iron meteorites. These are iron-nickel alloys, with macroscopic structures determined by cooling history and nickel content. The trace elements measured correlate, imperfectly, with the structure of the meteorite. Co and Cu abundances vary by a factor of <10, while As, Au, and Ir vary by 1 to 2 orders of magnitude. Ga shows the largest variations, from 2 to 3 orders of magnitude, and also the best correlation with structure.

Tektites are small objects of silicate glass which are found widely dispersed on certain areas of the earth's surface. They are not associated with any volcanic activity, and it is generally agreed that the only other natural source providing enough energy to melt or vaporize silicates would be the impact of a very large meteorite. There is considerable controversy at present as to whether this impact took place on the earth or on the moon.

With the technique of neutron activation and direct γ-counting, it is possible to detect γ rays due to 17 elements in tektites. These include the major elements Fe and Na, the lanthanides La, Ce, Sm, Eu, Dy, Yb, and Lu, and other trace elements such as Mn, Cr, Co, Sc, Th, Cs, Ta, and Hf. Most of these elements have been studied in only a few scattered samples. As a reconnaissance survey, a total of 12 tektites from Australia, Indochina, the Philippines, Texas, Czechoslovakia, and the Ivory Coast have been investigated. The relative abundance of the lanthanide elements is essentially identical for all tektites and is equivalent to that found for shales. Terrestrial shales analyzed with use of the neutron activation–γ-counting technique show the same elements, with comparable concentrations, as those seen in tektites. The similarity in trace element content between tektites and shales supports a terrestrial origin for tektites.

The neutron activation–γ-counting technique was applied in an investigation of the lanthanide distribution in garnet as a function of metamorphic grade in the rocks of Dutchess County, N.Y. For structural reasons, the heavy lanthanides preferentially enter the garnet. The earliest-formed garnets in Dutchess County are enriched in the heavy lanthanides by a factor of 200 relative to lanthanum, while garnets from a rock situated 5 miles away in a more heavily metamorphosed zone are enriched by a factor of 40. This difference is assumed to be due to differences in the temperature of formation of the two garnets.

Work continues on measuring cosmic-ray exposure ages for iron meteorites as samples become available. This involves determination of Ar^{39} in the meteorite by low-level counting and of Ar^{38} by mass spectrometry. The Ar^{38}/Ar^{39} ratio measures the time period during which the meteorite was exposed to cosmic rays. The initiating time for this exposure was the breakup of a large body in space, and the terminating time was the fall of the meteorite to earth. To date, 20 meteorites have been investigated, and 4 have been found to have exposure ages in the range of 5 to 50 million years, at least an order of magnitude lower than the ages of the majority of iron meteorites. This indicates that perhaps 20% of all iron meteorites fall in this group.

Helium, neon, and argon isotopes are produced in extraterrestrial materials primarily by spallation reactions or by radioactive decay of uranium, thorium, or potassium. Rare gases produced by spallation are useful in estimating the length of

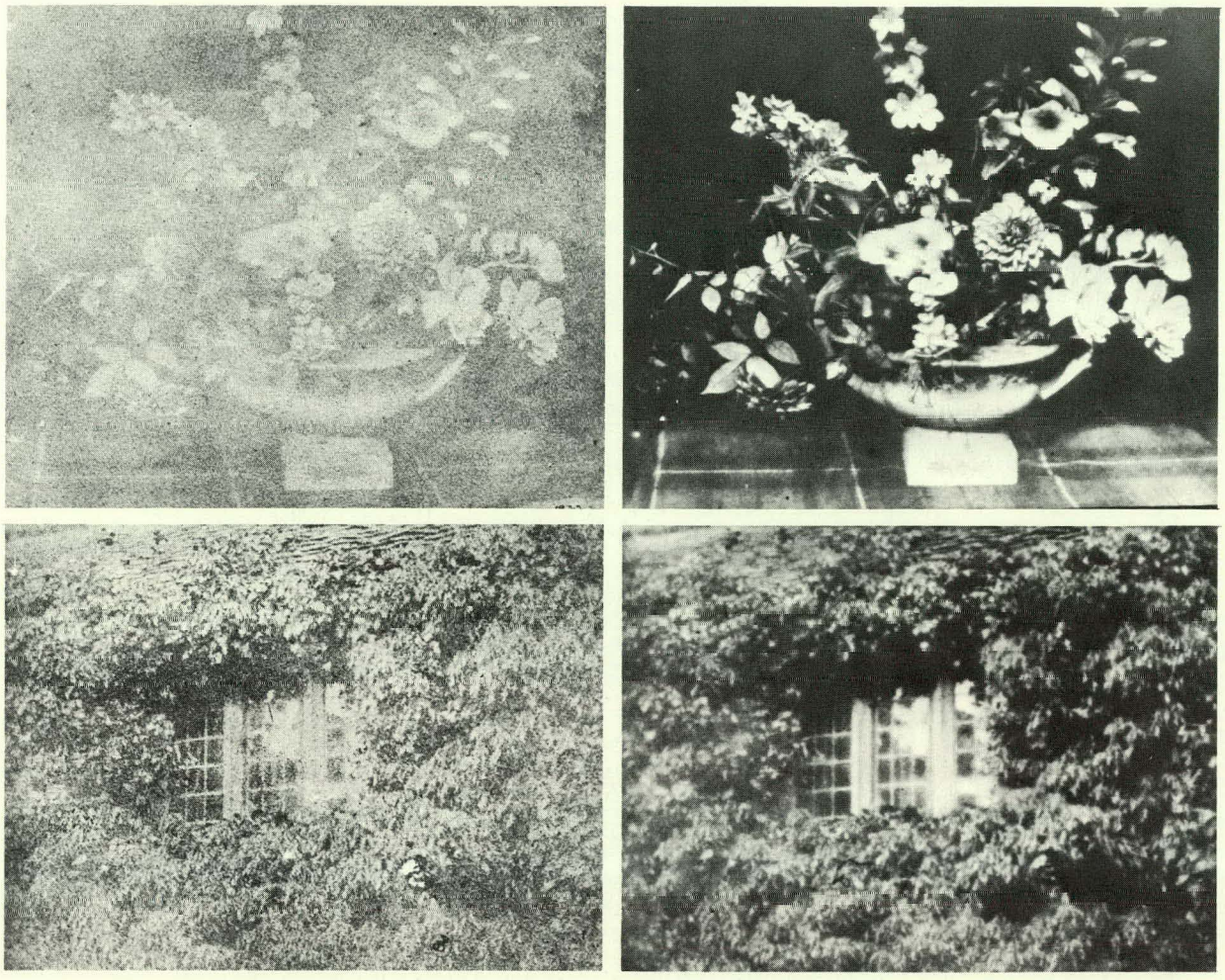


Figure 3. An example of image enhancement by the use of neutron activation followed by autoradiography. At the left are two badly faded Fox Talbot calotype positive prints from the collection of the Smithsonian Institution; the corresponding autoradiographs are at the right.

time that a meteorite has been exposed to cosmic rays, whereas rare gases from radioactive decay are useful in determining the initial time of crystallization of the meteorite parent body. By comparing different rare-gas concentrations in different mineral phases, the thermal history of meteorites subsequent to crystallization can be deduced.

To understand the production and retention of rare gases in meteorites, mass spectrometric analyses were made for helium, neon, and argon isotopes from olivine, pyroxene, and feldspar concentrates of 12 stone meteorites. Concordant K-Ar ages of $\approx 4 \times 10^9$ years have been determined for the mineral separates of all these meteorites. Since Rb-Sr dating has shown that these meteorites differentiated at an age of 4.5×10^9 years, crystallization of the parent body or bodies was completed in $\approx 0.5 \times 10^9$ years. The diffusion of radiogenic argon from these meteorites has not been important since their formation.

Investigation of Art and Archaeological Objects

Neutron activation analysis is a preferred method for the examination of paintings and ancient artifacts because of its nondestructive nature. Solid-state detectors were employed in activation analysis studies of ancient precious-metal objects and some pre-Islamic South Arabian pottery. The high-resolution γ-ray spectra obtainable with these detectors makes it possible to carry out detailed analyses of very minute specimens without resorting to chemical procedures.

Neutron activation is also being used in conjunction with autoradiography to regenerate the images of faded prints and manuscripts.

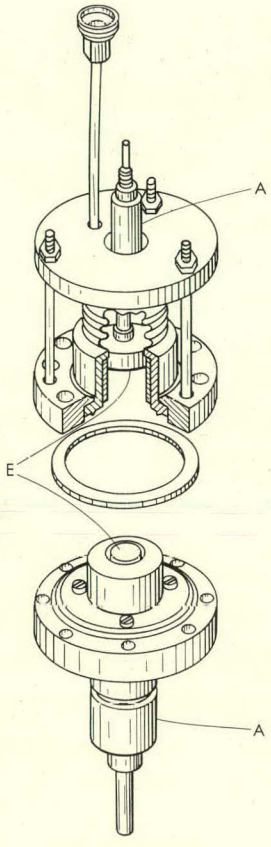


Figure 4. Metal cell for measurement of the conductivity of liquids during irradiation. The electrodes (*E*) are supported by alumina insulators (*A*).

RADIATION CHEMISTRY

The passage of charged particles through matter leaves a track of unstable intermediates which undergo various reactions before ultimately forming stable products. The energy released by the particles is initially deposited at random, but it can eventually produce large changes in minor components of a system, or, in heterogeneous systems, it can migrate across interfaces to other phases.

While much can be learned about the unstable intermediates by studying the behavior of the products under varying conditions, more direct information can be obtained by studying the intermediates themselves. The development of new techniques for the observation of intermediates, some of which are very short-lived, is an important part of this research and often involves the use of intense pulsed electron beams.

The identities and origins of some of the free radicals produced in water radiolysis have been studied. The HO_2 radical, which has a pK of 4.5, was also found to have the acid form $H_2O_2^+$. The radicals were produced either by electron irradiation of water or by the oxidation of hydrogen peroxide with ceric ion in a flow system, and the concentration of the radicals was followed by quenching the surviving radicals with tetranitromethane. The rate constant for radical combination was found to depend on acid concentration below pH 2 as well as above pH 3, and was best interpreted in terms of the association of HO_2 with acid to form $H_2O_2^+$. The pK of $H_2O_2^+$ is 1.0.

Another species was observed in pulsed radiolysis studies of aerated solutions, apparently produced by reaction of the basic form of the hydroxyl radical, O^-, with oxygen. This species exhibited strictly first-order decay and thus is not likely to be the free radical O_3^-; it is probably a dimer, either O_4^{-2} or O_6^{-2}.

Previous studies had indicated that at least part of the hydrogen atom yield in water radiolysis was due to the reactions between hydrated electrons and hydrogen ions taking place as these species diffused out of the spurs in which they were formed. This conclusion was confirmed by the observation that the hydrogen atom yield was reduced in the presence of phosphate ion and hydroxide ion, which react with the hydrogen ion. These studies, combined with calculations based on the diffusion model, indicate that $\simeq$½ of the hydrogen atoms are formed by the diffusion mechanism.

The yield of free ions in liquid (those escaping initial recombination with their partners) has been successfully correlated with a model developed by Onsager which treats the recombination of a pair of ions in terms of the electrostatic forces between them. The model accounts well for the temperature coefficient of the ion yield in hexane and in various solvents of different dielectric constants, if it is assumed that the electron travels about 80 Å from the positive ion before its energy is decreased to that of its surroundings.

In continuing studies of heterogeneous systems, the yield of nitrogen from diazoethane adsorbed on solids and then irradiated was found to decrease with increasing dose. In the case of sodium chloride this effect was found to be correlated with the buildup of color centers. Apparently the defects represented by color centers compete with the diazoethane adsorbed on the surface for the energy deposited in the solid.

HOT ATOM CHEMISTRY

The study of hot atom chemistry or of the chemical effects of nuclear transformations concerns itself primarily with chemical reactions brought about by atoms or molecular fragments having excess kinetic energy. The emphasis in research in this field varies from studies on the nature of the solid state to the use of recoil fragments for preparing labeled compounds.

Work was continued on the simple labeled compounds that result when C^{11}, generated, for example, in the nuclear reaction $N^{14}(p,\alpha)C^{11}$, reacts with various substrates. With mixtures of nitrogen and hydrogen or nitrogen and a hydrocarbon, $HC^{11}N$ was found to be the only detectable nitrogen-containing compound produced by a true hot reaction between C^{11} and nitrogen, and not by some secondary low energy process. This was demonstrated by the addition of increasing amounts of rare-gas moderators to the reactant gas, whereupon the yield of $HC^{11}N$ decreased gradually to zero. These experiments suggest that hot carbon first reacts with N_2 to form $-C^{11}N$, and the latter then abstracts a hydrogen atom from a substrate molecule to form stable $HC^{11}N$.

In analogous studies of mixed systems containing oxygen, the probabilities for the formation of $C^{11}O$ and $HC^{11}N$ were measured. With these probabilities it becomes possible to make a quantitative prediction of the relative yields of other hot products. For example, the ratio of the yields of $C^{11}O$ and $C_2{}^{11}H_2$ calculated by these means was in excellent agreement with the experimental ratio previously found at BNL for oxygen-hydrocarbon systems.

The reactions produced by C^{11} in both gaseous and liquid methylamine were investigated. The mechanisms for the formation of the various products in these systems proved to be analogous to those observed in simple hydrocarbons. Acetylene-C^{11} and ethylene-C^{11} were produced as "fragmentation products" by the decomposition of excited intermediates. "Synthesis products," formed by the addition of one carbon atom plus an appropriate number of hydrogen atoms to a substrate molecule, were ethylamine-C^{11} and dimethylamine-C^{11}. In the liquid phase, the yield of fragmentation products was less, and that of synthesis products more, than in the gas phase, in agreement with the mechanism of de-excitation by fragmentation developed previously. One of the reaction products, labeled acetonitrile, was subjected to degradative analysis. The results imply that its precursor was excited ethyleneimine. It was also shown that reactive intermediates containing C^{11} underwent insertion reactions in C—H bonds more easily than in N—H bonds, in agreement with previous work on pure ammonia done here.

The double-label technique was used in a study of the reactions produced by hot carbon atoms in a series of deuterated alkyl compounds, CD_3CH_2X and CD_3CD_2X (X = F, Cl, Br, I, CF_3, CH_3). These compounds reacted with hot carbon atoms to produce isotopically pure acetylenes, $HC^{11}{\equiv}CH$ or $DC^{11}{\equiv}CD$, and the fraction of hot yield as acetylene-C^{11} was found to increase in the order X = CF_3, F, Cl, Br, I, i.e., in the order of decreasing bond dissociation energy of the C—X bond. This correlation between bond dissociation energy and efficiency of acetylene production supports the hypothesis that in at least some organic systems the course of hot atom reactions is governed primarily by chemical factors, rather than by purely physical factors such as the masses of the interacting atoms and molecules.

Studies continued on the oxidation during γ-irradiation of tracer amounts of thallous ion in-

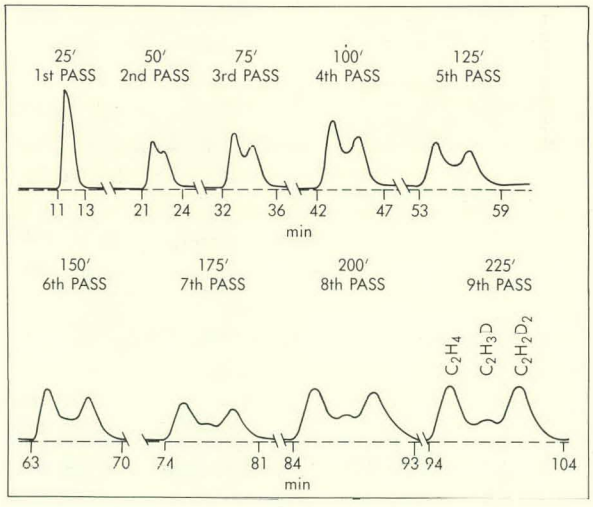


Figure 5. Separation of deuterated ethylenes containing C^{11} by gas chromatography with a silver nitrate–ethylene glycol on firebrick column. The effluent is recycled through the 25-ft column, so that 9 passes are equivalent to a 225-ft column. Acetylene formed in the reaction of C^{11} atoms with deuterated alkyl compounds has been reduced to produce the ethylene analyzed in this way.

corporated in potassium chloride crystals. The extent of oxidation was determined by dissolving the irradiated crystals in water and analyzing for the relative amounts of thallous and thallic ions. The extent of oxidation measured in this way proved to be ½ of that obtained by spectrophotometric measurements of the quantity of thallous ion in undissolved crystals, which suggests that the species produced by γ-irradiation is Tl^{+2}, which undergoes disproportionation to Tl^{+} and Tl^{+3} when the crystals are dissolved. For a given γ dose the fraction of thallium oxidized was found to increase with decreasing thallium concentration, leveling off at about 50% oxidation at the lowest concentrations. These results were independent of the γ dose rate for rates between 1 and 10 mr/hr.

Studies on the chemical fate of Tl^{204} produced by neutron irradiation of several thallous salts showed that the fraction of Tl^{204} appearing as oxidized thallium varies from zero in TlCl to 0.2 in $TlClO_4$. γ-Irradiation of the salts before, after, or during neutron bombardment had no effect on these results. Thermal annealing after neutron irradiation caused complete reconversion to the reduced form. Oxidation may result from internal conversion of the capture γ rays.

The chemical states of Cr^{51} produced by neutron irradiation of several chromium compounds were re-examined. These studies necessitated a detailed investigation of the possible exchange and substitution reactions of the various chromium species. No chromous ion could be found in neutron-irradiated potassium chromate, in contradiction to recent suggestions. Rather, in both potassium and ammonium chromates a large fraction of the reduced chromium was found in the form of a dimer. In the case of hydrated chromic salts, neutron irradiation produced substantial fractions of Cr^{51} in the form of chromous ion as well as dimer, but the values were not reproducible. No well-founded mechanism to account for all these results can yet be proposed.

MOLECULAR AND CRYSTAL STRUCTURE

The High Flux Beam Research Reactor (HFBR) achieved criticality on October 31, 1965, and the start-up program has been completed. By the time this report is issued, operation should have been routine for several months. This unique facility provides significantly more intense neutron beams, which makes it possible to increase resolution, sensitivity, and the rate of data collection. The installation of the joint Chemistry-Physics spectrometers is almost complete. The powder, polarized-beam, and 3-crystal neutron spectrometer units are operative, as well as the automatic x-ray spectrometer. The spectrometer control system, involving a single on-line computer for the nine experimental units, was put into operation, and there are no major problems in the systems program. A number of operating programs are available.

Magnetism

Neutron diffraction is being extensively used to investigate fundamental characteristics of magnetic materials. The interaction of neutrons with an ordered array of atomic magnetic moments gives rise to scattering and a characteristic diffraction pattern quite analogous to the patterns obtained when x rays are scattered from solids. The magnetic pattern is superimposed on the diffraction pattern arising from the nuclear scattering and can be separated from it by appropriate techniques.

During the year the magnetic structure of MnP was determined. MnP has a distorted NiAs structure with a relatively low magnetic moment of 1.3 μ_B per Mn atom. Neutron diffraction measurements confirmed the ferromagnetic structure in the temperature range between 50° and 291°K. At lower temperatures, there is a magnetic modulation in which the four Mn spins of the unit cell are ferromagnetically coupled in pairs across the centers of symmetry and these pairs, in turn, form a spiral.

The intermetallic compound CeBi crystallizes with the rock salt structure. Magnetic measurements made elsewhere showed a complex metamagnetic behavior. Zero-field neutron diffraction measurements indicated a transition at 25°K to an antiferromagnetic structure consisting of ferromagnetic sheets antiferromagnetically coupled. The spins are perpendicular to these sheets. This structure persists until the temperature is lowered to 12°K, when additional magnetic peaks appear in the pattern. These are characteristic of a structure with double layers of ferromagnetic sheets antiferromagnetically arranged. At 4.8°K, both magnetic "phases" are still present and the neutron diffraction data can be analyzed in terms of the coexistence of two magnetic phases with about 75% in the low-temperature form and the rest in the high-temperature one. The transition at 12°K

is marked by a hysteresis, the transition on heating occurring at 14°K.

The system $(Mn_xFe_{1-x})Sn_2$ was further investigated in the iron-rich region. For $x=0.25$, the magnetic structure is that of the high-temperature $MnSn_2$ ($x=1.0$), i.e., ferromagnetic sheets antiferromagnetically coupled. When $x=0.10$ there are additional magnetic diffraction peaks which are characteristic of the magnetic structure of $FeSn_2$ ($x=0$). For $x=0.13$ and 0.16, this "mixed" pattern shows further splitting arising from some modulation of the magnetic structure.

The magnetic structures of $Ca(Cr_xFe_{2-x})O_4$ and $Ca_2(Cr_xFe_{2-x})O_5$ have been studied by means of neutron diffraction as model systems for comparison with theoretical predictions about superexchange. The compound $CaFe_2O_4$ ($x=0$) becomes antiferromagnetic at $\simeq$170°K. The Fe—O—Fe— ... atoms, with a bond angle of 130°, are coupled antiferromagnetically to form chains. These in turn are ferromagnetically coupled through other Fe—O—Fe bonds with a bond angle of 99°. The compound $Ca(CrFe)O_4$ ($x=1.0$) has the same chains, but these are now coupled antiferromagnetically across the 99° bond. This structure exists in the composition range down to $x=0.05$, the compound with lowest Cr content so far examined. The other end member, β-$CaCr_2O_4$ ($x=2.0$), has a complex magnetic structure probably involving noncollinear spins. Below 730°K, $Ca_2Fe_2O_5$ ($x=0$) is antiferromagnetic, with all Fe—O—Fe linkages antiferromagnetic. This structure is retained in the range $0 \leqslant x \leqslant 0.5$.

Magnetic susceptibility measurements provide another tool for the investigation of the electronic structure of materials. These measurements permit very direct comparisons to be made with theoretical calculations of wave functions and energy levels in molecules.

The magnetic susceptibilities of a number of rare-earth thienylfluoroacetylacetonates (TTA's) were measured as a function of temperature. The most interesting one was praseodymium $(TTA)_4$. Analysis for metal, carbon, and hydrogen suggested that it contained Pr^{+4}. However, the magnetic susceptibility measurements over the temperature range 76° to 300°K showed that it had a constant moment of 3.5 μ_B, close to the theoretical value of 3.58 μ_B for Pr^{+3}. An x-ray structure determination of the material indicated the presence of NH_4^+ and/or water of hydration, the former being confirmed by Kjeldahl analysis. The

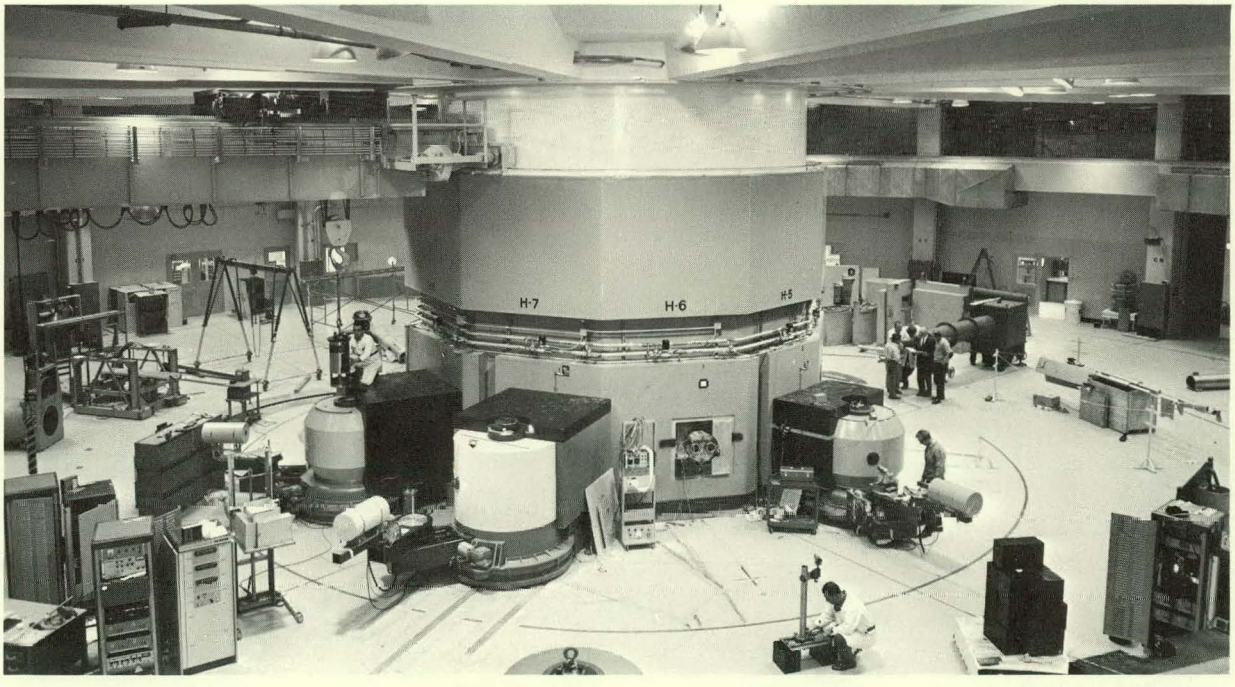


Figure 6. Joint Chemistry-Physics neutron spectrometer installation at the High Flux Beam Research Reactor. Three of the eventual five spectrometers are shown.

over-all structure may be considered as composed of $Pr(TTA)_4^-$ units bound by NH_4^+ and/or H_2O hydrogen bonds. The Pr coordination consists of eight oxygen atoms at the corners of a regular polyhedron that has D_{4h} symmetry. In all the other complexes, the measured susceptibilities are in good agreement with theoretical predictions.

Group theoretical arguments indicate that the magnetic moments of transition metal ions in low-spin states should be given by $\mu=[L(L+1)+4S(S+1)]^{1/2}$, where $L=\pm1$ or 0, as in the case of p electrons. This is restricted to the case of negligible spin-orbit interaction. Several compounds meeting these requirements have been examined and the correspondence with the theoretical value, 3.87 μ_B, is excellent. For example, in the temperature range 76° to 298°K, $K_3Cr(CN)_6$ has a moment of 3.85 μ_B and K_3MoCl_6 has a moment of 3.83 μ_B

Chemical Crystallography

Crystallography provides the best method for the precise and unambiguous determination of molecular structure. In combination with other physical measurements it provides the key to the understanding of chemical bonding and hence of reaction mechanisms, and to the interpretation of spectra. The unique combination of x-ray diffraction, neutron diffraction, and outstanding computational facilities at Brookhaven has made possible broad and comprehensive attacks on significant problems in organic, inorganic, and physical chemistry.

Work on the structure of penta-oxyphosphoranes continued. A structure refinement was completed for a second crystalline form of the compound obtained by the reaction of tri-isopropyl phosphite and phenanthrene-quinone. The molecular structure agrees in all respects with that obtained from a structural study, completed last year, of another crystalline form. The unit cells and space groups of other members of this important class of compounds have been determined in order to select compounds for future structural study.

Dimethyltin difluoride is found to have a structure consisting of infinite planes of tin atoms and bridging fluorine atoms, with the methyl groups perpendicular to these infinite sheets and completing the octahedral coordination of the tin atom.

A structural determination of $K_3Cu(NO_2)_5$ has been almost completed. Five NO_2 groups are bonded to the copper atom, but not all through the nitrogen atom, and lie at the corners of a distorted trigonal bipyramid. The structure as a whole consists of closest packed ions, with the potassium ions in the tetrahedral and octahedral holes.

The structure of iron maleonitrilediethiolate has been determined. Each iron atom is coordinated to five sulfur atoms at the corners of a square pyramid. These pyramids share edges in such a way that the molecular structure can be described as a dimer in which two sulfur atoms form bridges between the iron atoms.

Neutron diffraction of polycrystalline samples has been used to study the structures of $NOPtF_6$, $NOIrF_6$, O_2AsF_6, and O_2SbF_6. These structures are isomorphous with that of O_2PtF_6 reported last year. These compounds exhibit disorder of the O_2^+ and NO^+ ions, and it has been impossible to obtain precise values of the bond lengths in the cations. Nevertheless, the data for all the compounds are consistent with formulation as A^+B^-.

The structures of both the paraelectric and ferroelectric phases of ammonium sulfate have been refined from single-crystal neutron diffraction data. The transition from the paraelectric to the ferroelectric phase is not an order-disorder transition but is involved with a reorientation of the ammonium groups to form somewhat stronger but less symmetric hydrogen bonds in the ferroelectric phase. There is little change in the sulfate ion geometry in going from one phase to the other.

The hexagonal phase of ammonium fluosilicate has been examined. This is a disordered structure involving the reflection of the ammonium ion through a pseudo-mirror plane. At room temperature there is so much thermal motion of the ammonium ion that it has proved impossible to obtain a sensible refinement of the structure in terms of the usual ellipsoidal approximation of thermal motion.

Neutron diffraction data from cubane, a cage hydrocarbon, have been obtained and refined. The positions of the carbon atoms agree well with those obtained in an x-ray diffraction study elsewhere, while the C—H bond lengths are normal. The precise thermal parameters have been analyzed to obtain not only the rigid-body vibrational parameters of the cage but also the internal modes involving the hydrogen atoms.

The structure of 2,2′-biphenyldisulfide has been determined. The C—S—S angles are $\approx$90°. This forces the two phenyl rings out of a coplanar configuration, with a dihedral angle of $\approx$60°.

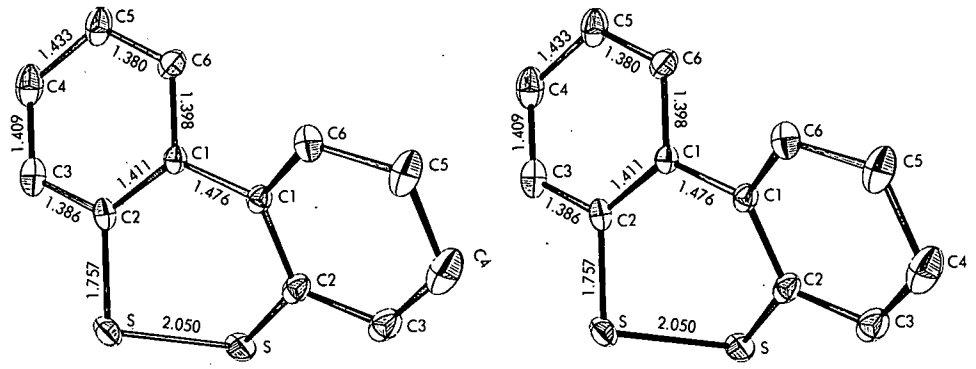


Figure 7. Molecular structure of 2,2′-biphenyldisulfide, shown in a stereographic projection which was computed and drawn by a digital computer and associated plotter. The stereo pair can be viewed with a small, hand-held stereoscope, or by holding the page a few inches from the eyes and placing a card perpendicular to the paper between the two projections.

Mössbauer Spectra

The structure of a binuclear ferric phenanthroline chloride complex was deduced from a combined Mössbauer and radiochemical study. Two of the four chloride ions in the complex were shown to be kinetically inert. The structure deduced is one in which each iron is octahedrally coordinated to two phenanthroline groups, with an oxygen atom forming a bridge between two iron atoms, and a chloride atom *trans* to the oxygen.

Calculations were made for the electric field gradients encountered in metal complexes of a wide variety of geometries, including all the geometrical isomers possible for various ratios of two types of ligands. These calculations were used to interpret Mössbauer spectra obtained here and elsewhere.

ISOTOPE EFFECTS

Calculations of Equilibrium and Kinetic Isotope Effects

The theoretical treatment of isotope effects rests on a rigorous statistical mechanical foundation. In practice, however, it is necessary to search for suitable approximate methods. An approach of great utility has been the use of an appropriate polynomial expansion of the reduced partition function. The expansion was previously done by means of a Bernoulli series, in terms of a variable proportional to the isotopic shift in vibrational frequency and inversely proportional to the temperature. A new expansion in terms of Chebyshev polynomials has been developed recently. This reduces to the Bernoulli expansion in the region where the latter converges, but extends the validity of conclusions based on the polynomial expansion to larger values of the variable, i.e., to higher frequencies or lower temperatures.

A theoretical investigation of the origin of secondary β-hydrogen isotope effects in terms of hyperconjugative models has produced satisfactory results for reactions forming carbonium ions. This study has now been extended to reactions in which alkyl and substituted-alkyl radicals are produced. The results again compare favorably with the very limited experimental data available: although the effect predicted for the ion reactions was $\approx$14% per deuterium atom compared to 10 to 15% observed for pure S_N1 reactions, the effect predicted for the ethyl radical was about 5%, and that for the α-phenylethyl radical was $\approx$3%. The latter value was found to correspond quite well with the experimental effect observed subsequently at this Laboratory.

Vapor Pressures of Isotopic Species

Differences in vapor pressures between the isotopic varieties of a substance yield information about the nature of intermolecular forces in the condensed phase, changes in the intramolecular forces (chemical bonding) on condensation, and the nature of molecular motions in the condensed phase. Isotopic differences in vapor pressure were measured at BNL for molecules of different structural types. A number of new phenomena associated with hindered molecular rotation and coupling of rotation with translation and intramolecular vibrations were demonstrated.

During the year considerable effort was devoted to the quantitative understanding of the symmetry-governed rotation-vibration coupling discovered a few years ago in liquid ethylene. Measurements of vapor pressures are required with a precision of a few microns in a pressure range below 100 mm Hg. Such a measurement was achieved for ethylene-d_4 by the adaptation of quartz spiral Bourdon gauges. These new measurements definitely show that a theory using the harmonic approximation does not predict vapor pressures quantitatively. Theoretical and experimental studies based on an anharmonic model were begun. The experiments will require new measurements in a low pressure range for the various deuteroethylenes as well as molal volume data at corresponding temperatures.

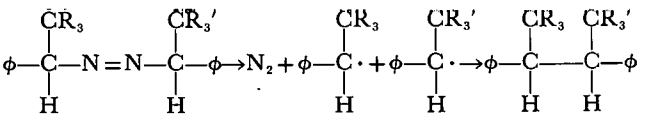
A new type of molecular structural effect on vapor pressure was found during the past year. It is known that most hydrocarbons show the cross-over phenomenon, i.e., at temperatures below the cross-over point, the light isotopic species is the more volatile (normal behavior), and above the cross-over point the heavy species is the more volatile. The cross-over temperatures of CH_3D and CH_2D_2 are 97.7° and 92.0°K respectively, and liquid CHD_3 has a higher vapor pressure than CH_4 down to the triple point ($\approx$90.7°). The existence of a new type of structural effect was recognized in experiments of column distillation of tracer CH_3T, which showed that the cross-over point of CH_3T is about 103.7°K, i.e., $\approx$12° higher than that of CH_2D_2, which has the same molecular weight. This large effect is predicted by the structural theory of isotope effects in condensed media and is associated with the hindered rotation in liquid methane and the difference in the effect of the polarizability on bonds.

The Equilibrium Constant of the Reaction $H_2O + D_2O \rightleftharpoons 2HDO$

A detailed experimental study of this equilibrium constant has been carried out with use of especially designed sample-handling systems and precise mass spectrometric techniques. The value obtained for the equilibrium constant at 0°C, 3.74 ± 0.02, is slightly lower than the value 3.85 obtained by a statistical mechanical calculation using the harmonic oscillator approximation. It is in clear disagreement with the results (values as low as 3.44) of more elaborate calculations reported in the literature, which take into consideration anharmonicity of vibrations. Theoretical work has shown that the usual method of treating anharmonicity effects is inadequate. Preliminary calculations using a more complete method give a theoretical value in good agreement with the experimental value.

Kinetic Isotope Effects and Organic Reaction Mechanisms

Other workers have shown that a 10 to 20% decrease in the rate of carbonium ion formation occurs when a hydrogen atom beta to the site of reaction is replaced by a deuterium atom. This appears to be caused by hyperconjugation in the transition state. The role of hyperconjugation in the stabilization of radicals was studied in the thermal decomposition of the species designated Ia and Ib in reaction (1). The isotope effect has the value $k_H/k_D = 1.018 \pm 0.001$ per atom of deuterium. Machine



I II (1)

a: R=R′=H
b: R=R′=D

a: R=R′=H
b: R=H, R′=D
c: R=R′=D

calculations indicated that ¼ of this effect can arise simply from the increased mass of the separating radicals without changes in the force constants involving the protons of the methyl group. Hence hyperconjugation in this system seems to be relatively unimportant as a factor in the stabilization of the radical. The principal factor appears to be interaction with the π-system of the ring.

A novel method was used to determine the cage effect in reaction (1). A mixture of equal quantities of deuterated (Ib) and nondeuterated (Ia) azo compounds was allowed to decompose, and the relative quantities of compounds IIa, IIb, and IIc in the products were determined by mass spectroscopy. The deviations of these ratios from a random distribution allowed a calculation of the cage effect, which would increase the probability of recombination for fragments from the same molecule. A factor other than the cage effect may

cause deviation from random distribution in general measurements of this type, namely, differences in the rates of decomposition of a pair of similar molecules such as Ia and Ib. In the present case, this factor was shown to be negligible by calculations of the deviation as a function of the ratio of rate constants. The value obtained by this new method serves as a check on the chemical scavenger method, the one most often employed to study cage effects.

In collaboration with the Rutgers group, C^{13} and O^{18} isotope effects in the solvolysis reaction (2) were determined at BNL by mass spectrometric analysis of carbon dioxide liberated in the reaction.

$$\phi_3P^+CH_2\text{—}\underset{\text{III}}{\overset{\overset{O}{\|}}{C}}\text{—}O\text{—}R \xrightarrow[Ac_2O]{AcOH} \phi_3P^+CH_3Br^- + CO_2 + ROAc \quad (2)$$

a: $R = \phi_2CH$—

b: $R = CH_3(CH_2)_7$—

c: $R = CH_3(CH_2)_5\text{—}\underset{|}{C}HCH_3$

The striking result found was that for IIIa, $k_{12}/k_{13} = 1.045$ and $k_{16}/k_{18} = 1.015$, while for IIIb and IIIc, $k_{12}/k_{13} = 1.020$ and $k_{16}/k_{18} = 1.000$. This suggested that two different mechanisms operate. The changes in force constants necessary to produce these observed isotope effects were investigated by means of calculations involving the "cut-off" procedure. It was found that IIIa probably solvolyzes by rupture of the

$$CH_2\text{—}\overset{\overset{O}{\|}}{C}$$

bond, with simultaneous rupture or loosening of the O—R bond. For compounds IIIb and IIIc, the C^{13} and O^{18} effects can be accounted for by a mechanism consisting of the sequence of reactions (3) to (6).

$$\phi_3P^+CH_2\text{—}\overset{\overset{O}{\|}}{C}\text{—}OR + CH_3CO_2H \rightleftharpoons \phi_3P^+CH_2\text{—}\overset{\overset{H}{|}}{\underset{\underset{O\diagdown\!\!\diagup C\text{—}CH_3}{|}}{\overset{\overset{O}{|}}{C}}}\text{—}OR \quad \text{fast (3)}$$

$$\phi_3P^+CH_2\text{—}\overset{\overset{H}{|}}{\underset{\underset{O\diagdown\!\!\diagup C\text{—}CH_3}{|}}{\overset{\overset{O}{|}}{C}}}\text{—}OR \rightarrow \phi_3P^+CH_2\text{—}\overset{\overset{O}{\|}}{C}\text{—}O\text{—}\overset{\overset{O}{\|}}{C}\text{—}CH_3 + ROH \quad \text{slow (4)}$$

$$ROH + Ac_2O \rightarrow ROAc + AcOH \quad \text{fast (5)}$$

$$\phi_3P^+CH_2\text{—}\overset{\overset{O}{\|}}{C}\text{—}O\text{—}\overset{\overset{O}{\|}}{C}\text{—}CH_3 + AcOH \rightarrow \phi_3P^+CH_3 + CO_2 + Ac_2O \quad \text{fast (6)}$$

It should be noted that the isotope effects in steps (3) and (4) partially cancel each other. The calculated over-all isotope effect, a combination of the separate isotope effects of the two steps, compares favorably with the experimental results.

PHYSICAL CHEMISTRY

Inorganic Reactions in Solution

Work on inorganic reactions in solution includes studies of reaction kinetics, with emphasis on substitution and oxidation-reduction reactions, and studies of equilibrium systems, with emphasis on complex ion and solvent extraction equilibria.

The unstable, sulfur-bonded thiocyanate complex of Cr(III), $CrSCN^{+2}$, was prepared by allowing Cr(II) to react with stable nitrogen-bonded thiocyanate complexes of Fe(III) and Co(III). A characteristic reaction is

$$FeNCS^{+2} + Cr^{+2} \rightarrow Fe^{+2} + CrSCN^{+2}.$$

The complex $CrSCN^{+2}$ reacts with Cr(II) to form the stable nitrogen-bonded isomer $CrNCS^{+2}$ according to the reaction

$$CrSCN^{+2} + Cr^{+2} \rightarrow Cr^{+2} + CrNCS^{+2}.$$

In the absence of Cr(II), $CrSCN^{+2}$ undergoes aquation and spontaneous isomerization. Chlorine converts $CrSCN^{+2}$ to $CrCl^{+2}$, but it converts $CrNCS^{+2}$ to Cr^{+3}. The linkage isomers also differ in their reactions with Hg(II): $CrSCN^{+2}$ and $CrNCS^{+2}$ react with Hg^{+2} to give Cr^{+3} and $CrNCSHg^{+4}$, respectively.

The kinetics of the oxidation of ferrocyanide ion by chlorine and hypochlorous acid were studied. Chlorine reacts much more rapidly with ferrocyanide than hypochlorous acid does. This result may be contrasted with the behavior of these oxidizing agents towards ferrous ions. It has previously been shown at BNL that ferrous ions react much more rapidly with hypochlorous acid than with chlorine. The oxidation of ferrocyanide proceeds via the formation of a short-lived intermediate, $Fe(CN)_6Cl_2^{-4}$, whose rate of decay is accelerated by ferricyanide ions.

The kinetics of formation of the mono-oxalate complex of Fe(III) were studied. The reaction is

$$Fe(H_2O)_6^{+3} + \begin{matrix} O-C=O^{-2} \\ | \\ O-C=O \end{matrix} \rightarrow (H_2O)_4Fe\begin{matrix} O-C=O^{+} \\ | \\ O-C=O \end{matrix} + 2H_2O\,.$$

The results show that the rate of formation of the complex is primarily determined by the rate of loss of a water molecule coordinated to the Fe(III). The loss of the second water molecule required for the closing of the chelate ring occurs relatively rapidly. The stability of $FeOOCCOOH^{+2}$ determined in the course of these studies is lower than that reported by other workers.

In studies of the extraction of thallic chloride with mixtures of tributyl phosphate (TBP) and hexane, earlier estimates of the stability constants of $TlCl_3$ (K_3) and $TlCl_4^-$ (K_4) at $I=0.50$ M, 25°C, were confirmed. New measurements were made at $I=1.50$ M and 3.00 M, and K_3 and K_4 were determined. The extraction of $HTlCl_4$ was shown to be small compared to that of $TlCl_3$; it becomes appreciable at HCl concentrations a few tenths molar and higher, when the TBP concentration is >5 vol %. $HTlCl_4$ is solvated by three molecules of TBP in the organic phase, $TlCl_3$ by two. The extraction of thallic chloride with methylisobutyl ketone (MIBK) has been systematically investigated. No evidence for the extraction of $TlCl_3$ has been found. With pure MIBK the main extracted species appear to be H^+_{solv} and $TlCl_4^-$. With MIBK-hexane mixtures, the undissociated acid $HTlCl_4$ is also present, and its dissociation constant in the organic phase is determined from the extraction data. Concurrently, the extraction of perchloric acid and its dissociation in the organic phase have been investigated.

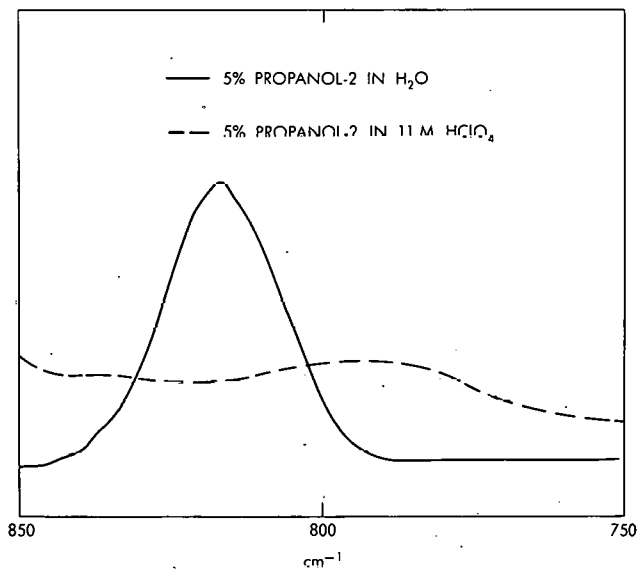


Figure 8. Raman spectra of 5% solutions of 2-propanol in water and in concentrated perchloric acid, showing the band used to determine the concentration of unprotonated alcohol.

Measurements of the protonation of methanol and 2-propanol in strong aqueous acids were made by means of Raman spectroscopy. The concentration of unprotonated alcohol was determined by measuring the intensity of a band that was shown to disappear in very concentrated acid solutions. Methanol was studied in hydrochloric acid solutions, while 2-propanol could be studied in both hydrochloric and perchloric acid. The results indicate that these alcohols are 50% protonated (i.e., $[ROH_2^+]/[ROH]=1$) when the acidity function of the medium is −4.8 to −5.0. This estimate of the pK of the alcohol is about 2 pK units lower than previously determined values that depend upon rate constant measurements. It is also lower than previous Raman determinations made in sulfuric acid would indicate. However, the experiments in the latter case are complicated by the fact that there is a very strong band due to sulfate in the same spectral region as the alcohol band.

Ion-Molecule Reactions

Work on ion-molecule reactions during the course of the year has cleared up a long-standing difficulty in the field. It has been demonstrated that, contrary to the prevailing view, the Gioumousis-Stevenson theory, which is known to describe accurately the rates of ion-molecule reactions as a function of ion velocity in the case of elementary reactions such as

$$Ar^+ + H_2 \rightarrow ArH^+ + H\,,$$

also gives an accurate account of more complicated reactions of the type

$$CH_4^+ + CH_4 \rightarrow CH_5^+ + CH_3\,. \qquad (1)$$

The theory, attractive by virtue of its simple assumptions that the cross section for an ion-molecule collision is correctly given by Langevin's classical mechanical expression and that reaction occurs at every collision, expresses the reaction

cross section as a linear function of $1/v$, where v is the ion velocity.

The prevalent view that the theory is inadequate to account for complicated reactions is based on extensive measurements of the rate of reaction (1) at several different laboratories, all apparently showing that the measured rates were lower than predicted by theory and had a different functional dependence on ion velocity. In all these experiments the cross section for the reaction between CH_4^+ and CH_4 was computed from the observed rate of CH_5^+ production on the assumption that reaction (1) is the only possible reaction path, the assumption being justified by the argument that CH_5^+ in its ground state is energetically incapable of dissociating.

The Brookhaven work shows that some of the CH_5^+ is produced in excited states from which dissociation is energetically possible. In addition to reaction path (1), there is the reaction path (verified by experiments with deuteromethanes)

$$CH_4^+ + CH_4 \rightarrow \text{excited } CH_5^+ + H_2 . \qquad (2)$$

Thus, the cross sections based on measurement of the rate of production of CH_5^+, which neglect the excited CH_5^+, are necessarily low. In addition, they have the wrong functional dependence on CH_4^+ velocity because of the nature of the velocity dependence for the production of CH_5^+ in its various excited states. When the reaction cross-section measurement was based on observation of the rate of disappearance of CH_4^+, which takes both reaction paths into account, the experimental cross sections agreed accurately with the theoretical ones.

Some details of the production of excited CH_5^+ in the $CH_4^+ + CH_4$ reaction have been unraveled. The sources of the required energy are the vibrational energy of excited CH_4^+, always present to some extent in the ion beam, and the kinetic energy of sufficiently fast CH_4^+ ions. It appears that the conversion of kinetic energy to vibrational energy in the present reaction is more efficient than in other reactions studied at Brookhaven.

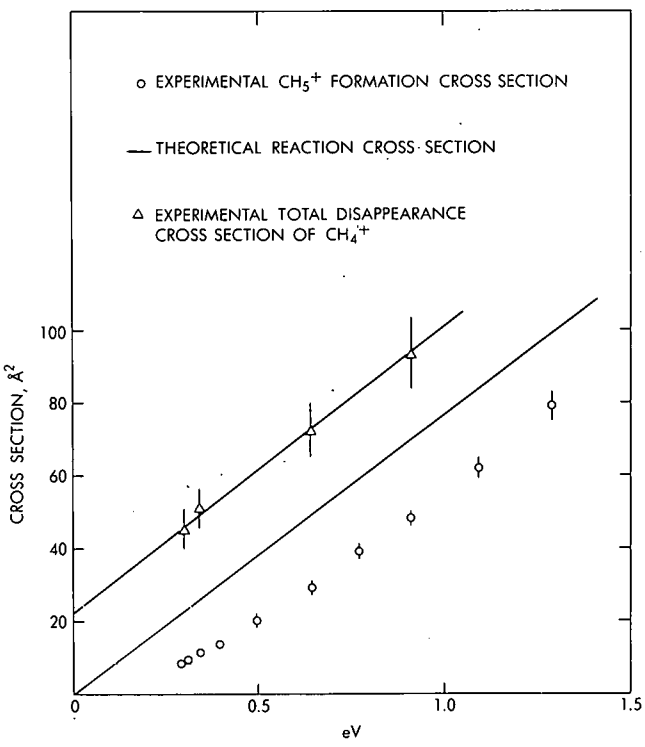


Figure 9. Reaction cross sections as a function of energy in the CH_4-CH_4^+ system. The straight line through the origin represents the theoretical Langevin cross section. Experimental points for total reaction of CH_4^+ (triangles) have the same slope as the theoretical line. The nonzero intercept is due to ion losses in the spectrometer analyzer tube. The cross section for CH_5^+ formation (circles) is only a fraction of the total cross section for CH_4^+ reaction.

Kinetic Studies of Hydrogen Atom Reactions

A new method developed at Brookhaven for the determination of small concentrations of hydrogen atoms in the gas phase makes use of the extremely strong absorption of the Lyman-α resonance line at 1216 Å. This line is generated by dc discharge in a mixture of a few percent of hydrogen in a rare gas at a total pressure of a few torr and is detected by an ion chamber filled with a mixture of nitric oxide and argon. Both source and detector are fitted with LiF windows that transmit in the vacuum uv region. About 90% of the photocurrent through the detector (measured with a micro-microammeter) is produced by 1216-Å radiation. With this very simple arrangement, it is possible to detect hydrogen atom concentrations of 10^{11} atoms/cc.

A flow system incorporating this detection device was used to study rates of the reactions between hydrogen atoms (generated by microwave discharge) and ethylene or acetylene. In both cases the reaction is first order with respect to each reactant. In the reaction with ethylene, a dependence on inert gas pressure was found which

can be related to the competition between decomposition of the ethyl radical formed and its deactivation by collision:

$$H + C_2H_4 \rightleftharpoons C_2H_5^*, \quad C_2H_5^* + M \rightleftharpoons C_2H_5 + M .$$

Classical Calculations on Energy Transfer

Computer calculations on classical translational-vibrational energy transfer have been continued. These calculations have further demonstrated the inadequacy of the various approximation procedures devised to deal with such processes. Programs have now been written to do calculations for 3-dimensional processes, which will involve translational-vibrational-rotational energy transfer, and some preliminary results have been obtained.

Theoretical Organic Chemistry

The research in theoretical organic chemistry is concerned with the structures and reactivities of organic systems. The methods of attack include linear free energy (LET) relationships of the Hammett-Taft type as well as semiempirical quantum mechanical calculations by the LCAO†-MO method. Attempts are being made to interrelate the two approaches with the hope of providing quantum mechanical bases for the LET relations.

The theoretical and statistical studies of the effect of substituents on the reactivities of disubstituted benzenes were extended to larger and more complicated aromatic molecules. The statistical treatment involves nonlinear least-squares analysis of reactivity data to fit a dual substituent LET equation of the Taft type, i.e., $\log k/k_0 = \rho_I\sigma_I + \rho_R\sigma_R$. Various models for transmission of electronic effects may be incorporated in this equation in the form of mathematical constraints upon the parameters, mainly the ρ's. Alternatively the parameters can be determined statistically, with essentially no constraints, and the results used to judge the adequacy of proposed models. With the latter approach, which minimizes bias, preliminary results on several naphthalene, quinoline, and isoquinoline reactivities indicate that satisfactory fittings are possible in terms of the dual substituent equation. Further, and more important, the unbiased inductive effects reflected in ρ_I are found to be distinct functions of the position of substitution and to conform very closely to the position dependence predicted by the Kirkwood-Westheimer model for ion-dipole interactions. The resonance effects as reflected in ρ_R are likewise found to be in satisfactory agreement with accepted resonance–polar transmission models. Further applications of the method are under investigation.

The Pariser-Parr-Pople LCAO-MO method for alternate hydrocarbons has been subjected to closed-form analysis to determine the self-consistent-field effects upon wave functions for various neutral and ionic molecular species. The results of this investigation are of interest in applications to various direct properties such as charge densities and bond orders, and to derivative properties such as ionization potentials, electron affinities, and uv spectra. They will ultimately be used in the construction of semiempirical molecular orbital (MO) programs for other organic molecules and inorganic molecules. The utility of this approach will lie mainly in the semiempirical derivation of various parameters for heteroatoms. In the same connection, integral programs that have been constructed and already used will be generalized for use in the organic and inorganic-molecule MO program.

Quantum Theory

A projection-operator formalism was developed for treating collision problems and was applied to the problem of rotational excitation in the collision of slow electrons (2 to 3 eV) with nitrogen molecules. It was found that two processes may be distinguished: direct rotational excitation, in which the electron moves in the field of the molecule in its ground electronic state; and resonance rotational excitation, in which higher electron states of the molecule enter. Interference between the two processes is possible. By using this theory and with the help of semiempirical values for the electronic resonance energy and the width of the appropriate compound state, it was possible to obtain the experimentally observed positions of the peak maxima and minima in the multipeak cross section for electron scattering by N_2.

In another theoretical study, a method was developed for modifying approximate wave functions by application of "weighting operators" that weight the wave functions differently at different

†Linear combination of atomic orbitals.

points of configuration space without significantly affecting energy values computed with use of the unmodified wave functions. One advantage of this method is that, within the framework of double perturbation theory, it provides a means of calculating expectation values of operators other than the energy with first-order accuracy. This is frequently not possible in standard double-perturbation theory. In addition, the weighting-operator method provides a rule for making the best selection from a set of proposed forms of approximate wave functions.

High Energy Accelerators

The Accelerator Department is charged with the responsibility of operating, maintaining, improving, and exploiting the two major high energy research facilities at Brookhaven, the 3-BeV Cosmotron and the 33-BeV Alternating Gradient Synchrotron (AGS). It is also responsible for advanced accelerator development programs and the design, fabrication, and operation of experimental community property including beam separators, electronic scalers, and magnets.

In order to carry out the Department's program more effectively, five organizational divisions were created: the AGS Division, the Experimental Planning and Support Division, the AGS Conversion Division, the Advanced Accelerator Development Division, and the Cosmotron Division. The program and activities of each Division are summarized in the following sections.

ALTERNATING GRADIENT SYNCHROTRON

The past year was outstanding in several respects. General performance of the AGS improved to such an extent that during the latter part of the year the weekly average intensity was consistently in excess of 10^{12} protons/pulse. The addition of a second external beam system, serving the North Experimental Area, resulted in an increase in the scope of the research program. Further, because of the higher beam intensities, radiation damage to components became a significant operational factor and accounted for a relatively large amount of AGS downtime.

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

Operation

The performance of the AGS continues to improve with respect to both beam intensity and running time available for experiments in high energy particle physics. This trend is evident from the following tabulation.

	Fiscal 1965	Fiscal 1966	
	2nd half	1st half	2nd half
High energy physics, percentage of scheduled time	54.2	64.3	68.6
Beam intensity, av	6.1×10^{11}	7.9×10^{11}	10.2×10^{11}

During the first half of the fiscal year AGS downtime due to component failure was significantly reduced. However, because of radiation damage resulting from the consistently improving beam intensity, the failure rate increased during the second half. The failures were mainly related to vacuum "O" ring deterioration and magnet cooling hose ruptures in areas adjacent to the target locations. Gradual replacement of organic compound "O" rings by metal "O" rings and replacement of the magnet cooling hoses by metal pipes should reverse the trend in machine failure.

As a result of better over-all performance of the linear accelerator (linac) and improvements in the AGS rf system, together with precise orbit control, the average AGS intensity increased significantly. The highest weekly average was $>1.3\times10^{12}$ protons/pulse.

The addition of the fast external beam for the North Experimental Area made it possible to use a zero degree secondary beam from an external target located near the I-10 straight section for the 80-in. bubble chamber. This facility is now routinely used to supply two beam bunches to the external target while simultaneously providing protons during a machine flat-top to two internal targets in a sharing mode. An earlier fast spill for the F-10 target is also possible.

The main magnet power supply operated in a very satisfactory manner during the year. A total of $\approx7.5\times10^{6}$ magnet current pulses were produced. The only failure of significance was due to a shorted coil in the series inductor.

General radiation exposure of AGS personnel was ≈20% higher during the first quarter of fiscal 1966 than during the first quarter of fiscal 1965. Comparisons were made by considering the num-

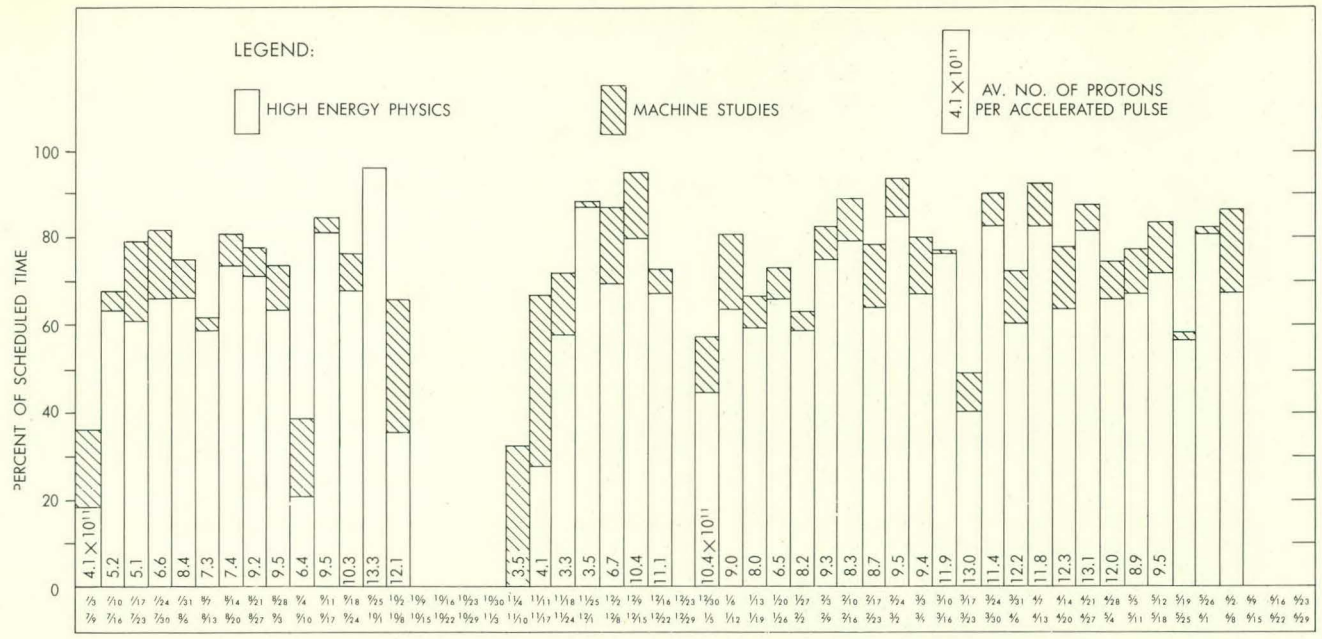


Figure 1. Utilization of the Alternating Gradient Synchrotron for high energy physics and machine studies.

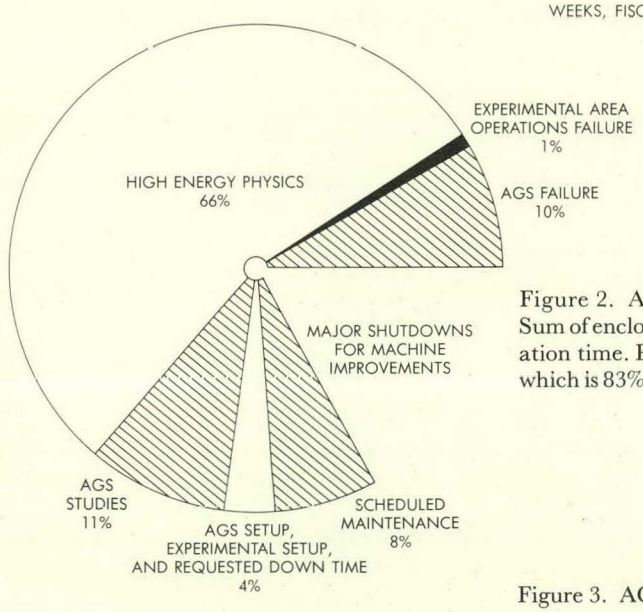
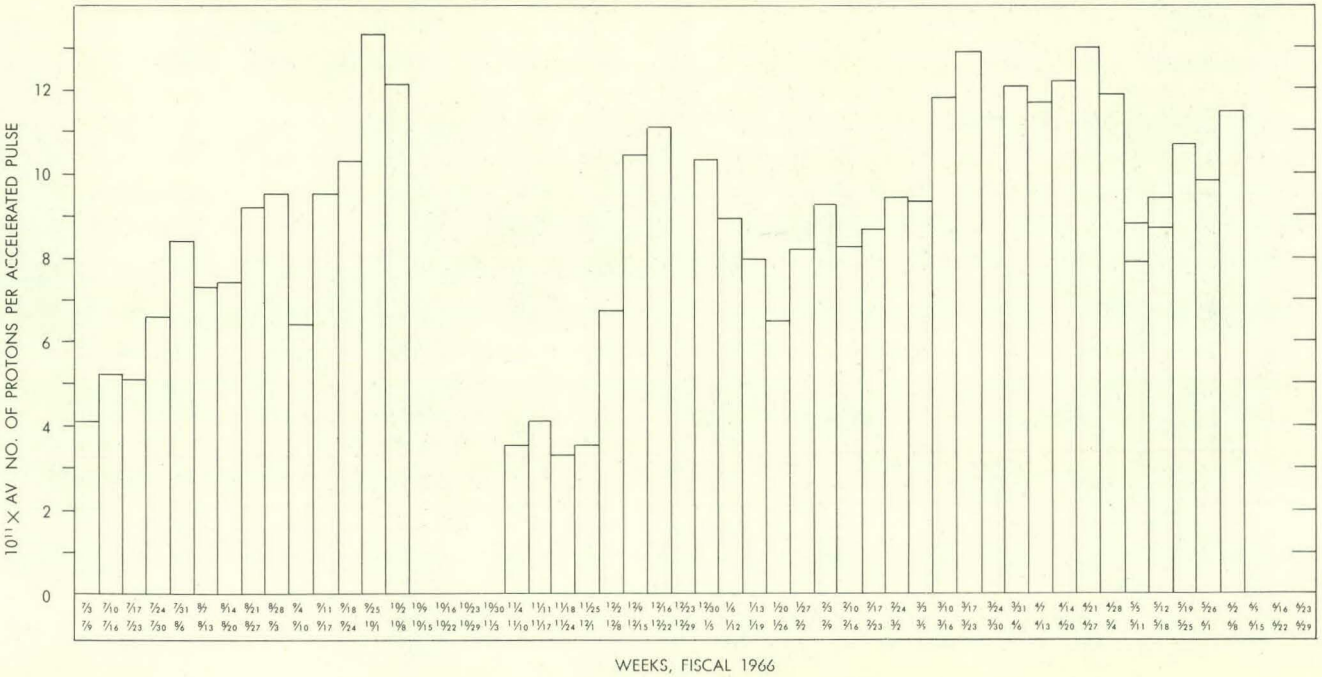


Figure 2. AGS utilization during fiscal 1966. Sum of enclosed areas represents scheduled operation time. Percentages refer to scheduled time, which is 83% of maximum possible running time.

Figure 3. AGS performance during 1966, weekly average beam intensity.



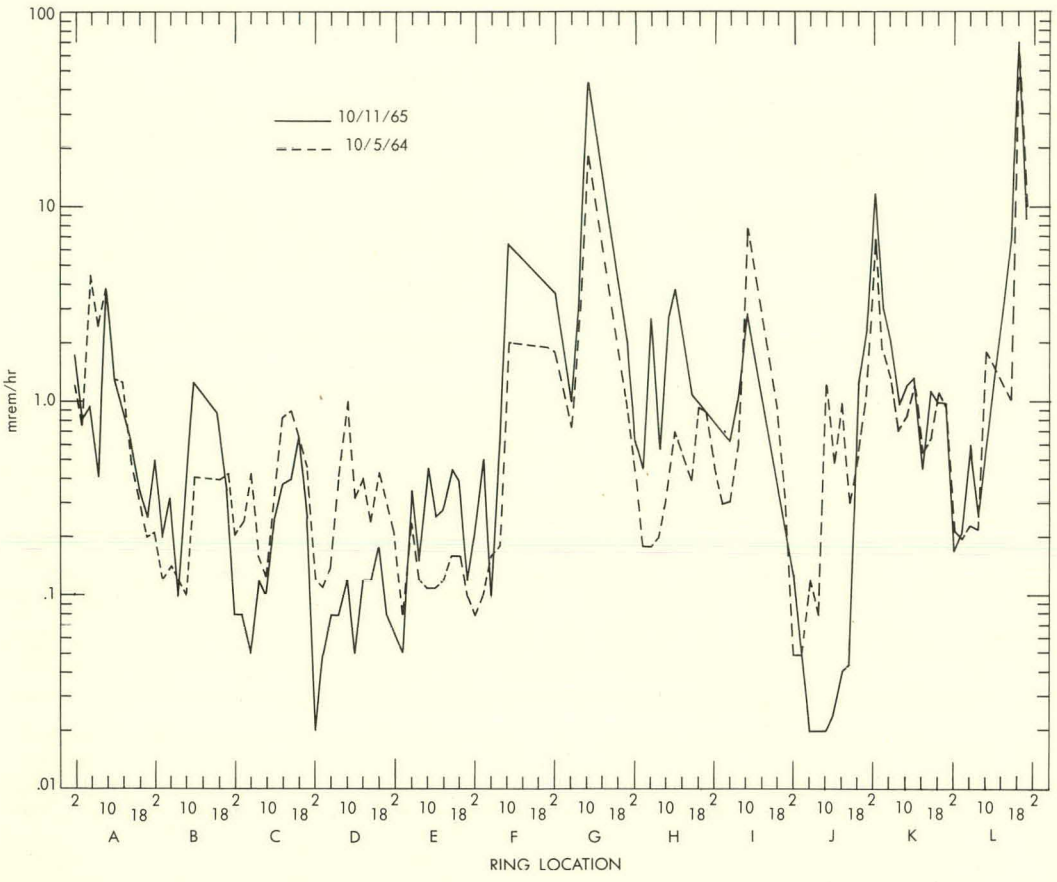


Figure 4. Residual radiation levels in the AGS ring 7 days after machine shutdown measured at a radial distance of 2 meters from the vacuum chamber.

ber of persons exposed in an ascending range of exposure levels. Six exposure levels, ranging from 0 to 2000 mrem, were established. Exposures at the three lower levels (<500 mrem) were not materially different during the two periods under consideration. The number of persons exposed to a level of 500 to 1000 mrem increased by $\approx$1.5, and the number exposed to a level of 1000 to 1500 mrem increased by a factor of 6. Three persons received exposures in the range 1500 to 2000 mrem during the 1966 period, whereas none received an exposure in this range during the comparable period in 1965. Continuous efforts are being made to reduce the individual exposure levels, mainly by training additional personnel for specific tasks. In addition, increasing use is being made of automated apparatus. An example is the programmed transfer mechanism for target interchange, which has performed reliably and made it possible to reduce personnel exposure. As a consequence of the higher beam intensities, routinely accelerated residual radiation levels within the magnet enclosure are increasing (see Figure 4). Ion chamber measurements were made at a radial distance of 2 meters from the vacuum chamber at the downstream end of every even-numbered magnet. Comparisons were made of results obtained 7 days after the start of the October 1964 and the October 1965 shutdown periods. In general, an increase in residual radiation levels was noted, those in the vicinity of the major target areas being higher by a factor of two.

Accelerator Studies

An appreciable number of studies were again devoted to achieving higher beam intensities in the AGS. The highest intensity obtained so far is 2.1×10^{12} protons/pulse. The weekly average beam intensity is of the order of 1.3 to 1.4×10^{12} protons/pulse. Thus the AGS routinely runs close to

the maximum obtained value. Fast switches operating in 1 μsec instead of 150 μsec were designed for the low-level rf system and improved the bunching factor and phase oscillation amplitudes at the beginning of the rf cycle. Preliminary tests of adiabatic capture were made, and the results appeared to substantiate theory. The application of sine and cosine 17 θ gradient correction proved successful and demonstrated that the half-integral stopband could be corrected with very high precision. This suggests that very large incoherent shifts in ν values due to space charge may not lead to beam blowup, and the AGS may be expected to exceed the present peak intensity.

Other intensity effects are expected to become serious as the intensity increases. One such effect is the occurrence of coherent oscillations. The growth of coherent vertical oscillations was observed for the first time in the AGS when a poor vacuum pressure existed in certain sections of the ring because of ramming of the ejector magnets of the external beam system. This instability can occur both before and after transition; however, it is generally present when a poor ring vacuum ($>10^{-5}$ mm Hg pressure) exists in certain segments of the ring. It can also be stimulated artificially by excitation of a tickler coil at the proper frequency. Recently it has been shown to occur spontaneously even with relatively good vacuum conditions. An instance was observed with a magnet cycle flat-top near injection. Extensive studies have been made in an attempt to explain the occurrence of this instability at certain times in the acceleration cycle and to study its threshold behavior (see Figure 5).

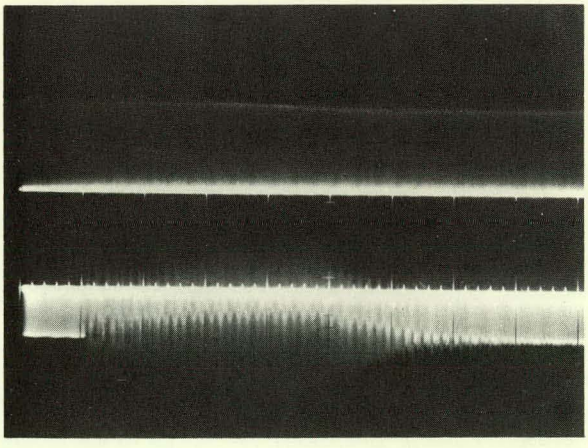


Figure 5. Example of vertical coherent oscillatory behavior in the AGS. The upper trace is the sum signal from the vertical electrodes and is proportional to beam intensity. The bottom trace is the difference signal from these electrodes and relates to position of the beam within the vacuum chamber. In this case the vertical coherence was artificially stimulated. Note the resultant beam loss.

Injection studies have been concentrated on efforts to improve injection parameters in order to further increase the beam acceptance of the synchrotron. Multiturn injection studies were made with a low-current, high-brightness ion source injecting 15 to 20 turns into the synchrotron. Under these conditions the number of injected protons was of the order of 6×10^{12} protons. This cannot be routinely achieved because of present limitations of the linac rf system.

Studies with a low energy external beam, using the fast kicker to eject the proton beam, dealt mainly with the development of emittance measurement techniques in the 50 to 500-MeV energy range. Preliminary results were obtained on beam behavior during the early acceleration cycle.

Measurements of the coherent vertical ν-value shift at injection as a function of beam intensity gave a result $\simeq$50% smaller than that predicted by a simple theoretical calculation.

Studies for the planned slow external beam system have been continued. Provisional backleg windings were used for the orbit bump needed for the slow extracted beam technique, and it was found that with the present arrangement of the backleg windings the half-integral stopband was excited, which resulted in appreciable beam loss. A modified arrangement has been decided upon and will be installed shortly. Further investigations have shown that successful high-field aperture correction can be made with only 12 of the 24 horizontal sextupole magnets. As a consequence, 12 units can be removed and the freed 5-ft straight sections utilized for other purposes.

Technical Development

Linear Accelerator. Modification and development of the injector for the AGS have continued. During the year a duoplasmatron ion source with a small plasma expansion cup was installed on the preinjector. This source was specifically constructed for limited total beam intensity. As a consequence of this modification, improved source brightness values were obtained and linac performance was improved.

In addition, the electronics in the Cockcroft-Walton ion source dome have been improved. Design is under way for the remote readout of critical ion source parameters via a high-frequency transmitter-receiver link.

The development program for the high-gradient accelerator column is progressing satisfactorily. A 750-kV test facility has been completed and an accelerator column has been assembled (see Figure 6). High-voltage tests have been started and preliminary tests in combination with a duoplasmatron source have been completed. A duoplasmatron with a large expansion cup has been constructed and studied extensively. With a Pierce-type extraction geometry optimum results have been obtained for beam intensities of up to 300 mA.

Continual improvements have been made in the linac with a view toward increased reliability of operation and increased beam intensity. A new system of constant-current, remote-programmed power supplies has been installed for the injection area focusing magnets. Locating these supplies behind an additional shielding wall along the linac tank, instead of in the injection area, has cut down the radiation exposure received by the semiconductor components. This has eliminated downtime due to these power supplies, a source of difficulty in the past. A doublet focusing element has also been installed at the end of the linac tank to handle the increased beam intensity from the linac and also to provide the necessary optics for a pulsed emittance measurement device.

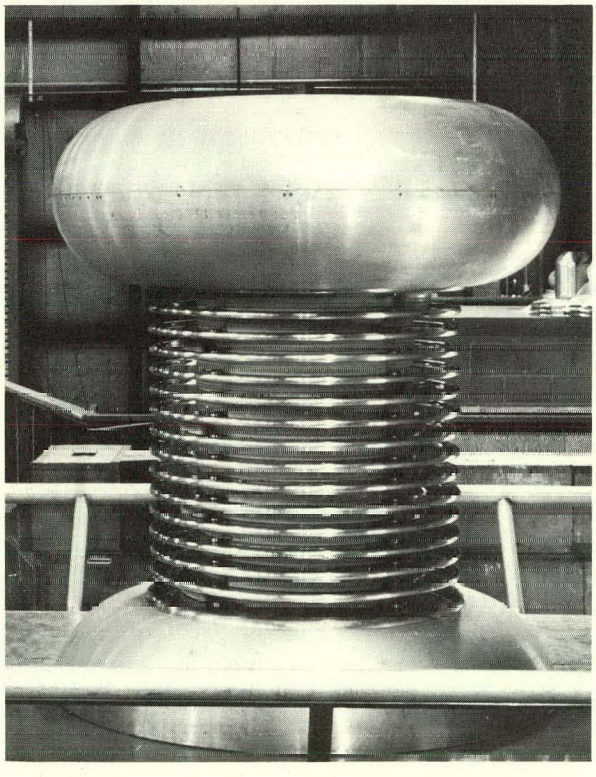


Figure 6. High-gradient accelerator column.

As part of the program to remove critical components from the injection area, the current-regulated power supply for the momentum-analyzing magnet has been redesigned; the components are all solid state, and the motor-generator set is no longer needed. The momentum-analyzing system now contains, in addition to an oscilloscope display of the 50-MeV beam energy distribution, a digital readout of the energy spread. This information is available between injected pulses for diagnostic purposes.

A fast emittance measurement device has been installed for analysis of the 50-MeV proton beam. This allows complete measurement of the linac beam emittance during a 40-μsec beam pulse, which greatly facilitates linac parameter studies. Heretofore the linac emittance was routinely measured with a manually operated slit system using many linac beam pulses to obtain a complete emittance determination.

An improved rf power system for the linac tank drive has been installed. The equipment utilizes a 40-kV, 700-A hard-tube modulator and FTH 515-type tubes in the final dual-drive stage to the linac cavity. Extensive reworking of the rf system controls was necessary. A circuit was developed and installed to allow for quick changeover between the hard-tube modulator and the original line-type modulator system and provide for complete remote control of both systems in the linac control room. An improved crowbar logic circuit for the hard-tube modulator, incorporating high-speed solid state digital modules, was developed, installed, and made operational. Certain novel features also were incorporated, including a current-time product-sensing circuit and an automatic reclosing circuit for three successive overcurrents. Further, an electronic program generator was incorporated to drive the hard-tube modulator; this provides more flexible control for beam loading compensation in the linac cavity.

Accelerator Components. The multiple-turn injection system has been revised to include a new high-voltage electrode for the electrostatic deflec-

tor. The inflector power and control system was completely redesigned and new circuits and control panels were fabricated to directly satisfy the needs of multiple-turn injection.

To decrease the amount of beam loss in the AGS ring, new fast-kicker ferrite magnets and appropriate supports were constructed. These increase the vertical aperture of the beam kicker from 2 to 2½ in.

To facilitate target blade handling and reduce radiation exposure to personnel as well as reduce machine downtime, an automatic programmed transfer mechanism was developed and installed in the G-10 target section. This, in conjunction with the automatic cycling air lock at this location, makes it possible to remove a target blade from the main AGS vacuum chamber and replace it by another held in a magazine without either shutting down the AGS or having personnel enter the machine enclosure. As many as eight different blades can be accommodated by the magazine.

The rf system of the AGS has been continually improved during the past year. The high-level stations now have new tuning servos, which have greatly improved the reliability by allowing automatic adjustment for changes due to drift and radiation damage to the transistor banks. Tests were conducted on the high-level amplifiers with the aim of extending tube life to at least 5000 hr. The rf low-level system has been redesigned and all circuits are now solid state. This change has produced a useful reduction in the space occupied by the low-level system, and the system's reliability is expected to improve.

The rf cavities are being modified with new central tube and vacuum seals for increased reliability. To date, 8 of the 12 units have been completed.

Special analogue-to-digital converters have been designed to provide an interface between the AGS and a PDP-8 computer. This computer will soon be used on line in the AGS control room to perform various monitoring and control functions. Most equipment in the control room is now solid state in order to achieve high reliability and dense packaging around the central console. A 40-channel, 4-fold coincidence detector was constructed for the main control room to eliminate the numerous bulky 4-channel units used previously.

Six rapid beam deflectors are under construction which, when installed, will add more flexibility to targeting procedures for the experimental program. The new deflectors will be capable of double pulsing, quick frequency, and polarity selection and will be electronically regulated to within 1%.

External Beam Systems. An additional fast external beam array has been provided by the installation of an ejection system at I-10 for use with the rf separated beam to the 80-in. bubble chamber. The ejection system includes the magnet, power supply, hydraulic ram and moving mechanism, vacuum box and special chambers, and a target and air-lock assembly for internal targeting.

To assure the reliability and efficiency of the fast external beam systems, procurement of complete spares and revisions to some of the mechanical components have been undertaken. Selection of material suitable for high vacuum and radiation environment has also been emphasized. New hydraulic units have been installed on the three rammed magnet units for the B-10 and I-10 fast external beam systems. This has reduced the shock load by a factor of three and consequently increased reliability.

Development of an improved fast-kicker, 10-ft straight section unit is in progress. The system will incorporate deuterium thyratrons. Modifications will be made to include more flexible control of the fast-kicker pulse length to provide for single or multiple-bunch beam deflection.

The performance specifications for the slow extracted beam system were determined, and active design of the major components is under way. Several prototype magnets and power supplies for the system have been tested. The proposed system will eliminate the hydraulic ramming mechanism currently used on the fast extracted beam by utilizing backleg windings on some of the main AGS magnets to produce a local orbit deformation. A 480-transistor power supply for use with the ejector magnet is being constructed. This supply will dissipate 300 kW. Transistor cooling is accomplished by use of a freon refrigeration system to cool a copper plate on which the transistors are mounted. The ejector magnet has been designed and released for fabrication. The magnet assembly consists of one 2-turn magnet segment and two 3-turn segments with space for coil ends and water-cooling between each segment. The septum thickness of this magnet is ¼-in. compared with the 1-in. thickness used for the fast beams. The magnet will be capable of taking 6350 amperes of current for a pulse length of 600 msec. A working model of the 0.030-in. septum magnet for the slow beam has

been fabricated and successfully tested. Considerable effort was devoted to minimizing the undesirable fringe field in front of the thin septum and the end effects due to the geometry of the septum and its electrical connections. The results of thermal testing proved very satisfactory, and this edge-cooled septum will be capable of running with a field of 1100 G for the same pulse length as the ejector magnet assembly. Satisfactory progress is being made on the design of the remote moving mechanisms for the septum and ejector magnets and the necessary vacuum boxes and special vacuum chambers.

Provisional magnet backleg windings have been installed on the yoke of selected main ring magnets. These provide for the orbit bumps in the F-5 and F-10 regions made necessary by the use of a stationary septum and ejector magnet system for the slow extracted beam system. Final design is proceeding on a set of these windings which will consist of several turns of water-cooled conductors for use with 1000-A power supplies.

Engineering Programs

Power. During the year the AGS consumed about 68,000,000 kWh of electrical energy. If the energy required for the 80-in. bubble chamber (supplied from an AGS feeder) is included, the figure becomes 84,000,000 kWh.

A new source of electrical power was installed in the center of the AGS ring. This installation included a new 10,000-kVA feeder from the main substation, a set of three 13,800-to-480-V, 3125-kVA substations, and a large 480-V distribution system to the West Experimental Area. Thus nine new experimental circuits were added to this area.

A new step-voltage regulator was added to the power supply for the rf equipment. This allows an increase in output voltage of 15% as well as a reduction of 15% in the voltage required for start-up.

A 480-V feeder was added to substation D to supply power to a new twin evaporative cooler in the North Experimental Area, and a circuit was added to substation G to supply a new magnet in the 80-in. bubble chamber.

The 4-unit power supply for the vacuum system control circuits was received and installed. This unit consists of a 50-hp synchronous motor, a 926-hp diesel engine, a 3-kW, 120-V, single-phase generator, and a flywheel. This separate power source will prevent voltage dips in the power line from affecting the vacuum system. In the past any power dip secured the vacuum controls and interrupted machine operation.

Some of the components of the main magnet power supply were improved. A new chassis for the automatic alignment of the peakers was installed. Study is proceeding on the development of solid-state ignitron control systems as well as a new regulator for the alternator field exciter.

New coils to replace the damaged ones in the series inductor were delivered and installed during the June 1966 shutdown. An electronic motor control using semiconductors and tubes was designed for the drive motor of the main motor-generator set and was connected for operational testing during the same period.

Mechanical Services. The AGS cooling systems have continued to perform well with normal, routine maintenance and with few interruptions of accelerator operation. The three AGS wells were shock-treated with phosphate to restore their yields and then treated with hypochlorite on a test basis during the June 1966 shutdown. The vacuum-pump closed system in the ring was modified to prevent flooding of the magnets in the event of a break in the system.

The 12 rf ring stations were modified to provide individual supply-and-return circuits for tubes and transistor banks with flow indicators and interlocks in each individual circuit. A small demineralizer was installed on each of two stations whose cooling systems had been carefully cleaned. Based on the excellent results obtained, an interim program involving demineralizers, larger pumps, rebuilt storage tanks, and relocation of cooling system equipment for all 12 stations has been initiated, and procurement of equipment is now under way.

Four additional 1-MW portable cooling systems have been procured and assembled for use in the Northwest Experimental Area. The 6-MW cooling system in the North Experimental Area has been repiped to make it a more permanent installation, and two 1-MW portable cooling systems using an ethylene-glycol solution as coolant have been installed to provide additional cooling for external beam No. 4. A closed water system has been installed in the linac to provide cooling for the hard-tube modulator and the FTH rf drive system.

Systems were designed and equipment was procured for mechanical cooling of the slow external beam and for various diffusion pump systems.

Vacuum. During the year the vacuum systems of both magnet ring and linac performed well.

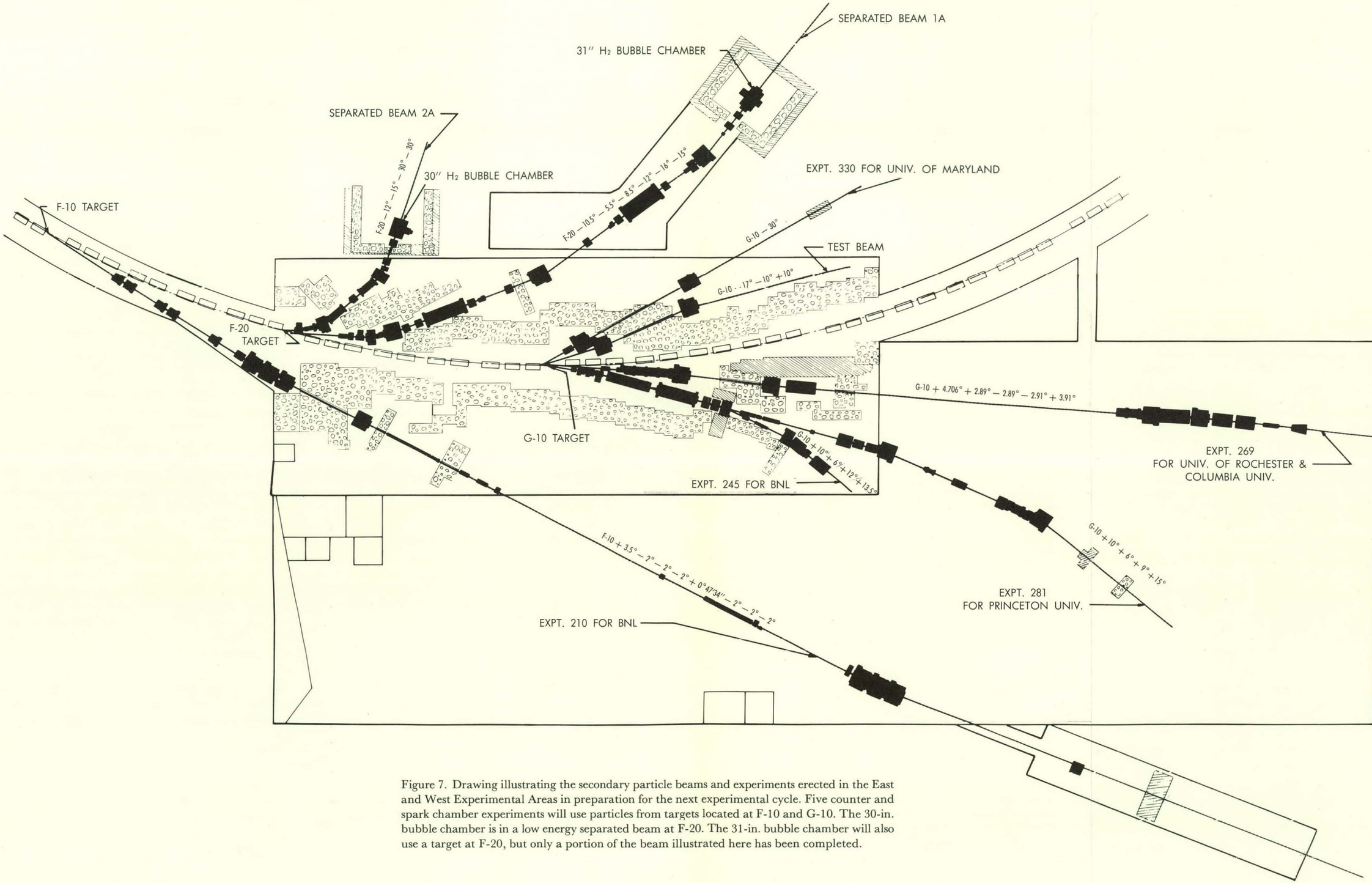


Figure 7. Drawing illustrating the secondary particle beams and experiments erected in the East and West Experimental Areas in preparation for the next experimental cycle. Five counter and spark chamber experiments will use particles from targets located at F-10 and G-10. The 30-in. bubble chamber is in a low energy separated beam at F-20. The 31-in. bubble chamber will also use a target at F-20, but only a portion of the beam illustrated here has been completed.

One of the main problems has been the persistent occurrence of leaks in magnet cooling-water coils in the vacuum chamber. These leaks have caused flooding of sections of the chamber. After repairs, the getter-ion pumps recovered from such flooding within a few hours. "O"-ring failure has become troublesome now that beam intensities average $>10^{12}$ protons/pulse. A program of gradual replacement of organic by metal "O" rings has been started. The metal rings are of Inconel-X, coated with a few mills of indium. Five sputter-ion-type pumps have been in service on the ring since April 1965 and have operated very satisfactorily.

Controls for sputter-ion vacuum pumps to be installed in two of the main ring superperiods were developed which use solid-state digital modules for the logic elements. This system will allow full and unattended automatic operation for start-up sequence, vacuum failure sequence, shutdown sequence, and single pump-on sequence. In addition, various program-selecting features have been incorporated to allow different modes and combinations of system element operation.

EXPERIMENTAL PLANNING AND SUPPORT

The research program in high energy physics at the AGS has utilized 4 experimental areas and 7 target stations during the year. The secondary particle beams in these areas are planned, equipped, erected, and operated by Division personnel. During normal operations, as many as 4 targets and 6 experiments often operate simultaneously. During the year 9 counter and spark chamber experiments were completed, >2 million pictures were taken in the 30-in. hydrogen bubble chamber, and >1.2 million pictures in the 80-in. bubble chamber.

Experimental Facilities

The protons from the AGS are used for both counter and bubble chamber experiments. Targets at AGS straight sections B-10, F-10, and G-10 are used for counter and spark chamber experiments, while the 30-in. bubble chamber uses beams from F-20, and the 80-in. bubble chamber is supplied by beams from I-10. Each area was extensively used during the year.

The Southwest Experimental Area is served by a fast external proton beam from B-10. The beam was used for only a brief period during fiscal 1966, but additional preparations and careful accelerator operation procedures were needed for the final experiment, another search for the intermediate boson carried out by Columbia University and Brookhaven physicists. The experiment consisted of looking for an anomalous source of high energy muons at large angles, such as might result from the decay of the intermediate boson. The proton beam was transported to an external target located just in front of the 82-ft-thick iron-plate shield wall. Counters in holes within the shield measured the muon spectra. The external proton beam was steered and focused very carefully on the target and produced pions that decayed to muons. The remote location of the Southwest Area and the 8-ft change in elevation between the plane of the circulating proton beam and the final target helped to keep the background low. The counting rate at large angles was $\approx$1 count/cm^2-hr. No evidence was found for the existence of the intermediate boson, and an upper limit of 2×10^{-34} cm^2 was set on the production cross section.

At ring location F-10 a high energy secondary particle beam has been erected and operated. The beam is being used by a Brookhaven group for an experiment in which the real part of the nuclear scattering amplitude is determined from measurements of the differential elastic scattering cross section at very small angles. The beam uses two target locations, one at the upstream end of the F-10 straight section when positively charged particles are desired, and the other at F-9 when negatively charged particles are needed. The beam is momentum-analyzed and focused on a 10-ft-long liquid hydrogen target located 400 ft from the internal target of the accelerator. A combination of vacuum tubes and helium-filled bags over the length of the beam minimizes the multiple scattering of the beam particles. When the beam is tuned for 20-BeV/c π^- mesons, there are 10^5 π^- mesons/pulse with a momentum resolution of $\pm0.29\%$. At 26 BeV/c there are 10^4 π^- mesons/pulse.

After passing through the hydrogen target the scattered particles are analyzed by hodoscope arrays placed in front of and behind three 30D72 spectrometer magnets. The angle of scattering can be determined to 1 mrad, and the absolute momentum of the elastically scattered particle to within 0.2%.

This beam and other counter beams and experiments for the coming experimental cycle are illustrated in Figure 7, which is a general layout of the East and West Experimental Areas.

The secondary beams from G-10 are utilized principally for particle physics research with counters and spark chambers. During the year four basic beams have been used repeatedly. Two beams are relatively simple arrays. One is a beam of K_2^0 mesons produced at 30° to the circulating protons. Physicists from the University of Illinois used this beam to search for the 2γ decay of the K_2^0. They produced an enriched beam of K mesons by using a lead filter and a sweeping magnet in front of the beam collimators. At the distance the detector was located from the target, a flux of 35,000 K_2^0 mesons was measured for 5×10^{11} particles/pulse on the target. The other beam is a charged particle beam produced at 17° and steered by two bending magnets into a test area. This test beam contains low energy particles and is frequently used by several groups at once for detector and equipment testing. Two beams on the outside of the ring at G-10 have been used extensively during the year for counter and spark chamber experiments. An intermediate energy beam emerges from the G-10 straight section at 4.5°. It has been used for pion and kaon beams from 6 to 18 BeV/c. At 12 BeV/c, 3×10^5 pions/pulse were measured. This beam was used by a group from the University of Pennsylvania for a measurement of the 180° scattering of pions on protons, and by a group from Yale and Harvard studying the decay of vector mesons into muon pairs. At present a pion/muon beam is being erected by using the 4.5° beam from G-10. Pions in the beam will decay to muons, and muon/proton scattering will be closely studied at high energies. This experiment is being undertaken by a research group from Columbia University and the University of Rochester.

The 10° beam at G-10 is a multipurpose separated beam used for 1 to 3.5-BeV/c particles. After passing through the electrostatic beam separators the beam is split into two branches. The short branch is used for low energy K-meson experiments. A Brookhaven group has done a $K^{\pm}$ total cross section experiment on hydrogen and deuterium from 1.5 to 2.5 BeV/c in that beam. The same group has been doing extensive measurement of the polarization of Ξ hyperons produced by K^--p interaction near 1.8 BeV/c in preparation for a measurement of the magnetic moment of the Ξ^-. When the beam is tuned for positive particles at 2 BeV/c, there is a measured flux of K^+ mesons of 10^4 to 10^{12} particles/pulse. The longer branch was first used by the original designers of the separated beam facility in an experiment to measure the cross section of the antiproton-proton annihilation into electron and pion pairs. After careful tuning of the beam, physicists from the California Institute of Technology and Brookhaven measured an antiproton flux of 5×10^4 at 2.5 BeV/c in this beam. This experiment was followed by two experiments using beams of K mesons. The first experiment, by a group from the University of Rochester, made a precise determination of $K^{\pm}$ lifetimes and searched for some violation of charge conjugation, parity, time reversal (CPT) invariance. A similar experiment is being done in the same beam by Princeton University.

In addition to the counter beams, the AGS provided beams for two operating bubble chambers. This was the first year of operation with the new low energy separated beam to the 30-in. bubble chamber. This beam, an improved version of the earlier beam for the same chamber, can provide K mesons up to nearly 1 BeV/c. It is composed of two stages of separation and uses the short electrostatic separators. The beam was carefully designed so that it could operate on every pulse, using only a small fraction of the circulating proton intensity. When it is tuned for K^-'s at 750 MeV/c, there are 100 per 10^{11} particles/pulse and, after degrading, 10 stop in the chamber on the average. The chamber background from neutrons is about one proton recoil per 10^{11} particles/pulse.

The beam was used with the chamber filled with liquid hydrogen for 260,500 pictures of K^--p interactions near 750 MeV/c for Duke University and for 696,000 pictures of K^--p interactions near 400 MeV/c for a group of physicists from Brookhaven, Yale University, and the University of Massachusetts. The chamber was used in a stopping K^- beam to take 586,000 pictures for the University of Maryland and Princeton.

With the chamber filled with deuterium, 431,000 pictures of π^+-d interactions were taken for Columbia University at a pion momentum of 850 MeV/c. For BNL and Carnegie Institute of Technology, 103,000 pictures of K^+-d interactions were taken near 625 MeV/c. In an exposure of K^--d interactions, 72,000 pictures were taken for a Brookhaven group. The chamber was also used for several test exposures.

In the North Experimental Area, electrostatically separated beam No. 3 has continued to serve physicists from many groups for research in the 80-in. bubble chamber. A new radio-frequency

separated beam, No. 4, the first of its kind in the United States, was brought into operation and has greatly expanded the range of experiments possible in the 80-in. chamber. To accommodate both beams for alternate use, beam No. 3 was rebuilt to aim into a new location of the chamber, beam No. 4 was aimed into the old chamber position, and the chamber was adapted to allow moving from one beam to the other.

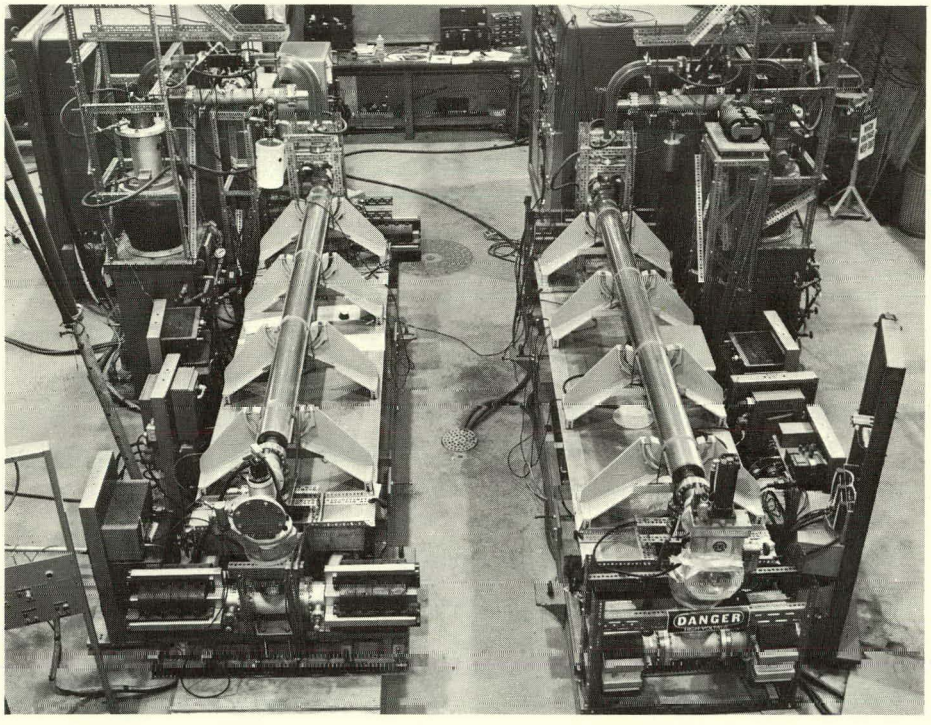


Figure 8. RF separator system before installation in the beam to the 80-in. bubble chamber.

Beam No. 4 employs a radio-frequency separator that has been under development in the Accelerator Department for several years. The principle of operation rests on an interference between two transverse oscillations induced on an essentially continuous beam at two points separated by a drift space. The phase of this interference for a given pion frequency depends on the time of flight along the drift space and is different for particles of given momentum and different rest masses. For a fixed choice of frequency and drift length and at certain momenta, this interference can be adjusted to be destructive for undesired particles and at the same time constructive for desired ones. This results in a vanishing net deflection for undesired particles and an angular oscillation of considerable amplitude for desired ones. The separator is restricted to operate at certain momenta, where for the fixed frequency and drift length the time-of-flight difference between desired and undesired particles is sufficiently different from a multiple of one oscillation period, and where, in the case of rejection of two contaminants (e.g., protons and K mesons in a K^+ beam) the time-of-flight difference between the undesired species is sufficiently close to an integral multiple of one period for both contaminants to be rejected simultaneously.

The radio-frequency separation technique opens up an energy region for research in bubble chambers in which electrostatic separation ceases to be practical. In beam No. 4, for instance, K particles can be obtained at momenta of 7.38, 9.0, and 12.8 BeV/c with high purity, whereas hitherto beam No. 3 had an upper operating limit of about 5 BeV/c for K mesons. In addition, beam No. 4 is built to transport, without separation, π^- mesons and protons at momenta up to 30 BeV/c. On the other hand, beam No. 4 ceases to operate as a separated beam in the lower energy region of beam No. 3.

The North Experimental Area thus has two mutually complementary tools available for physics

research at high energies in the 80-in. bubble chamber. In the summer of 1965 a total of 600,000 pictures were taken in beam No. 3. Of this number, about 235,000 were taken to complete runs started in previous years. The remainder were new experiments, including π^+-p exposures at 8.5 BeV/c and 7.75 BeV/c (60,000 and 34,000 pictures, respectively), a K^--p experiment at 4.2 BeV/c (55,000 pictures), K^+-p runs at 5.5 BeV/c and 3.0 BeV/c (54,000 and 113,000 pictures), and 47,000 pictures of p-p interactions at 7-BeV/c incident momentum. Beam No. 4 was constructed in the fall of 1965, was tested in December, and began operating in January 1966. Since then 600,000 pictures have been taken. These include π^--p exposures at 25 BeV/c and 16 BeV/c (102,000 and 62,000 pictures), a p-p experiment at 29 BeV/c (79,000 pictures), K^--p runs at 12.8 BeV/c, 9.04 BeV/c, and 7.38 BeV/c (107,000, 58,000, and 49,000 pictures, respectively), and K^+-p exposures of 79,000 pictures at 12.8 BeV/c and 63,000 pictures at 7.38 BeV/c. A K^- exposure at 12.8 BeV/c momentum in deuterium was started.

Experimental Equipment

The experimental equipment used in particle beam handling systems consists of magnets and their power supplies, beam separators, shielding, etc. At the end of the fiscal year 178 magnets, 141 power supplies, 12 electrostatic separators and 75,000 tons of shielding were in the inventory or on order. In addition, 10 MVA of electrical power and 4 large coolers for experimental water were acquired. A summary of equipment usage for the year showed that 85% of the magnets, 96% of the power supplies, and 87% of the shielding inventory were utilized.

During the past year several conventional magnets were added to the pool of equipment, including four 18D36 bending magnets, four 12S24 sextupole magnets, and five N8Q32 quadrupoles. Several unusual magnets were also designed. One of these was a 3-in.-diam quadrupole to be used for forming the external proton beam. With an input power of 65 kW it will produce a magnetic field gradient >10 kG/in. Five 18Q32 quadrupoles were designed for application where quadrupoles of wide internal aperture are needed.

The magnet design and study groups have designed a more efficient quadrupole with a somewhat enlarged cross section. It is hoped that this type of magnet, which has lower electrical power consumption, can be used in areas where compact magnets are not essential. Magnet studies and measurements have been done on the new magnets and on the large spectrometer magnets that are beginning to be used in high energy physics experiments.

Twenty-three new power supplies were purchased in the past year, all for use in general-purpose beam applications. Improved regulators for the power supplies are being studied to achieve more precise regulation than the currently available $\pm 0.1\%$ on magnetic field and improve the general reliability of the supplies.

No new beam separators were designed or acquired during the year. The 12 electrostatic separators continued to give satisfactory service. The short separators in the new low energy beam to the 30-in. bubble chamber operated reliably with 500 kV across a 4-in. interelectrode gap, while the older separators did almost as well. A development program on new electrode designs and tests is now under way.

The construction of the rf separator system was completed as described in last year's report. The separator was installed in beam No. 4 in the fall of 1965 and underwent deflection tests in December. At an input power level of 10 MW the deflections were found to impart a maximum transverse momentum of 16.5 ± 1.2 MeV/c to the particles traveling by in synchronism with the deflecting wave. This measurement agrees within experimental error with cold measurements on the deflector and with theoretical computation (15.2-MeV/c transverse momentum expected at 10 MW). The separator system has been operating successfully since January 1966, and only minor problems of reliability have been encountered. The setup and tuning adjustments of the separator in the operating beam are not complicated, and the deflection amplitudes and their relative phase are sufficiently stable to require only minor adjustments during a week's operation.

Cryogenic targets of liquid hydrogen, deuterium, and helium are used continually at the AGS and the Cosmotron. Twelve targets were designed and constructed for the AGS and seven for the Cosmotron. Many of them have unusual design features to meet the requirements of the specific experiments for which they were constructed. One such target system has two 6-in.-diam, 36-in.-long inner vessels surrounded by a concentric cylinder wrapped with superinsulation inside a vacuum

chamber. The target is connected to a 200-liter reservoir to reduce the number of hydrogen fillings needed. This and a special pressure regulator for liquid density control and a temperature control bath for the pressure-regulating control gas kept the density of the liquid in the target constant to one part in 10,000.

Most of the high-speed logic and scaling circuits used in the counter experiments at the AGS and Cosmotron are provided by the High Energy Electronics Equipment Pool. During the past year this group has invented a major portion of the electronic equipment for 40 experiments. These inventions are valued at several million dollars, and 90% of the equipment is in use at all times.

AGS CONVERSION

In June 1965 the AGS Conversion Division was activated to carry out the detailed design and execution of the AGS conversion program. For fiscal 1966, the conversion program was funded with $2 million to start detailed design. The full $47.8 million for construction has been authorized by Congress for fiscal 1967, and the program now awaits appropriation of the funds.

A number of senior staff members with extensive experience in accelerator design and construction were recruited from other parts of the Accelerator Department to form a strong nucleus for the Division's staff, and an aggressive recruiting program was undertaken to complete personnel requirements. The Division now includes 45 scientific and professional members and about 30 technical and support personnel. The projected peak size of the Division is about 70 scientific and professional and 110 technical and support personnel.

In September 1965, Informal Report BNL 9500, *Alternating-Gradient Synchrotron Conversion Program, Scope of Phase I*, was submitted to the Atomic Energy Commission. This report describes the preliminary designs for phase I of the program. The design goal for this phase calls for reaching an intensity of 10^{13} protons accelerated per pulse. A new high-intensity proton linac will be built as an injector; it will have an energy of 200 MeV and an ultimate peak intensity of 100 mA. The synchrotron's main magnet power supply will be augmented by doubling the capacity of the present motor-generator set. This will permit doubling the rate of rise of the magnet field and allow operation at a repetition rate of 1 cycle/sec with no flat-top or 1 cycle/2 sec with a 1-sec flat-top (50% duty cycle). The synchrotron rf system will be replaced by a new system capable of accommodating the increase in cycling rate. The magnet ring will be modified and the magnets, their connections, and the vacuum chamber will be made in modular form so that repairs may be made with a minimum of downtime and exposure of personnel to residual radiation. Special care will be taken to minimize radiation damage effects for all components that must remain inside the ring tunnel. Those components that can be located outside the tunnel will be removed to reduce radiation damage and increase the ease of servicing. Additional experimental facilities will be provided. A building of about 50,000 sq ft will be attached to the existing East Experimental Area, and one of 25,000 sq ft will be added to the west of the Target Building. New external beam facilities will be provided at the H-10 section of the ring.

During the year, good progress has been made in design work for all aspects of phase I of the program. Title I design is nearing completion. Modular prototypes have been designed and built for the component parts needed to modify the main magnet ring, and these are being evaluated. Design for the prototype of the ring rf amplifiers is complete and the unit is under construction. A design study is being carried out for the motor-generator set; it is hoped to incorporate as much as possible of the existing unit in the new set of double capacity.

Studies of beam loading in linacs have greatly improved the understanding of this phenomenon. Theoretical calculations have been compared with measurements made in the existing 50 MeV linac and the agreement is excellent. The problem of field distribution and control in a drift-tube cavity has been investigated in detail and a proposal made for the use of multiple drift-tube stems as a method of stabilizing the cavities. Continued development of the linac beam dynamics program has resulted in computer programs that accurately describe the particle motion in the linac.

Design and testing of prototypes for the linac 200-Mc/sec rf system are progressing. A 5-MW triode amplifier is being tested with a resistive load and will be connected shortly to a resonant load. Modulators, drivers, and control circuits are being developed for the system. Quadrupole magnets for the drift tubes have been developed, and numerous mechanical models of linac components are being tested.

The architectural engineering firm of Charles T. Main, Inc., of Boston continued work on the preliminary engineering program and in August 1965 issued a two-volume interim report on the required structures, services, and utilities. During the fall, preliminary engineering work continued and formal Title I reports were issued on the utilities, 69-kV substation, and transmission line. Draft Title I reports were issued on the Target Building modifications, the West Target Building addition, and the main Auxiliary Equipment Building. In January it was decided to discontinue architect-engineer work for six months so that Brookhaven would have sufficient time to establish various parameters required before the work on structures could profitably continue.

ADVANCED ACCELERATOR DEVELOPMENT

Magnet Design

As a first step in the design of a 600 to 1000-BeV synchrotron, a study was completed of possible magnet designs for operation at fields higher than the 13,000-G maximum field used in the AGS. A number of unconventional designs were studied in the hope of reaching fields as high as 30,000 G. None proved to be economically justifiable in terms of either power consumption or stored energy. Attention was then turned to possible improvements in the conventional design used in the AGS and in the CERN proton synchrotron. Several minor changes in design make it possible to operate at fields of about 15,000 G. The final design chosen is very similar to that arrived at in the 200-BeV accelerator design study made at Lawrence Radiation Laboratory (LRL).

For use in beam transport and, possibly, in linear accelerators, a theoretical study was made of field patterns in permanent magnet quadrupoles and dipoles. These would take the form of rings of permanent magnet material. By using available materials, it was shown that "pole-tip fields" of about 2000 G should be attainable in quadrupoles. Dipole rings can give uniform fields up to about 1500 G. Any desired quality in these fields can be achieved by successively removing higher order components in the field pattern.

Superconducting Magnets and Lenses

Dipole, quadrupole, and higher order (n-pole) field patterns can be produced by providing cosine $n\theta$ current distributions on the walls of a cylinder, the currents running parallel to the axis of the cylinder. In combination, fields of the pattern used in synchrotron magnets can be produced. Analysis of external field patterns shows that addition of an appropriate current distribution on a coaxial cylinder of larger radius can result in reduction to zero of fields external to the larger cylinder. Approximations to the cosine distribution have been evolved to simplify construction procedures. Other possible distributions (elliptical cylinders and planar distributions) are also under study.

Several superconducting quadrupoles have been constructed, some of flat current sheets and some following the principles just outlined. Performance of these quadrupoles is in agreement with the theoretical predictions. Gradients of 8.5 kG/cm have been achieved in a 25-cm-long quadrupole with a 7.5-cm bore.

Fields that rise rapidly and continuously for use in synchrotron magnets appear to be possible, but several basic problems remain to be solved.

Injection Studies

In considering an injector for a super-energy accelerator, attention has been concentrated on a "slow booster" synchrotron which injects during a single injector pulse. This is in contrast to the rapid cycling boosters proposed in the LRL and CERN design studies for 200- and 300-BeV accelerators. Use of a slow booster requires that its beam be extracted over a few tens of turns, an operation intermediate between single-turn extraction and slow extraction, both of which are in use. This intermediate "decaturn extraction" has been given extensive study and three possible methods of achieving it have been evolved. Analysis and computer studies indicate that any one of these methods can be used with satisfactory results.

200-BeV Site Studies

In view of Brookhaven's inclusion in the final list of six possible sites for a 200-BeV accelerator, further studies have been made of the best possible location for such a machine at Brookhaven. A location north of the AGS seems the most feasible. Here several beam runs are possible with lengths >1 mile without important interference with existing facilities, injection from the AGS is possible if desired, and beams from both the 200-BeV ring and the AGS can be brought to a 14-ft bubble chamber.

Theoretical and Experimental Accelerator Studies

As the intensity of the beam in the AGS increases, effects of the dense space charge in the beam become increasingly evident both in the synchrotron ring and in the 50-MeV linac injector. Beam loading in the linac has complex effects resulting in distortion of the rf field pattern. An analysis of these effects has been completed and its results confirmed in principle and in detail by measurements on the linac.

A study has been begun of the usefulness of a small computer as part of the control system of the AGS; a PDP-8 computer has been acquired for this purpose. It is not planned initially to give control of the machine to the computer, but rather to use it to provide rapid solutions to setup and observation problems that now are solved by rather slow and laborious methods.

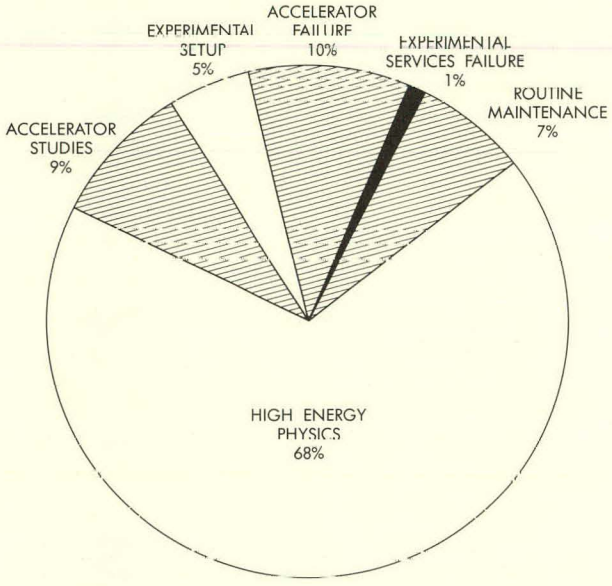


Figure 9. Cosmotron utilization during fiscal 1966.

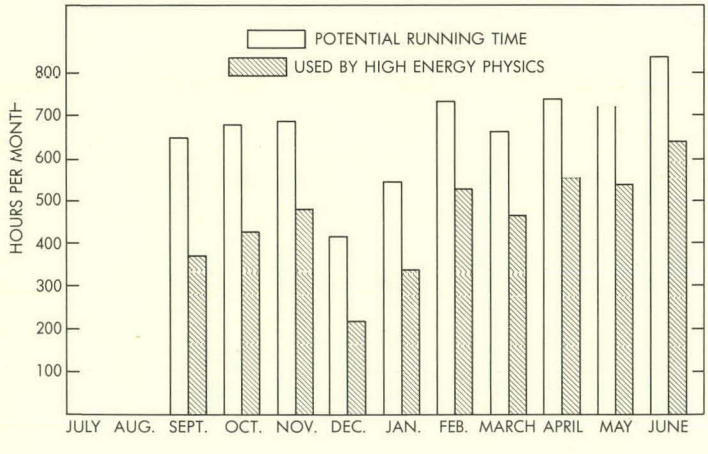


Figure 10. Use of the Cosmotron for experiments in high energy physics during fiscal 1966.

COSMOTRON

The failure of the main power supply alternator described in last year's report was repaired ahead of schedule and the Cosmotron began operation on August 2, 1965. Operation for the rest of the year was at a high level of efficiency, 21 shifts per week. Figures 9 and 10 present a breakdown of the use of operating time.

Use of the Cosmotron for research showed a continuing trend toward increased use by groups from outside the Laboratory. Also notable was an increase in running time per experiment, due to the fact that experiments are becoming more complex and sophisticated.

In March the AEC informed the Laboratory that operation of the Cosmotron should be terminated in fiscal 1967 because of funding limitations and pressing needs for new facilities. Operations were reduced to a 15-shift/week basis as of July 1, 1966, and will cease about January 1, 1967.

Research Program

A counter group from the University of Rochester completed an experiment on the production of proton isobars in proton-helium collisions at various energies.

Scientists from the University of Michigan completed measurements of the polarization parameter in p-p elastic scattering at 6 proton energies in the range 0.75 to 2.8 BeV.

Another group from the University of Michigan completed an experiment on clastic p-d scattering at incident proton energies of 1.0, 1.3, and 1.5 BeV for values of the four-momentum squared $(-t)$ from 2.6 to 5.0 $(\mathrm{BeV}/c)^2$. At incident energy of 2.0 BeV, the measurements covered values of $-t$ from 0.44 to 1.54 $(\mathrm{BeV}/c)^2$.

A counter group from the University of Wisconsin failed in an attempt to measure the leptonic decay parameters of the Σ^- hyperon because of low yield and a large background of electrons from multiple-pion production. With slight modification of the apparatus they completed measurements on the nonleptonic decay parameters of the Σ^+, Σ^-, and Σ^0 hyperons as a function of energy.

Several exposures of primates to proton beams of several energies were made for the United States Air Force School of Aerospace Medicine. Mortality studies were made to determine the $LD_{50/30}$, and investigations on hematology and serum enzyme levels were also carried out.

Measurements to detect interference effects between $K_1^0 \rightarrow \pi^+ + \pi^-$ and $K_2^0 \rightarrow \pi^+ + \pi^-$ decays were completed by a group from the University of Rochester.

A group from BNL, Rice University, and the University of Maryland has started a program in nuclear structure using an external proton beam from the Cosmotron and a 2-arm magnetic spectrometer. The energy spread in the beam has been measured to be $\leqslant 2.5$ MeV, and the inherent long-term energy stability is approximately one part in a thousand. Experiments under way include reactions of the (p,2p) and (p,d) type and p-d elastic scattering.

A group composed of scientists from Brown University, the Massachusetts Institute of Technology, and Padua University is setting up a counter–spark chamber experiment to investigate branching ratios for the decay modes of the three nonstrange meson resonances, η^0, ρ^0, and ω^0.

A group from the BNL Chemistry Department is studying the angular and energy distributions of protons, α particles, and pions emitted from complex nuclei during the cascade stage of high energy nuclear reactions. The BNL 14-in. liquid hydrogen bubble chamber was operated with thin target foils placed inside the chamber; 160,000 pictures were taken and are being analyzed.

Another group is studying the high energy fission of uranium and bismuth by observation of coincident fragment pairs with semiconductor detectors.

A counter group from Columbia University is in the preliminary stage of an experiment to test the conservation of C (particle-antiparticle conjugation) in the electromagnetic interaction between strongly interacting particles. The test consists of a measurement of the energy distributions of π^+ and π^- in η^0 decay.

In addition to the above major experiments a large number of short exposures were made for radiochemists from BNL and Columbia University as well as for the BNL Medical Department.

Accelerator Studies

A number of investigations have been made to obtain a better understanding of how the Cosmotron may be modified to improve its utility as a research tool.

For some time it has been known that machine intensity is reduced if the rest time between pulses is made too short. This effect was traced to field distortions near the injection radius. Reconnection of certain pole-face windings allows some amelioration of distortion, with a net improvement of 10% in the machine duty cycle.

A program has been in progress for some time to increase the number of injected protons. One promising approach is to increase the time during which the rising magnetic field will accept protons from the injector. This can be realized if the injection energy is increased by raising the voltage of the Van de Graaff liner during the injection pulse. The pulsed voltage supply for the liner has been modified to give a negative 200 kV, approximately twice the previous value.

Attempts to increase the intensity further by injecting long pulses have introduced two problems which must be resolved: (1) short ion source cathode life, and (2) excessive electron loading of the acceleration tube. Preliminary observations indicate that acceleration-tube loading limits the total charge that can be accelerated per pulse. It may be necessary to use the new totally shielded acceleration tube to permit long pulsing at high intensity. Work continues on ion source cathode development.

Extensive measurements have been made of the emittance or phase-space area of the ion beam in the Cosmotron injection system. Measurements in the region immediately following the probe at an energy of 20 keV and an intensity of 50 mA indicate an emittance of about 20 mm-mrad. This is substantially smaller than that reported for duoplasmatron sources under comparable conditions and presumably results from the "close-coupled" extraction geometry recently developed for this source. After acceleration to an energy of 3.5 MeV, the total beam emittance increases to about 250 mm-mrad rather than decreasing as theory predicts to about 2 mm-mrad; this gives a discrepancy of a factor of about 100 between theory and practice. Further work will be required to clarify the relative importance of the various factors that can contribute to growth of emittance with acceleration in contradiction to theory. Possible factors include (1) lens aberrations, including nonuniform distribution of space charge, (2) randomly distributed surface charges residing on exposed insu-

lators and/or insulating films on metal surfaces, (3) nonlinear effects occurring in the vicinity of crossovers in field-free drift spaces as the result of electron trapping in the space charge field, and (4) charge exchange during acceleration.

To meet the more stringent requirement on energy spread in the external beams, resonance methods for beam extraction are being considered. This technique reduces the energy dispersion caused by the radial betatron oscillations and eliminates the Landau energy spread associated with the present lip and jump-target method. Some experiments have been done which agree well with numerical calculations. Additional computations also have shown that an improved energy spread and ejection efficiency can be obtained by using a 2-magnet ejection system.

In response to several inquiries from experimenters concerning the feasibility of doing so, an attempt has been made to accelerate deuterons in the Cosmotron. In order to use existing major components of the machine with little or no modification, the following method of injection and acceleration is used. D_2 instead of H_2 is fed into the ion source of the Van de Graaff accelerator. The deuterons produced are accelerated to ½ energy in the Van de Graaff. Since the particles now have the same momentum as protons normally do on entering the Cosmotron, the same injection analyzing magnet and Cosmotron main magnet parameters are used. The inflector voltage is reduced to ½ its normal value. The velocity of the deuteron in the machine is ½ that of protons at this time. Since the rf system will not operate without major modification at ½ frequency, the particles are accelerated for about 100 msec on the second harmonic. The frequency is then reduced by a factor of 2 and the particles can be accelerated to full energy, about 2.3 BeV. About 5×10^{10} deuterons/pulse have been accelerated to full energy. A rough measurement of the stripping cross section in beryllium at zero degrees gave a value of 2.7 barns/sterad. Fermi momentum should give an energy spread of about 150 MeV and angular divergence of 37 mrad full width at half maximum. Preliminary calculations indicate that elements up to about carbon could be accelerated to 1.15 BeV/nucleon. Accelerating heavier elements would require an improved vacuum system.

An interesting phenomenon was observed in a preliminary exercise in the deuteron acceleration study. If protons are accelerated for a short period of time and then allowed to coast, the azimuthal bundle of protons formed by the rf should debunch. At low intensities this indeed happens. At high intensities, however, the particles remain bunched because of longitudinal space charge effects. Some preliminary experiments were done to observe the effect of varying the energy spread in the beam. Qualitatively the results are in accord with theory and constitute probably the cleanest demonstration of the effect to date.

Minor changes were made in the main control room. The system that keeps the rate of beam spill constant during flat-top has been improved substantially by increasing its bandpass. The saturation characteristics of the alternator of the main magnet power supply were studied with better regulation in mind, and studies of space charge effects at injection and capture times were continued. A device has been constructed and tested which will insert the external beam extraction magnet late in the acceleration cycle. This should lead to an appreciable improvement in beam intensity because of the increased radial aperture at injection.

Accelerator studies to produce external proton beams of longer duration continued. A 1-sec flat-top has been attained on the motor-generator set for all normal energies; however, the motor control current at 3 BeV was marginal. As a consequence of the decision to shut down the Cosmotron, improvements in this and other components necessary for an effective long spill, as well as other major machine modifications, are no longer being actively studied.

Instrumentation

Recent developments in instrumentation fall into three general categories: radiation detectors, computer systems, and circuits. The radiation detector work has involved fabrication of lithium-drifted germanium detectors for applications in high-resolution gamma spectrometry, improvements in the field of digital readout spark chambers, and development of thermoluminescent dosimeters for health physics applications. The use of computers as research tools has continued to expand. Novel circuit developments ranged from a parametric amplifier for use with the germanium detectors to a pea-sized telemeter transmitter.

LITHIUM-DRIFTED GERMANIUM DETECTORS

The most exciting new development in the field of radiation detection is the germanium detector. Detectors made of silicon have revolutionized the field of charged-particle spectrometry in the past seven years. Recently, several laboratories have made detectors of germanium which have very high energy resolution for gamma rays as well as for charged particles. During the past year the Instrumentation Division has set up facilities and developed techniques for making large-volume, high-quality germanium detectors. High-purity, p-type germanium is purchased from commercial sources, cut into the desired shapes, and then lapped and etched. Lithium is diffused into one surface, then drifted through the crystal under an applied field; thus the remaining impurity centers are compensated or neutralized. The lithium-diffused surface serves as one contact for the detector, the uncompensated p-material or an opposing p-contact as the other. The device is installed in a cooling vessel and operated at liquid nitrogen temperature. This general procedure has been worked out at a number of laboratories. However, it has been difficult to achieve consistent results and to produce relatively large-volume detectors with good resolution. It was found at BNL that poor performance could often be attributed to the condition of the lithium-rich contact. Lapping and etching of this face until a uniform, low-resistance surface is reached appears to be necessary to make a detector that has low leakage with a high ($>$100 V/mm) bias. The p-type contact also presents problems. A method has been developed for obtaining a reliable p-contact by means of gallium diffusion. The lithium drift process is slow and the drift rate decreases as the compensated region increases; hence it has not been practical to make detectors $>$1 cm thick. Comparatively large volumes have been achieved by drifting from a large surface area. The resulting detectors have a large capacitance and correspondingly poor resolution. A technique initiated at Argonne National Laboratory has been exploited to achieve thicker compensated regions. The lithium is diffused into two opposite faces of a block and drifted toward the center from both faces by applying an ac drift field. When the lithium-compensated regions merge, a dc drift completes the compensation process. With this procedure 15-cc detectors have been produced, and larger volumes with low capacitance are confidently predicted.

DIGITAL SPARK PLANES

These detectors for recording trajectories of high energy particles have been under continuous development for three years. The first large-scale tests of a wire spark-plane system were reported last year. The system, using 12 planes in a magnetic spectrometer and feeding the data directly to a PDP-6 computer, was used in a small-angle elastic scattering experiment at the AGS accelerator. The wire spark planes provided high spatial resolution and high speed. In one experimental run, 1 million events were recorded and analyzed in an 8-hr period.

The electrodes (described previously) were etched, like printed circuits, by using 1-oz copper on 4-mil Fiberglas sheet. More recently ½-oz copper on 3-mil Kapton (a high-temperature organic plastic) has been used to reduce the amount of material in the beam, which causes noticeable scattering at lower energies. These new electrodes have been used in a double-arm spectrometer experiment at the Cosmotron. To further reduce scattering, hand-strung, 2-mil stainless steel wire

was used in the first two planes, so that the electrodes were 92% transparent.

Much additional information has been accumulated on the relationship of the resolving time to the clearing and pulsed high-voltage fields for neon-helium-ethyl alcohol mixtures, in order to understand the electron drift and capture parameters that affect spark chamber performance.

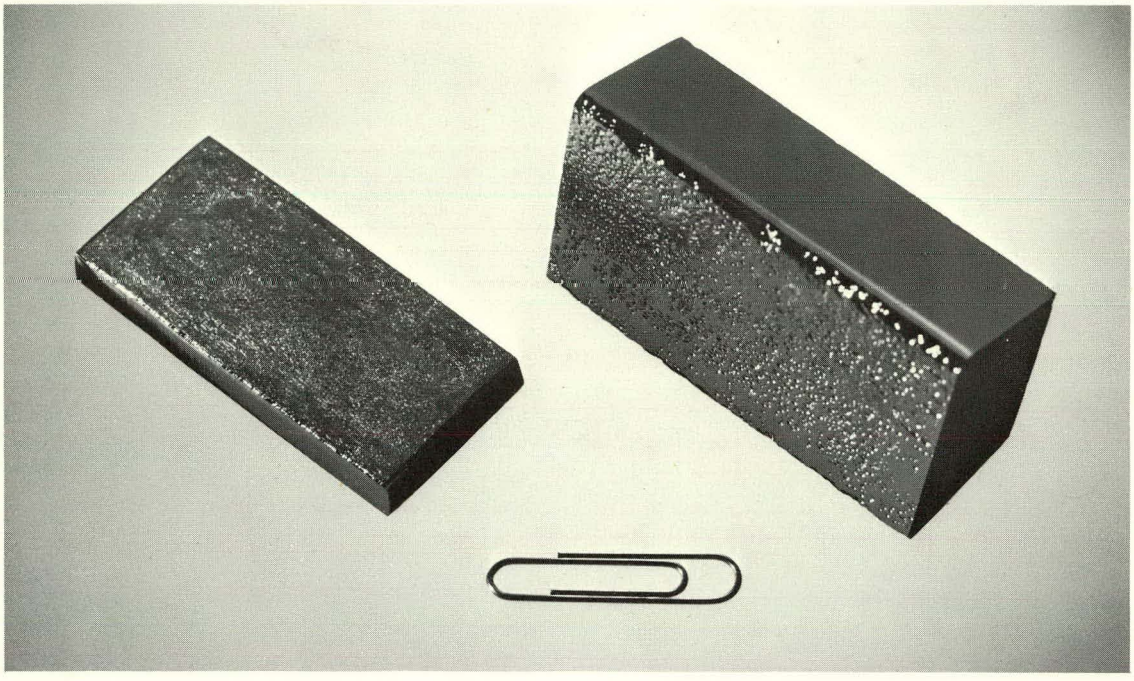


Figure 1. Large-volume, semiconductor gamma-ray detectors. Both germanium crystals were compensated by drifting lithium from opposite sides to achieve a thick, uniform, sensitive region. Top of crystal at left has gallium-indium p-contact. Crystal at right is 2 cm thick. Paper clip is shown for size comparison.

Larger planes with a sensitive area of 18×36 in. have been operated successfully. Small planes having twice as many (40) wires per inch have been built. Planes providing digital information from the pulsed high-voltage electrode, as well as the grounded electrode, are now in use. The high-voltage pulser for the large planes uses a hydrogen thyratron circuit, which has a firing delay of only 30 nsec. An experiment using the large planes for recording dual tracks is being installed at the AGS.

THERMOLUMINESCENT DOSIMETER

Thermoluminescent materials have long-lived excited states. Electrons may be elevated into these states by radiation. When heated, the trapped electrons are released, and light proportional to the integrated radiation dose is emitted. Measured amounts of thermoluminescent powder have been sealed into packets of high-temperature plastic (Kapton). The packets may be reused for dose measurements or calibration purposes. A reading station with quite reproducible characteristics has been developed. The light-sensing element is a photomultiplier tube, and the heating element is a heavy plate of glass, maintained at a suitable high temperature. The dosimeter packet is slid onto the glass plate, heats up, and emits a pulse of light. Since the hot glass and most of the chamber, which are exposed to the photomultiplier, are maintained at a constant temperature, the photomultiplier "dark" current is high, but constant. The thermoluminescent flash produces a transient increase in tube current which is easily and precisely integrated to give a reading of the radiation dose. The linearity and sensitivity of the packets can be increased by exposing them to a radiation dose that is high compared to the normal operating range. By these means thermoluminescent

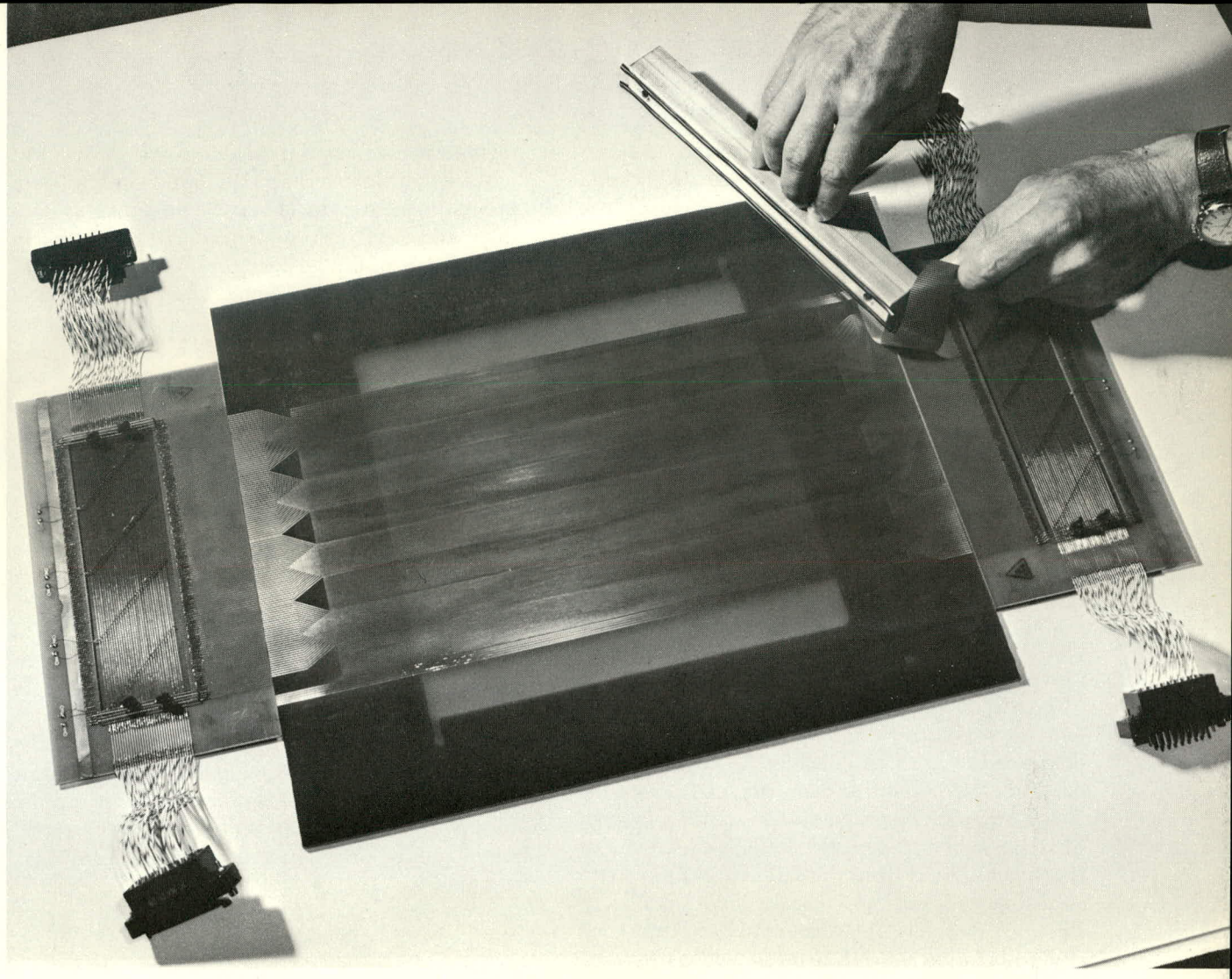


Figure 2. High-resolution spark plane with 40 wires/in., fanned out at the edges in groups of 32 to match 20/in. memory core boards.

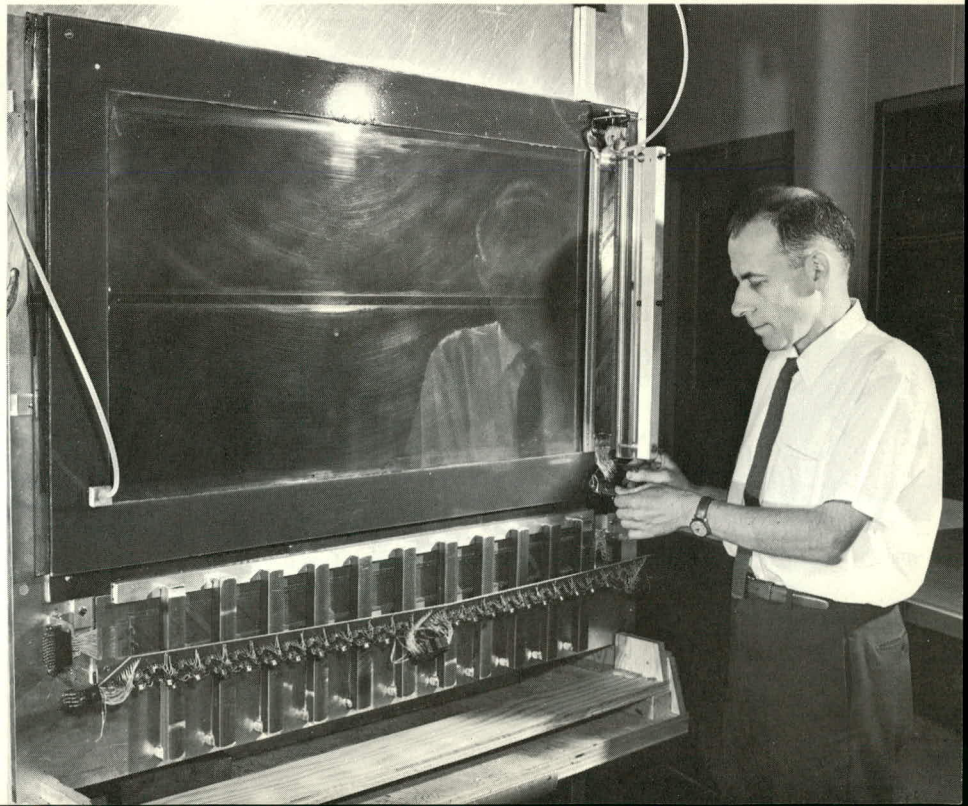


Figure 3. Digital spark plane with 1.5×3.0-ft sensitive area. Printed wires of back electrode are vertical, those of front electrode are horizontal. Readout elements are visible at right and below. Front electrode is pulsed to a high voltage.

devices have been brought to the point where they are rugged, reusable, and have a sensitivity comparable to, if not exceeding, that of pocket film badges.

ON-LINE COMPUTER SYSTEMS

The first on-line computer system designed at Brookhaven was a multiparameter analyzer to accumulate and display combinations of pulse heights from two or more particle detectors. This system, which proved the advantages of the computer approach, is now in use at Rutgers University. This year a design study for an improved system was carried out jointly with the Physics Department. The new computer will be about ten times as fast, to accommodate higher data rates and perform more extensive analytical computations, and will be provided with much more elaborate data displays.

The second Brookhaven on-line computer system, for use in neutron time-of-flight analysis, was designed to record and display the data from the fast and the slow neutron choppers simultaneously. This system has recorded data at the Brookhaven Graphite Research Reactor (BGRR) on an almost continuous basis from the fall of 1963 until this spring, when it was moved to the High Flux Beam Research Reactor. The system has been expanded (by addition of more fast memory, a magnetic tape deck, and interface electronics) to analyze time-of-flight and pulse height from two detectors for the fast chopper experiment and to record time information from as many as 32 detectors for the slow chopper.

An SDS 920 computer system has been assembled to monitor up to 13 manual bubble chamber film-scanning tables. Coordinates are fed directly to the computer from digitizers on the scan tables. The programs test the data as they are entered to make sure that track coordinates and fiducials are entered in the proper order, that the points lie on curved lines, and that the data are in suitable form for analysis by the CDC 6600 computer. When an error is detected, the operator is notified so that a correction may be made promptly while the picture is still on display.

A design study for a much more sophisticated system for bubble chamber analysis and data retrieval was initiated in cooperation with the Bubble Chamber Group (Physics Department). The computer system not only will monitor a number of scan tables, as described above, but will be coupled to the CDC 6600 central data processing center, to 12 very flexible display consoles, and to 20 teletypewriters. The displays will be capable of flicker-free presentation of a full page of text, graphs, or images composed of tens of thousands of points. From the console, direct interaction with the CDC 6600 computer will make it possible to monitor and guide the analysis at any point in the process of geometric track reconstruction, kinematic analysis, fit selection, or histogramming. It will also be possible to reanalyze old data stored in the central computer mass store.

The Instrumentation Division purchased a small (PDP-8) computer and magnetic tape to assist in the development of digital wire spark planes. An interface was built to transfer spark coordinate information from the spark planes to the computer; and programs were written to analyze data for efficiency of sparking, multiple sparks, and similar useful parameters. With this special equipment it has been possible to make and to test a new type of spark plane within a month. The system will also be used to record the data from a high energy spark chamber experiment and for development of on-line computer techniques.

ELECTRONIC CIRCUITS

The silicon and germanium radiation detectors described in the first section have a very high intrinsic energy resolution, but the output electrical signals are so small that amplifier noise is a problem. In fact, even ideal amplifiers employing tubes or transistors as active elements degrade the information available from high-quality semiconductor detectors. In principle, it is possible to build parametric amplifiers, by using purely reactive elements, that are noise-free in the amplification process. Such amplifiers have been developed for radio and other applications where the signal source is primarily a resistive impedance. However, radiation detectors present primarily a capacitive reactance, and therefore a different approach was needed to apply the parametric principle. This has proved to be very difficult to achieve, but a working model has been developed. A tuned circuit incorporating varactor diodes is pumped at a frequency slightly different from twice its resonant frequency so that it operates as a subharmonic oscillator. The oscillation ampli-

tude is stabilized by low-frequency negative feedback. The detector is connected to a neutral point on the tank circuit, and the charge released by a gamma ray in the detector changes the bias on the varactors and slightly alters the tuning, whereupon the signal level in the tuned circuit starts to increase or decrease, depending on signal polarities. The rf tank-circuit signal is amplified, rectified, and fed back to the input through a resistor-capacitor network, as is customary in charge-sensitive, negative-feedback pulse amplifiers. Unfortunately, the parametric circuit has negative feedback mechanisms of its own which reduce the gain to a useless level. To counteract these effects a controlled amount of positive feedback was added to this part of the circuit. Since the tolerable noise level corresponds to only a few electrons per pulse, the resistance in the tuned circuit must be held to an absolute minimum and the circuit must be thoroughly isolated from any external noise signals. The final parametric amplifier is perhaps not quite so good as the most recent cooled, field-effect transistor amplifiers when used with small, low-capacitance semiconductor detectors. However, its noise level increases only slightly with increasing detector capacitance, and it will be especially useful in deriving optimum performance from the newer, large-volume germanium detectors.

An electromechanical, constant-velocity servo has been constructed in cooperation with O.C. Kistner of the Physics Department for use in Mössbauer scattering experiments requiring high statistical accuracy. The apparatus can be programmed to cycle through a preselected set of as

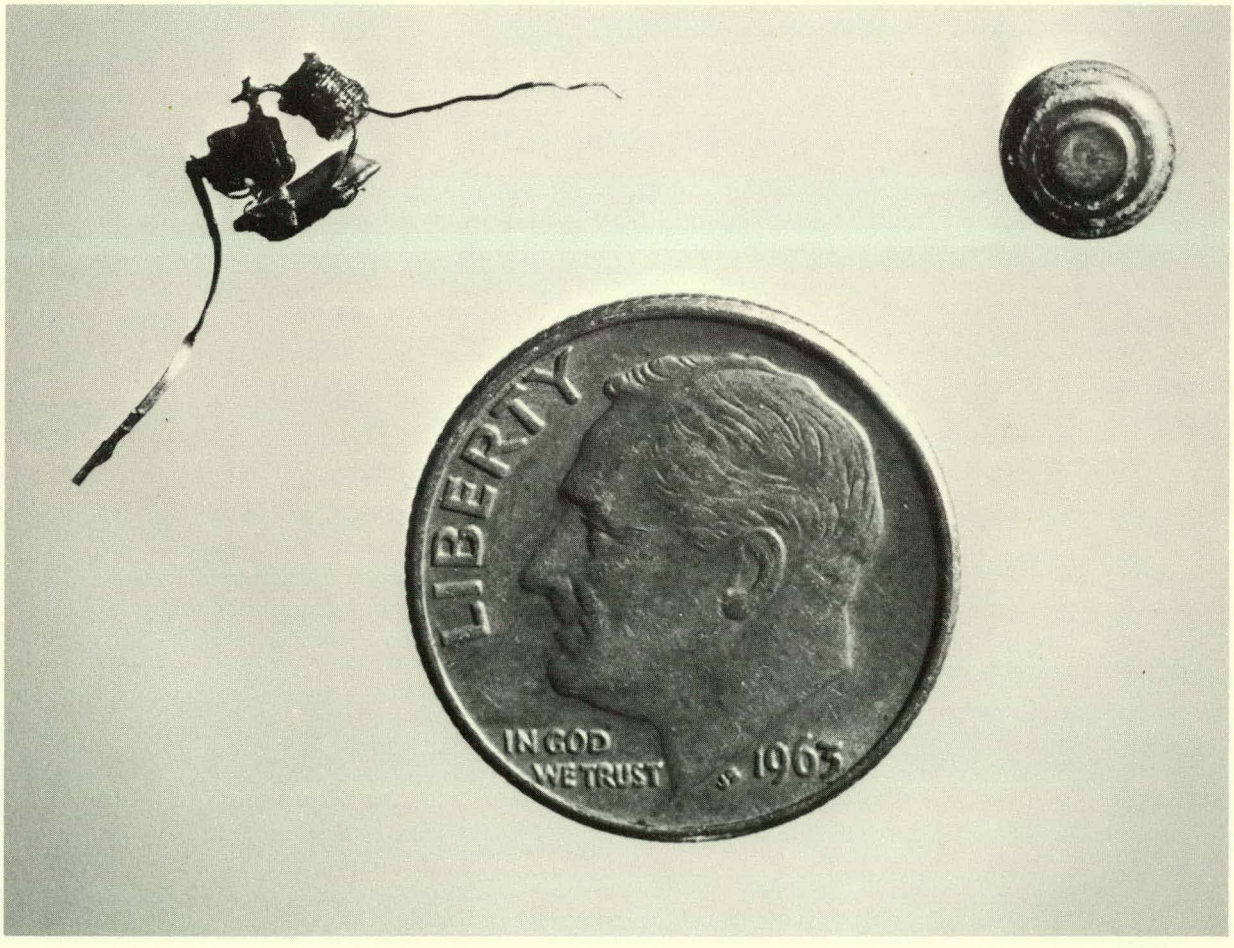


Figure 4. Temperature telemeter transmitter (left) and battery (right) to fit into pea-sized dummy fuel element for reactor heat-transfer measurements. Dime is shown for size comparison.

many as 256 discrete constant velocities in either direction, with provision for grouping the velocities to cover interesting resonances.

The programmer consists of an up-down counter and some toggle-switch-controlled logic circuits driving a digital-to-analogue converter whose output is the reference input to the velocity servo. The drive and velocity-sensing elements are two short, cylindrical voice coils on a single form supported by flat springs in a long, uniform, annular magnetic field. The voltage generated by one coil moving in the magnetic field is compared with the reference voltage, and the difference is amplified and applied to the other coil to form a closed servo loop.

Flyback is initiated when the displacement exceeds a preset value indicated by the drive coil current. A V-shaped voltage waveform is then generated by an operational integrator and some switching circuits. This voltage is added to the reference voltage and instructs the transducer to accelerate and then decelerate linearly in the flyback direction to provide a smooth return to the original velocity with no sudden velocity changes that would excite mechanical resonances.

Many other circuits were provided in response to specific requests, some involving a substantial amount of skill in development. One project involved redesign of the current regulator for the magnet of the 60-in. cyclotron and supervision of the design and production of 23 current-regulated supplies for the new poleface windings (currents to 2000 A). Another project was to design the circuits of a monitor for the rf separated beam at the 80-in. bubble chamber. The beam consists of from one to twelve 20-nsec bursts, separated by 200-nsec intervals. The detector is a thin plastic scintillator coupled to a photomultiplier tube. The output charge is doubly integrated, then differentiated with time constants selected so that the resulting pulse amplitude is highly proportional to the initial charge, regardless of whether it arrived in one or several bursts. The pulse amplitude is measured by conventional techniques and a digital output is available. A range of 1000 to 1 in amplitude is provided, and the scale may be changed by a factor of 10 to cover 10^{-12} to 10^{-8} coulombs. A pulsed light source is attached to each scintillator for calibration purposes.

One novel development is a tiny transmitter which, together with its battery and a radioactive source to provide heat, fits inside a sphere ⅜ in. in diameter. The sphere will be used in a reactor mock-up to determine the cooling efficiency for spheres bounced around in a liquid. The temperature-sensing element is a thermistor which determines the audio oscillation frequency of a "squegging" oscillator.

METEOROLOGY

Wind, Dispersion, and Deposition

A routine feature of hazards analyses involving major sources of radioactivity has been an estimate of the worst possible dispersion conditions that might accompany a postulated accidental release. It has been recognized that such conditions are necessarily a function of the duration of the release and that it is unrealistic to assume the continuation of adverse meteorological conditions for long periods, but simple techniques of relating dispersion to time have not been easy to develop. Proper estimates involve calculating downwind concentrations for the shortest periods of interest and expanding the evaluation in time by summation of successive periods. Variations in wind direction, wind speed, and dispersion conditions are thus completely taken into account and a dispersion climatology may be developed.

For periods of up to a few hours, a fixed wind direction and extremely adverse dispersion conditions may be assumed, but for longer periods the least favorable circumstances are almost always determined by lack of variability in the wind direction.

The most common expression of this lack of variability is persistence, determined by tabulating the number of hours during which the wind remains in some preselected angular direction sector. This method can fail to indicate the extent of a given hazard, since the deviation of the wind from a given sector for an hour effectively ends an instance of persistence, even though the wind may resume the same direction immediately thereafter.

The Meteorology Group examined the applicability of the statistical concept of "constancy," represented by the ratio of the vector mean and the scalar mean of the wind velocity, as a tool for indicating more reliably the effect of wind direction variations. If the wind direction does not change, a constancy value of 1 is possible; conversely, if there is extremely wide variability the value of the ratio falls to nearly zero.

This expression has several advantages. It is very simple to apply, it requires no prior decisions regarding appropriate widths of direction sectors, the resulting values can easily be converted to a numerical probability statement, and the data provide an immediate indication of both the type of meteorological conditions and the direction involved in the least favorable cases.

The initial results for the Brookhaven site are quite interesting. Periods have been found in which the wind direction is almost invariant for as long as 4 days. This is rather surprising, since typical persistence analyses did not suggest periods of that length. In addition, a high constancy seems always to be accompanied by relatively strong winds. Thus, at this site the most constant meteorological condition over long periods apparently cannot be the deep temperature inversion which is usually selected as the least favorable short-term dispersion case.

A second study relating meteorological parameters and dispersion conditions stressed the estimation of dispersion conditions from various combinations of available meteorological instruments, ranging from ideal to minimal. Although this system was developed specifically for Brookhaven, it is thought to have general application.

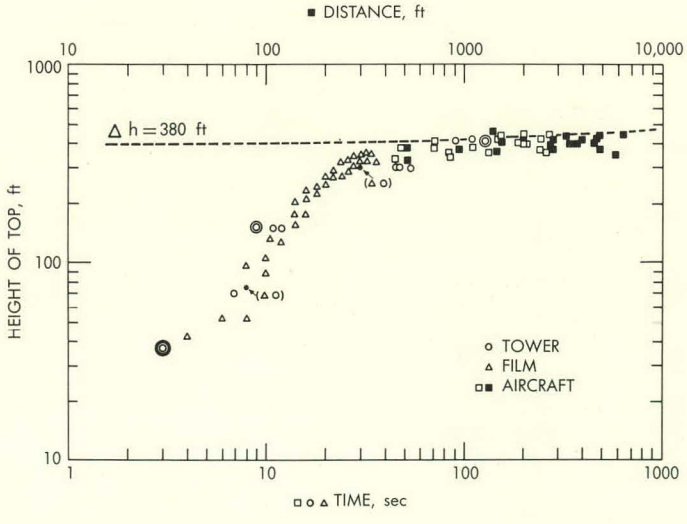


Figure 5. Cloud top vs distance downwind and time after ignition. Plotted symbols show the height-vs-time development of the tops of a series of four clouds generated by burning rocket fuel. Mean windspeed, 8.4 m/sec; lapse rate, $+4\times10^{-2}$ °C/m. The dashed line represents the top of a passive cloud originating from a theoretical point source at 380 ft above the ground.

The dispersion and deposition field experiments were concentrated on forest studies. There are now 12 complete tests using the 3-color pollen releases from different heights and horizontal positions simultaneously, supplemented by a smaller number of tests in which pollen was released inside the forest. Because of the large amount of data required for significant results, this program has been devoted almost exclusively to data collection and processing in fiscal 1966. Since no mechanical technique has yet been found to substitute for counting of the colored pollen particles on the slides by technicians, there is a large time lag before analyses of the data can begin.

Buoyant Puffs

One of the most rewarding programs conducted by the Group in recent years has been the study of the ascent of buoyant clouds. In 1965 the experimental work, consisting of the generation of hot clouds by rocket fuel under varying meteorological conditions, was completed. Data were also collected by the same technique at a remote site where very much larger amounts of fuel were used. Total fuel releases studied ranged from approximately 10 to 100,000 pounds.

A simple, reliable technique for differentiating the buoyant rise of the cloud from that associated with natural atmospheric dispersion was developed and thoroughly proved. In Figure 5 the dashed line represents the path of a cloud top from a theoretical point source at height Δh above ground, whereas the plotted points indicate successive positions of actual cloud tops as they rose and began to disperse naturally in a series of four tests under inversion conditions, each involving heat release of 10^8 cal. Matching the theoretical cloud top with the actual points at considerable distance from the source provides a reproducible estimate of Δh, applicable to any visible cloud.

It is not surprising that this technique gives good results under stable conditions where natural dispersion is very small and the cloud behaves almost like a balloon. It is gratifying, however, to find that an identical mathematical expression also describes the behavior of such clouds under unstable conditions, as long as the cloud retains its cohesive form.

BGRR Plume

Improved analytical and sampling techniques developed by the Health Physics Division made it

possible for the first time to study ground-level concentration distributions of the BGRR cooling air. Heretofore general assessments of these distributions were available from measurement of Ar^{41}, but the large gamma-ray contribution made it practically impossible to obtain point concentrations. The technique used during the past year depends upon the minute amount of I^{131} released from the BGRR stack. Despite some interference from Chinese weapons tests and modest uncertainties concerning both the output of I^{131} and the accuracy of its detection, good comparisons have been made between predictions and measurements of ground-level I^{131} concentrations.

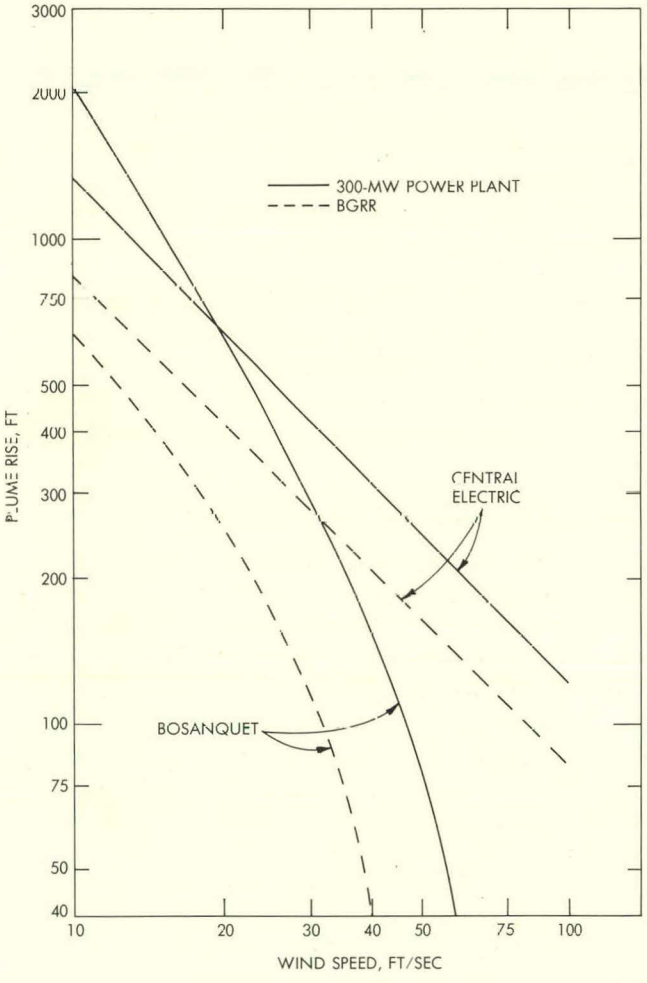


Figure 6. Comparison of plume-rise formulas. The plots show that predictions of the Bosanquet and Central Electric plume-rise equations are about identical in the typical (15 to 25-ft/sec) wind-speed range when applied to a 300-MW power plant. Similar plots for the plume from the Brookhaven Graphite Research Reactor differ significantly at all speeds.

The data also showed that the Bosanquet, Carey, and Halton equation (1950), which has been widely used to estimate the buoyant ascent of large volumes of stack gas, does not apply well to the BGRR stack. Under typical daytime conditions, predictions based on this formula grossly overestimated ground-level concentrations within 1 km but were in close agreement beyond 2 km, a clear indication of underestimation of the plume rise. The equation for plume rise developed by the Central Electric Authority in Britain was used to re-evaluate the concentrations, with much more satisfactory agreement.

This result seemed strange, since the experience at the sites of several large fossil-fuel power plants had shown the Bosanquet estimates of effective stack height to be good. The problem was resolved when calculations revealed that the Bosanquet and Central Electric estimates agree well for 300 to 1000-MW power plants, but give differing results for the smaller BGRR plume. Figure 6 shows the comparison.

Further study is needed to determine what adjustments in the meteorological predictions of dispersion from the BGRR are still required. For example, the prediction system shows a consistent tendency to slightly underestimate concentrations, even at large distances from the source. This suggests some discrepancy in the prediction technique that is not associated with stack height, or possibly a tendency to overestimate the I^{131} measurements.

Instruments

Completion of a variety of automatic data-collecting systems, including printing counters and the scaler–IBM 526 card system mentioned last year, has allowed rapid progress to be made in wind profile and structure studies. One of the most interesting aspects of this work has been the investigation of the influence of the tower structures on wind measurements. The presence of a structure, even one as open as the main Brookhaven tower, can cause deviations of the mean wind speed measurements to reach 20% of those observed at the top of a small, independent spire 100 or more feet from the large structure.

Nuclear Engineering

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

In the second category is the long-range work of developing components that may bring about significant advances in reactor technology and radiation application. Some of the more important phases of this work are the development of reactor fuels, high-temperature volatility and fluidized-bed processing schemes, utilization of fluidized beds for water desalination, radiation engineering methods, waste processing devices, and direct conversion concepts.

The engineering and evaluation studies in the third category are focused on practical application of the work in the preceding categories. Typical studies that continued during the year concerned pulsed fast reactors, chemonuclear reactors, and rotating-bed concepts. Assistance was given to the Division of Reactor Development and Technology of the Atomic Energy Commission in the review of the Molten Plutonium Fast Breeder program.

Because of the Commission's policy of concentrating efforts on a few mainline conceptual designs such as the Liquid-Metal Fast Breeder Reactor, the High-Temperature Graphite Reactor, and the Heavy Water-Moderated Organic-Cooled Reactor, the Department has had to curtail its efforts on the settled bed reactor systems. In the future, its program will be more closely aligned with the AEC's mainline programs. A Liquid-Metal Center has been established in the Metallurgy Division, with engineering testing, corrosion fundamentals, and sodium solution chemistry as the main efforts. The Reactor Physics Division will place more emphasis on critical experiments for fast reactors. The development of the nitrofluor process has reached a point where meaningful information is available for evaluating the technical and economic potentialities of this process: hence this work will probably be phased out this year.

A cooperative program on superconductivity between the Cryogenics Group of the Physics Department and the Metallurgy Division has been continued with studies related to the temperature and magnetic field limitations of superconductivity, the role of surface currents in hysteresis, and the thermodynamic properties of hysteretic superconductors.

The High Flux Beam Research Reactor (HFBR) went into routine operation. The preoperational and operational tests on the reactor confirmed the expected reactor physics performance precisely. The only difficulties encountered during start-up and subsequent high-power operation were with conventional mechanical components, and these problems are gradually being eliminated.

At the request of the AEC, the Reactor Cross Section Evaluation Center will act as the hub of a short-term national effort to provide a set of evaluated cross sections of immediate use to reactor designers. Dr. S. Pearlstein has been named Chairman of the working group that will be responsible for providing the cross sections on a tape format called ENDF/B. During 1967 these cross sections will be tested by major AEC contractors for reliability and accuracy, and the results will be useful in improving future cross-section sets for reactor use.

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

Dr. Herbert Kouts, Associate Head of the Reactor Physics Division, has spent the year at the Centre d'Études Nucléaires de Saclay working with the experimental reactor physics group and will return in August 1966. Dr. Robert L. Hellens, Leader of the Reactor Physics Analysis Group, Reactor Physics Division, returned from a year of detached service at the Winfrith Heath site of the Atomic Energy Authority in England. Jack Chernick, Associate Head of the Reactor Physics Division, was named co-winner of the American Nu-

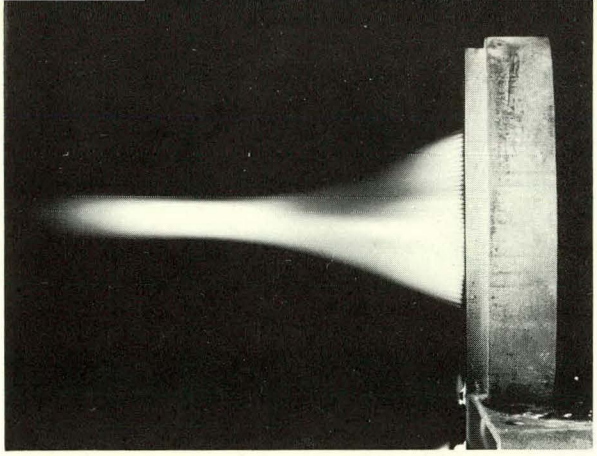


Figure 1. Focusing collimator for low energy gamma rays. Light rays reflected from smoke in a darkened room simulate the pattern of gamma rays passing through the collimator, here shown standing on edge. In practice the left (convergent) side of the collimator is placed against the subject to be radiographed in such a position as to bring the focus (left) within the organ to be scanned. A 3×3-in. scintillation crystal with appropriate photomultiplier tube and associated recording equipment is placed against the right (divergent) side of the collimator. The entire assembly then moves back and forth over the subject, scanning the organ to be visualized. Thus a statistically large number of counts from a relatively small spot are accumulated, and a high-resolution autoradiograph is produced in a relatively short time. The 140-keV gamma rays of Tc^{99m} are ideal for this kind of collimation, and the collimator was developed at Brookhaven to assist in making this isotope more useful.

clear Society's Special Award, given this year for outstanding contributions to reactor physics. Mr. Chernick was cited for the breadth and variety of his contributions, particularly work on "resonance absorption, reactor kinetics and leadership of a distinguished group of reactor physicists."

D. Ballantine of the Radiation Division, in cooperation with Dr. Okamura of Kyoto University, Japan, coordinated and organized the Joint US/Japan Conference on Radiation Chemistry in Hawaii. Staff members from the Nuclear Engineering, Biology, Medical, and Physics Departments and the Information Division operated gamma facilities and presented lectures at the Werken met Atomen Exhibit, Utrecht, Netherlands, sponsored by the AEC's Division of Technical Information.

REACTOR PHYSICS

Theoretical Reactor Physics

Research in neutron thermalization was concerned with deepening the understanding of the rapid developments of the past few years. Williams' solution to the thermal Milne problem was generalized to include absorption laws of the form $1/v^n$. The ensuing solution agreed remarkably with elaborate numerical calculations based upon more complicated kernels. It also predicted the experimental extrapolation length and a range of diffusion lengths in light water.

The pulsed neutron problem was examined in the limit of small sample size with use of synthetic kernels. In one case the influence of exact boundary conditions was assayed. The decay constant was computed as a function of sample size for sphere and slab, with scattering governed by a simple, separable kernel. In this context, several theorems were proved about the eigenvalue spectra. The exact results were compared with the prediction of asymptotic transport theory, and a size-dependent extrapolation length was obtained.

In another investigation, the effect of crystalline moderator structure upon decay constants was considered. A synthetic kernel, adjusted to reproduce the more important features of scattering by beryllium, was used, and the time-evolution of a neutron pulse was studied in some detail. It was found that in the "forbidden region" $[\lambda > (v\Sigma)_{min}]$, where experiments give λ_0, there nevertheless is a strong peak in the continuum contribution which may be identified with λ_0. Closer analysis shows that the zero in the critical equation for the decay constant has moved onto another sheet of a Riemann surface which characterizes the problem.

Other aspects of thermalization on which progress was reported include the refinement of the maximum absorption theorem for diffusion length and the treatment of transport problems by the method of invariant imbedding.

Research in the theory of resonance absorption was concerned with applying the intermediate resonance absorption approximation to all species in a lattice system. Numerical results were in good agreement with Monte Carlo calculations and showed marked improvement over direct computer code (ZUT) calculations. The next step in the improvement of the analysis is a more realistic treatment of the spatial dependence of flux in the lattice cell.

General aspects of calculation by variational methods have also been examined. In particular, a study has been made of the relationship between variational principles in time-dependent neutron diffusion theory and in classical mechanics. In ad-

dition, the problem of choosing one variational functional over another in the computation of a particular weighted average has been investigated.

In fluid dynamics, a study of the steady motion of a disc through a viscous fluid has been completed. Attention has now been turned to the problem of solving the Navier-Stokes equation for the *accelerated* flow of a viscous fluid around a sphere. The problem of 2-phase flow has been investigated in the context of the flow of boiling water in heated pipes. Experiments characterized by high pressures and long heating lengths have been analyzed, and a critical boiling length at which the system is least stable has been shown to exist. This result can be used to explain previous ambiguities in the effect of subcooling on stability. Another aspect of fluid dynamics, the packing of large numbers of hard spheres into rigid containers, has received considerable study via computer simulation. Most of the resulting configurations have been analyzed and are found to adequately represent loose packings of spheres in containers.

Reactor dynamics received attention through the study of coupled fast reactor cores and through research on the general theory of dynamical stability. Practical formulas giving the amplitude and frequency of limit cycles (for reactor oscillations) have been derived along with several general stability criteria.

Experimental Reactor Physics

The reactor physics program has included a broad spectrum of integral experiments with critical, exponential, and nonmultiplying assemblies, designed to study basic reactor systems. In addition, the research reactor program included start-up measurements in support of the HFBR and an experimental study of swimming pool reactors with the Beam Experiment Test Assembly.

The Minimum Reflection Critical Facility was used to study graphite-moderated cores using highly enriched U^{235} fuel in critical assemblies. In the course of the experiments, nominal graphite-to-U^{235} atom ratios ranged from 22,900 to 950. The assemblies were very nearly homogeneous, requiring only small corrections to account for the flux depression within the fuel. Measurements on six assemblies of varying carbon-to-uranium ratios included the following parameters: buckling, disadvantage factor, prompt neutron generation time, temperature coefficient of reactivity, and spectral indices. The latter measurements were accomplished by the activation of In, Au, Lu, Mn, Pu, and U.

A critical assembly is being built to measure cross sections and resonance integrals of transuranic isotopes. The assembly consists of graphite and enriched uranium and contains an oscillator which can move small samples of the material to be studied in and out of the central region. Cross sections and resonance integrals can then be inferred from the effect of the samples on the overall reactivity of the system. Construction will be completed by the end of fiscal 1966.

Exponential experiments with the $U^{233}O_2$-ThO_2 fuel elements have progressed along two lines, namely, studies of uniform lattices with H_2O moderator and studies of a clustered lattice with organic coolant and heavy water moderator. The study of uniform lattices is a continuing program at BNL which has encompassed variations of fuel-rod diameter, enrichment, and spacing. The purpose of the uniform lattice studies is to provide a basis for the confirmation and improvement of theoretical techniques in reactor physics. The organic-cooled cluster lattice study is part of the cooperative program with the Babcock & Wilcox Co. to provide data on a few specific lattices. These data will be used by B&W for the design of a reactor of this particular type.

The 1-MeV Van de Graaff generator was used as a pulsed source of neutrons for measurements with the 1.25% enriched uranium slabs in water, and for neutron diffusion measurements in a graphite prism containing cadmium rods. The pulsed experiments with 1.25% enriched uranium demonstrated conclusively the effect of a water reflector on such measurements and indicated the problems introduced by a reflector in calculating the behavior of a subcritical multiplying assembly. The neutron diffusion measurements in graphite indicated a small deviation from neutron diffusion theory. It was shown that the difference could be eliminated by making an arbitrary, yet consistent, correction to the extrapolated distance of thermal neutrons at the boundaries.

Measurements of neutron migration anisotropy have been made by using ¼-in.-thick aluminum plates in water with a 1:1 volume ratio (see Figure 2.) Measured values of anisotropy in both the neutron age and neutron diffusion length are somewhat larger than predicted by conventional theories. Experiments are under way, using a 2:1 vol-

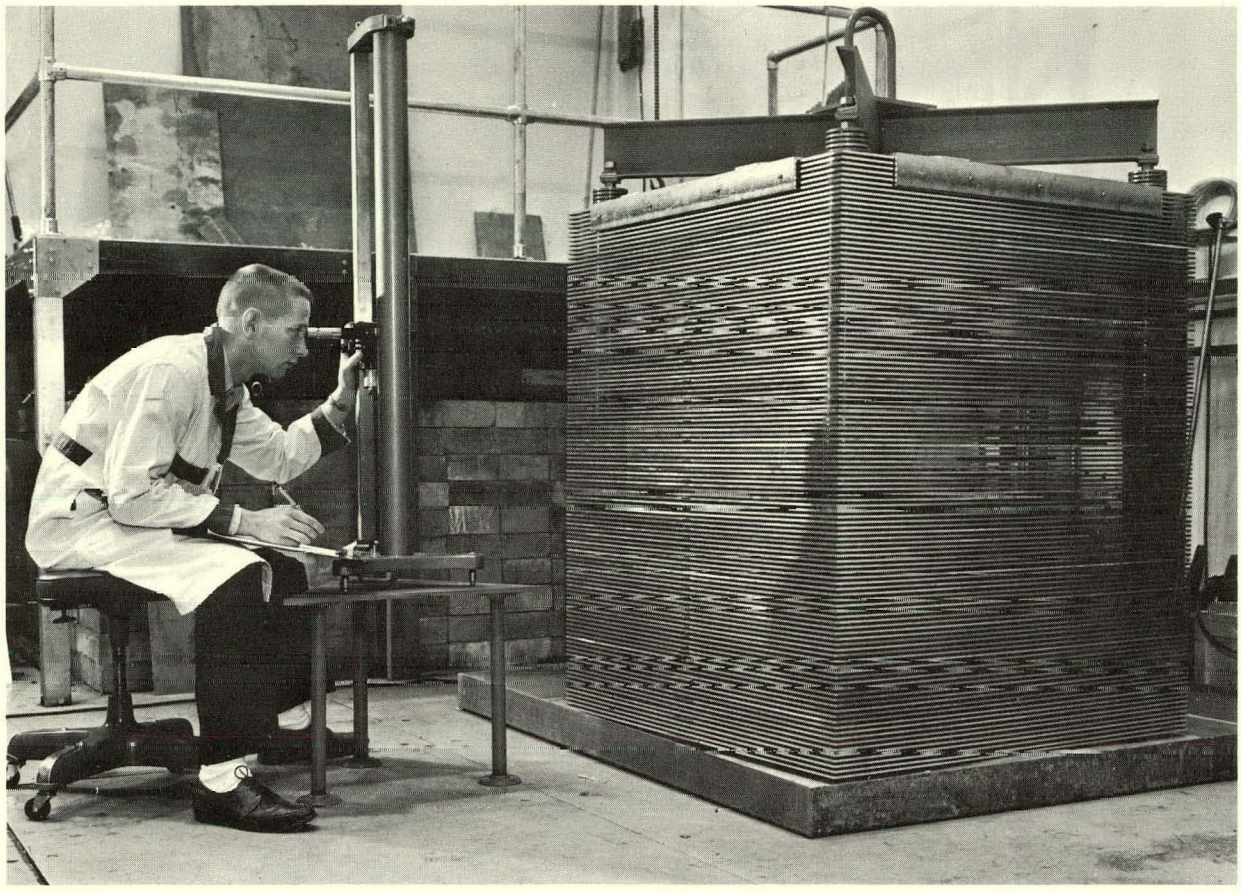


Figure 2. Aluminum stack for measurement of neutron migration anisotropy.

ume ratio of aluminum to water, to confirm these results.

The Beam Experiment Test Assembly was used to study neutron beams from split-core water-moderated reactors. It was shown that introduction of a horizontal gap in the plane of the beam tubes can effect an improvement in the quality of the thermal neutron beam extracted from the assembly. However, application of the split-core concept to reactors operating at >1-MW power would require a different approach in the control of the reactors because of decoupling effects in the split core.

Start-up measurements were conducted on the HFBR to confirm the design parameters. All the reactor physics parameters were found to be in agreement with predicted values, and no unexpected reactivity effects were found to exist.

The power levels of Neutron Source Reactors I and II were increased from 1 kW to the design value of 100 kW. These reactors provide broad beams of neutrons for the exponential experiments and neutron migration measurements.

Reactor Physics Analysis

The work in reactor physics analysis has been strongly affected during the past year by the advent of some new computer codes which link a number of well-known theoretical methods in a consistent way. The HAMMER code, in particular, provides a detailed description of the space and energy distribution of neutrons in a reactor lattice cell with use of techniques that should be valid for either graphite or light or heavy water moderators. Thus comparative studies can be made on a consistent basis of a very wide range of lattice experiments, and such studies will comprise much of the work undertaken during the next year. So far, a limited number of light water and graphite systems have been analyzed with use of HAMMER, and

the consistency of the code will be compared with more elaborate Monte Carlo calculations.

As the analytical methods become more refined, the accuracy of the neutron cross-section data employed in the calculations becomes a major limitation on the precision attained. The sensitivity of reactor characteristics to cross-section uncertainties has been studied. At the same time a significant effort has been made to reduce errors of this sort by bringing the group's cross-section libraries into agreement with the latest evaluations of cross-section measurements. Particular attention has been given to resonance capture in U^{238} and Th^{232}, and theoretical results for the resonance integral, based on resonance parameters recommended in BNL 325 (Supplement No. 2), agree with integral measurements within the quoted experimental error. The theory of resonance absorption in heavy moderators has been improved by developing an intermediate approximation for the moderator as well as the absorber. The results show that significant errors in the resonance integrals of the wide, low resonances of uranium and plutonium are produced both by the narrow resonance (NR) approximation and by the conventional use of the NR integral in an exponential function.

One of the most persistent sources of uncertainty in the analysis of exponential experiments performed at BNL and elsewhere has been the evaluation of the reactivity worth of the reflector. Experimental determinations by different methods have always given significantly discrepant results, and conventional few-group theory displays large systematic errors. Some initial improvements have been made by using a more accurate neutron slowing-down spectrum in the reflector, and as a result it has been possible to account for much of the discrepancy between theory and measurements performed in the B&W high-temperature exponential facility. Work on a more exact treatment of the 2-region problem by multigroup S_n methods is in progress, but it is too early to tell whether this approach will resolve the apparent discrepancies in the BNL exponential analysis for uranium and thorium fuel.

Sigma Center

Neutron Cross Section Compilation. Volume III ($Z=88$ to 98) of the second supplement to the second edition of BNL 325 was issued in July 1965. It includes the neutron cross sections of the fissionable elements for which significant changes in knowledge have occurred since the first supplement was issued in 1960.

Volume II of the second supplement will consist of two parts, issued separately. Part IIA, covering elements with $Z=21$ to 50, is expected to be available for distribution in the summer of 1966. Part IIB, covering elements with $Z=51$ to 87, should be available for distribution during the last quarter of 1966. Its publication will complete the supplementing of the second edition of BNL 325.

The Sigma Center Information Storage and Retrieval System (SCISRS) has grown considerably, and $\approx$500,000 individual data points are now available on magnetic tape. All the data for cross sections of the fissionable materials were added during the year. The data for nuclides with $Z=1$ to 20 are being corrected, since a number of errors were found in the data supplied by outside sources. The bulk of the angular distribution data given in BNL 400 is available on tape, as are most of the data to appear in Volume IIA. Since the summer of 1965, all new data of any sort coming to the Center have been routinely processed into the SCISRS format and rapidly put on the tape.

One of the problems of the Center is dealing with large quantities of data from time-of-flight spectrometers. A test was run with $\approx$300,000 data points, received from Columbia University, which demonstrated the feasibility of adding such data in a short period of time by use of bulk time made available on the Laboratory's IBM 7094.

A letter describing the SCISRS system was sent to laboratories that might wish to obtain complete SCISRS tape libraries for their own use. Several such libraries were requested and have been sent out.

A subcommittee of the AEC Nuclear Cross Section Advisory Group has been formed to obtain information from reactor and weapons laboratories regarding their neutron cross-section needs for compilation and evaluation purposes. The subcommittee will draw up specifications for a new SCISRS format to satisfy these needs.

Reactor Cross Section Evaluation. The Evaluated Nuclear Data File (ENDF), designed to contain the evaluated neutron cross-section libraries of major laboratories, became operative. At present it consists of data from the Aldermaston-Winfrith data files and the Knolls Atomic Power Laboratory. Additional libraries are being converted to the ENDF format. Many requests for

cross-section data and service routines were processed by the Center.

The total cross section of sodium was calculated from 1 eV to 40 keV by using BNL 325 resonance parameters and the single-level formula with spin-dependent scattering radii. This model produced improved fits to the experimental data. Applications of the single-level formula to the transuranium elements provided consistency checks between differential and integral measurements. The nuclides U^{236}, Np^{237}, Pu^{238}, Pu^{240}, Pu^{241}, Pu^{242}, Am^{241}, Am^{243}, and Cm^{244} were investigated. Good agreement between resonance integrals extrapolated from differential data and integral measurements was noted for all cases except Pu^{238} and Np^{237}. New information was obtained for the capture integrals of Pu^{241}, Am^{241}, and Cm^{244} and the fission integral of Am^{241}.

The neutron cross-section fluctuations occurring in the high energy continuum region have been investigated. Random collision matrices are used to determine the cross-section statistics in this region. Numerical work is proceeding.

Pulsed Fast Reactor

A study has been made of advanced research reactor concepts to provide a significant increase in peak neutron flux for pulsed neutron beam experiments. The system selected for further concentrated study is a pulsed fast reactor.

The goal is to attain a peak neutron flux greater by at least two orders of magnitude than that available from a steady-state research reactor. Preliminary calculations have been completed for liquid-metal cores containing PuO_2–stainless steel cermet fuel elements. Two rotating wheels would provide the reactivity changes necessary for pulsing and would control the pulse repetition rate. One wheel could contain fissionable material, while the other would involve a moving reflector section.

Cores of various sizes ranging from 5 to 42 liters have been considered with power pulses up to 1 MW-sec at a repetition rate of 20 to 50 pulses/sec. The smaller cores have the advantage of a short prompt neutron lifetime (in the 10^{-8}-sec range), as well as a greater capability for obtaining large reactivity swings, although they are limited in pulse power by heat transfer and thermal shock problems. The larger cores can sustain greater power pulses; however, the neutron lifetime is longer and it is more difficult to obtain large reactivity swings with reasonable rotating equipment. Present efforts are aimed toward optimizing the concept between these extremes.

Evaluation and Technical Assistance

Design and Evaluation Studies. An economic study was made of the use of a lead bromide chemical direct-conversion device as a topping unit for a 1000-MW(e) nuclear plant. It was concluded that the system can be economic if current densities of the order of 2000 amps/ft^2 can be achieved and if cells and auxiliary equipment can be fabricated for about \$14/ft^2. The study indicates the need for extensive engineering work to make this proposed system practical. Two proposals were evaluated for the AEC. The first proposal was for the development of a remote rotor electric drive for use in large, seal-less sodium pumps. The second was for a high-temperature gas turbine system called the Supertemperature Dual-Flow Turbine System. Assistance was also given in a technical review of the Los Alamos Liquid Plutonium Fuel Program initiated by the AEC through the Liquid-Metal Fast Breeder Reactor Program Office at Argonne National Laboratory.

Transuranium Elements. Studies continued on the production of heavy elements such as Pu^{238} and Cm^{244} utilizing neutrons in the epithermal energy range. A number of conceptual fuel management schemes were studied with use of a computer code, PLUCAL. A second, more sophisticated program, called PUPER, designed for the Pu^{239} production chain, has been written. As with PLUCAL, all results indicate that there are distinct advantages in using a hardened spectrum for Pu^{238} production by multiple neutron capture.

Modification of Power Reactor Control Rods To Produce Salable Co^{60}. A study was made to determine the feasibility of substituting Co^{59} for some other structural materials normally used in the fabrication of control rods in order to produce salable Co^{60}. The results of the activation analysis indicated that significant quantities of high specific activity Co^{60} could be produced if a proper schedule of control rod insertions could be maintained.

Rotating Fluidized-Bed Research Reactor. An examination of the rotating fluidized-bed reactor concept proposed by L.P. Hatch indicated that this reactor could produce extremely high fluxes for significant periods of time. The significant fea-

ture of this system is the use of a particulate fuel in the form of a rotating annular fluidized bed, fluidized by a coolant gas and constrained in the core by centrifugal force. Physics and mechanical design studies indicate that it may be feasible to build a reactor of reasonable size with rather conventional equipment and to obtain fluxes of the order of 4×10^{16} neutrons/cm^2-sec at 5000 MW(t) for a period of $\approx$1 min. Fluxes of this type are an order of magnitude higher than those obtainable from recently built high-flux research reactors.

METALLURGY AND MATERIALS SCIENCE

Reactor Metallurgy

Materials for Containing Liquid Metals. Metallographic examination of the natural circulation loop fabricated of tantalum, which contained mercury boiling at 650°C and superheated to 750°C for 20,000 hr, revealed no corrosion or mass transfer. Further, there was no evidence of the stress corrosion cracking observed in some Nb-Zr alloys. Three natural-circulation boiling mercury loops were operated with the boiler at 593°C and the superheater at 702°C for 5000 hr to test the effect of adding zirconium and titanium to the mercury as inhibitors in loops fabricated of 2¼% Cr–1% Mo steel. No corrosion or deposition was detected in the inhibited loops; however, the uninhibited loop had a maximum depth of attack of 25 μ, a 1-g deposit in the boiler, and a 3-g deposit in the condenser. A large forced-circulation boiling mercury loop fabricated completely of refractory metal is in operation to test a tantalum alloy (Ta–9W–2.4Hf) for use as a turbine blade material. The boiler operates at 593°C (300 psia), the superheater operates at 702°C, and the vapor velocity through the turbine nozzles is 500 to 850 ft/sec.

Eighty reflux capsule tests and nine natural circulation loops have been operated and examined to evaluate the ability of refractory metal alloys to contain boiling alkali metals at temperatures up to 1200°C. Results of these tests indicate that all the alkali metals (Na, K, Li, Cs, and Rb) can be readily contained in refractory metals if the oxygen content of the alkali metal is maintained at a very low level and the refractory metal contains a getter element such as Zr, Ti, or Hf. Refractory metal alloys that show promise as turbine material for a cesium Rankine cycle system are being evaluated in the forced-circulation boiling loop shown in Figure 3. Molybdenum alloys TZM and TZC* are currently being tested. Cesium is circulated through the loop at 90 lb/hr, boiling at 960°C and condensing at 650°C, with a vapor velocity of 800 ft/sec and a vapor quality of $\approx$80% at the test blade materials. As of May 8, 1966, the loop had operated for 1000 hr under these conditions.

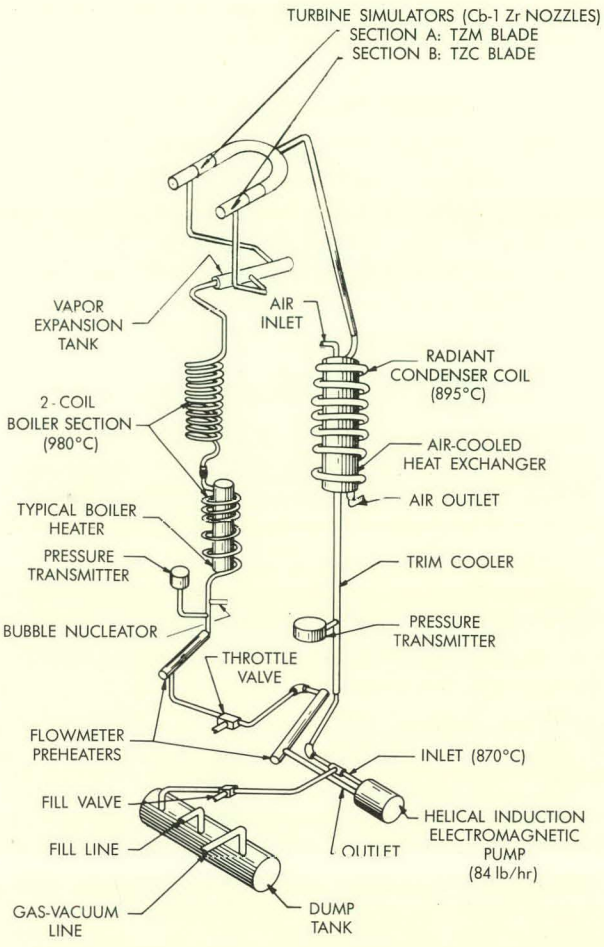


Figure 3. Schematic of pumped boiling cesium loop.

The corrosion program at the BNL Liquid-Metal Center has been redirected toward the study of materials to contain flowing sodium at temperatures up to 816°C. This program will provide information for the Liquid-Metal Fast Breeder Reactor program. Conventional alloys such as the stainless steels and cobalt alloys as well as the refractory metal alloys will be investigated.

*TZM = Mo + 0.5 Ti + 0.08 Zr + 0.015 C; TZC = Mo + 1.25 Ti + 0.03 Zr + 0.15 C.

Studies will be made of the corrosion mechanisms and the solution chemistry of liquid sodium.

High-Temperature Properties of Materials

Thermodynamic Properties of Refractory Metal Compounds. The free energies, enthalpies, and entropies of formation of ThP and Th_3P_4 were obtained with use of solid electrochemical cells. These thermodynamic properties were also determined by measuring the vapor pressures of nitrogen over the 2-phase system ThN-Th_3N_4 at temperatures of 1400° to 1800°C.

Thermal expansion data up to 2000°C have been obtained on several nonstoichiometric zirconium carbides and on the thorium compounds ThN, ThP, Th_3P_4, ThB_6, and ThO_2 with use of a high-temperature x-ray diffraction camera.

Electrical Properties of Refractory Metal Compounds. Measurements of the electrical resistivity, thermoelectric power, and Hall coefficients have been made on nonstoichiometric ThC, Th(C,N), ThN, and Th_3N_4.

The results on nonstoichiometric ThC are best explained with a 2-band conduction model in which the band overlap decreases with increasing carbon content. In the case of the thorium carbonitrides and ThN, the lower energy band is completely filled and the solid behaves as a metallic conductor with a single conduction band. Th_3N_4, on the other hand, has very high electrical resistivity and thermoelectric power and behaves as a semiconductor.

Graphite Lamellar Compounds. The free energies, enthalpies, and entropies of formation of the rubidium compounds were determined from measurements of the vapor pressures. The phases that occur in the rubidium-graphite system were found to be the same as those in the cesium-graphite system.

A theoretical calculation was made of the bonding energy of cesium in the cesium-graphite lamellar compounds based on the assumption that the cesium in the compounds is fully ionized. The results of the calculation are in good agreement with a value of the bonding energy derived from the thermodynamic data.

Effects of Radiation on Structural Materials

The iron and steel irradiation program has shown the following characteristics of fast neutron damage in annealed iron: The yield stress increases with fast neutron exposure at 70°C (343°K) until a threshold exposure of 2×10^{18} nvt ($E>1$ MeV) is reached. At this exposure and above, the yield strength increases more rapidly and a sharp ductile-to-brittle transition is produced in iron tensile-tested below 130°K. Reduction of interstitial impurities in solution by purification or the addition of a strong carbide and nitride former, such as chromium, prevents the occurrence of this embrittlement effect.

Irradiations were conducted at −70°C (203°K), where vacancies and interstitial impurities are immobile. No embrittlement was observed (see Figure 4), although the fast neutron exposure exceeded the threshold value of 2×10^{18} nvt ($E>1$ MeV). Additional data from iron irradiated at the 250°C embrittlement recovery temperature also show ductile behavior below the 130°K transition. These findings, coupled with data in the literature showing that nitrogen and oxygen defect combinations are recovered well above 250°C, indicate that the embrittlement is produced by a

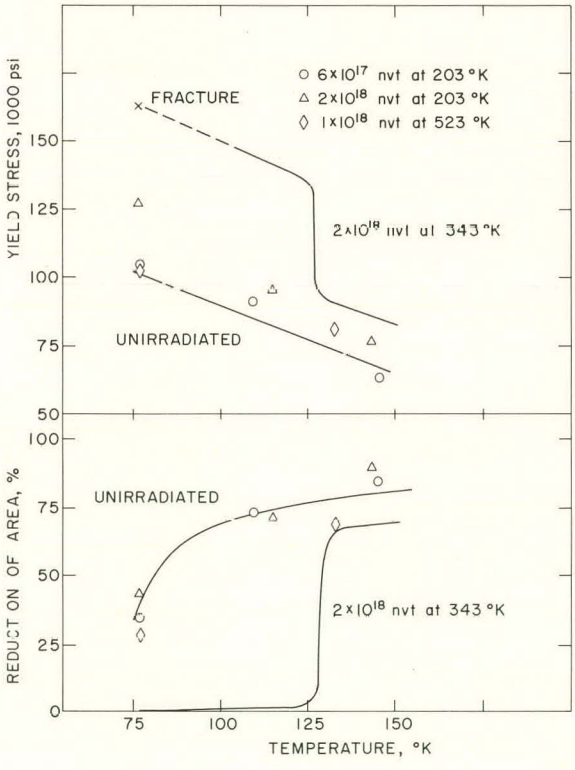


Figure 4. Yield stress and reduction of area vs temperature curves for Ferrovac iron before and after irradiation at 203°, 343°, and 523°K.

carbon-vacancy defect. Since the vacancy concentration at the threshold exposure far exceeds the carbon content, the defect must be a complex one involving several vacancies.

A program of periodically annealing steel after relatively short neutron exposures and thus preventing the formation of complex defects is being conducted. Embrittlement might be prevented from occurring in reactor vessels by utilizing periodic low-temperature anneals. Some beneficial effect of such treatment has been observed in A212B reactor steel after high (8×10^{18} nvt) accumulated exposures.

The effects of temperature, orientation, and irradiation on the deformation behavior of iron single crystals are being studied. Some of the tentative results indicate a 3½-fold increase in shear stress at room temperature due to irradiation, a constant fracture stress at low temperatures of 37.2 kg/mm^2 on the {100} plane, and a possible favoring of the {112} slip plane at low temperatures. Ductility at low temperatures is enhanced if slip is preceded by twinning.

The effects of irradiation on dislocation mobility have been studied by means of stress relaxation, strain rate, and prestrain tests. The results indicate that the major effect of radiation damage is to hinder the initiation of dislocation motion rather than propagation.

A correlation study has been made on irradiated Ferrovac iron in which radiation hardening has been related to the defect structure as seen in the electron microscope. By inference, at least three invisible defects have been postulated to explain the observed hardening in annealed iron. The formation and dissolution of these defects is a function of fast neutron exposure and composition.

An electron microscopy study is being conducted on the precipitation of carbon in irradiated iron. A reported enhancement of precipitation rate has been analyzed and the morphology of the precipitates has been studied as a function of exposure. These studies are being continued.

A liquid-helium-cooled field ion microscope has been built and is being used to study point defects in tungsten and platinum. Radiation-produced vacancies and depleted zones have been found in tungsten. Eventually defects in iron will be studied.

Alloy Theory and Nature of Solids

Liquid State of Metals. Experimental facilities have been set up for making measurements on the electron and mass transport properties of various liquid metals including liquid sodium. In developing the equipment, several useful measurements were made. For example, a dc electrical resistivity technique was used to show that previous "electrodeless" measurements in a variety of alloy systems were in error. In the previous measurements resistance anomalies had appeared at special compositions believed to correspond to compoundlike formation in the alloys. The present resistivity measurements on the Pb-Sn system show a smooth resistance vs composition behavior, which indicates that there is no compoundlike formation in this liquid alloy system. These measurements suggest that the general interpretation of compoundlike formation in liquid alloys derived from the electrodeless measurements is suspect. Measurements on a series of alkali metals confirmed that the thermoelectric power of the lighter metals is in good agreement with calculations. For the heavier alkali metals, the agreement with theory of the slope of the temperature dependence is good, while the magnitude of the effect differs from theory. The electromigration mobility was measured for a series of different metals in liquid bismuth. The systematic study of field effects is almost complete. The densities and surface tensions of liquid alloys of sodium with cadmium have been measured. The alloys' densities are greater and their surface tensions are less than those predicted for ideal mixing. While the various phenomenological theories are of some assistance in understanding the observations, there is as yet no fundamental

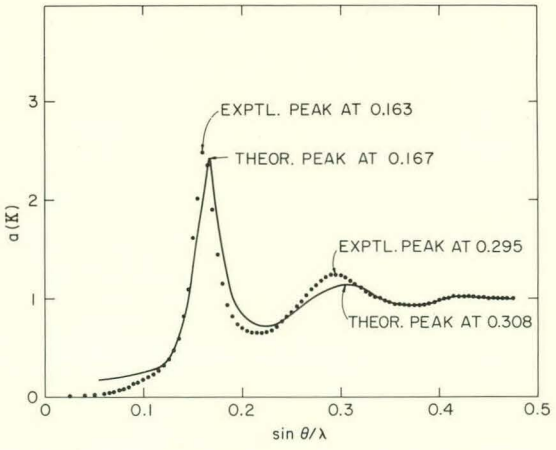


Figure 5. Theoretical curve for the structure factor $a(K)$ vs the experimental points taken from neutron data.

quantitative theory. Considerable progress has been made on computer studies of liquid sodium. By using molecular dynamic techniques and the long-range oscillatory potential considered appropriate for metals, calculations have been made of a series of fundamental properties. In Figure 5 the theoretical structure factor is compared with neutron diffraction data. Further analysis has yielded the diffusion constant and the various self-correlation functions of interest in statistical mechanics. From the mean square displacement and particularly from the velocity autocorrelation function, clear evidence is found for some solidlike behavior in liquid sodium. The calculations have also been used to examine the structure and its time dependence through the medium of 3-dimensional motion pictures. This promises to be an exciting new technique of studying liquids. Further studies are also being made of the phenomena of melting and crystallization.

Superconductivity. The superconductivity work has dealt with (1) the role of surface currents in hysteresis, (2) flux-trapping properties of high κ and low κ superconductors, (3) properties of ferromagnetic superconductors, (4) thermodynamic aspects of hysteresis, (5) properties of superconducting lamellar compounds, (6) paramagnetic limit of superconductors, and (7) changes of critical fields and critical temperatures in thin films.

New experiments involving surface coating, transport current, hollow cylinders, completely hysteretic systems, and ac susceptibility have demonstrated the major role of surface currents in hysteresis in low κ materials. A model interpreting the ac susceptibility data in terms of surface currents has been proposed.

Preliminary experiments on the flux-trapping properties of Nb-Sn and Nb-Zr show that these systems trap surprisingly small amounts of flux relative to low κ materials. Fundamental studies are in progress to investigate the significance of this observation. Studies of superconducting magnets have shown that stabilization is improved when the magnets are run in superfluid helium below 2°K instead of the usual 4.2°K. This effect has been explained in terms of the increased thermal diffusivity of the superfluid-magnet system.

Measurements of the superconducting and magnetic properties of ferromagnetic superconductors are being made. The results promise to yield interesting information regarding the superconducting state.

A thermodynamic description of superconductivity, in particular, that of hysteretic superconductors, has been formulated. This theory seems to be more consistent with the fundamental measurements than previous ideas.

A study of lamellar compounds has been undertaken to investigate the possibility of 2-dimensional superconductivity.

It is well known that some superconducting elements change transition temperatures when they contain oxygen or other elements in solution or compound. A program is being started to investigate the fundamental mechanism of this effect.

The work on thin films has led to surprising results regarding the superconducting transition temperatures of some thin film superconductors. In 100-Å aluminum films it was found that the transition temperature was increased by a factor of two. A model using a unique surface region and Ginzburg's ideas on surface superconductivity was highly effective in explaining these results. In tungsten films it was found that the transition temperature was raised from about 0.01°K in the bulk to about 4°K in films. The critical fields of the tungsten films were about 50,000 Oe in the main part of the film and near 100,000 Oe in the edge regions. Work is under way to investigate the detailed properties of these materials. Especially important is the possiblity of obtaining thin film materials with transition temperatures >18°K.

The effect of spin paramagnetism on the upper critical field of superconductors has been studied in $\approx$100-Å aluminum films. Experiments show that the upper critical field is higher than the value given by the usual argument that $H_c = 18{,}400\ T_c$. This observation is being interpreted in terms of recent theories and the effect of spin-orbit scattering. The results in aluminum are also being related to Knight shift measurements.

CHEMISTRY AND CHEMICAL ENGINEERING

Reactor Chemistry

Fluorocarbon Chemistry. The sensitivities of different fluorocarbons to ionizing radiation were found to vary by many orders of magnitude. The least sensitive, CF_4, was investigated after a rigorous purification and found to be even more stable than had been previously reported. The chief product in gamma radiation is C_2F_6; it is formed with a yield (G) of 10^{-2} molecules/100 eV ab-

sorbed. Most larger fluorocarbons have G values, for loss of starting materials, of the order of 1 to 5, and the radiolysis is not markedly temperature sensitive. A notable exception is perfluorobicyclohexyl, for which a G value of 2×10^5 was found at 450°C. Such a value is indicative of a chain reaction, the only one found, so far, in fluorocarbon radiolysis.

Transference in Fused Salts. Transference numbers and mobilities of ions in fused salt mixtures can be obtained by measuring the electromotive force (emf) of appropriately designed cells. With the cell

$$C,Cl_2 \,|\, KCl(l) \,\|\, KCl + PbCl_2(l) \,|\, Cl_2,C\,, \quad (1)$$

if the double line represents a ceramic membrane permeable only to potassium ions, the emf will depend only on the relative partial molar free energy of KCl in the mixture. If, however, the two salts are separated only by a porous barrier in which they can make contact, the emf contains an added term, the junction potential, from which transference numbers can be derived. Cells of both types have been successfully operated, with the salt system shown and with others. Mixture proportions were varied in order to get transference numbers as functions of concentration. Results for two systems are shown in Figure 6, which portrays the dependence of the potassium transference number on the KCl mole fraction in two systems. The straight line is what would be obtained if t_{K^+} were proportional to x_{KCl}. The divergences have not yet been explained. There is an interesting parallel, however, between the relative behavior of the two systems in this respect and with respect to their deviations from thermodynamic ideality. The latter are illustrated in Figure 7, which shows the relation between the activity of KCl and its concentration in three mixed-salt systems. Here the straight line represents Raoult's-law behavior. These data were obtained from cells of type (1) containing ion-permeable membranes.

Platinum Electrode in Tl(I)-Tl(III) Solutions. Attempts to study the kinetics of thallium ion oxidation and reduction at a platinum surface led to the discovery of some novel electrode phenomena. These are illustrated in Figure 8, which shows current-voltage curves obtained at a rotating-disk electrode (RDE) of shiny platinum in perchloric acid solutions of thallous and thallic ion (each 10^{-3} M). All potentials in the figure are referred to the normal hydrogen electrode (NHE). The fact that the cathodic currents on the scans taken in the reducing-to-oxidizing direction (right to left) are much higher than on the reverse scans is not unprecedented; but the maxima and minima ob-

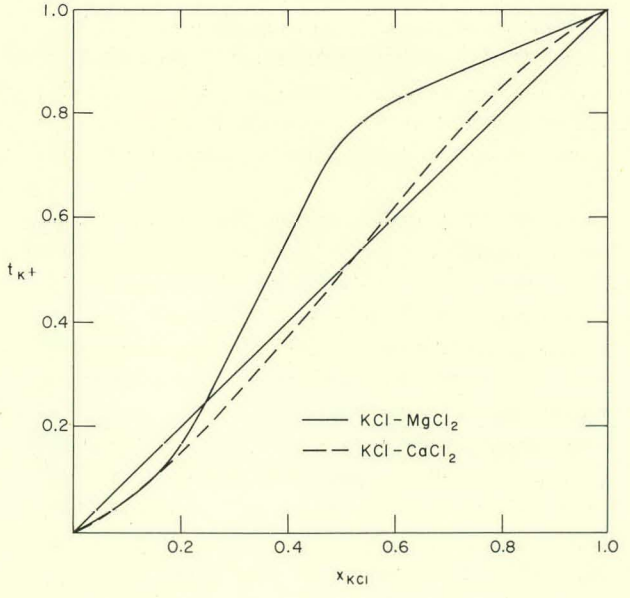


Figure 6. Dependence of potassium ion transference number, t_{K^+}, on mole fraction, x, of KCl in salt mixtures.

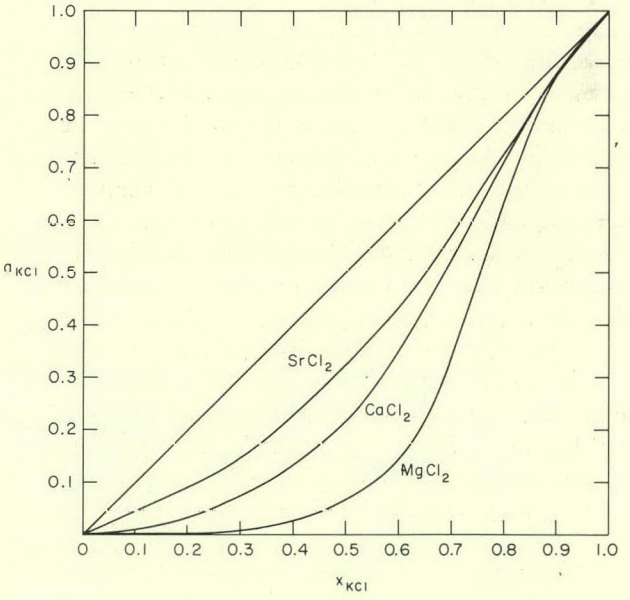


Figure 7. Dependence of activity, a, on mole fraction, x, for KCl in three binary salt mixtures.

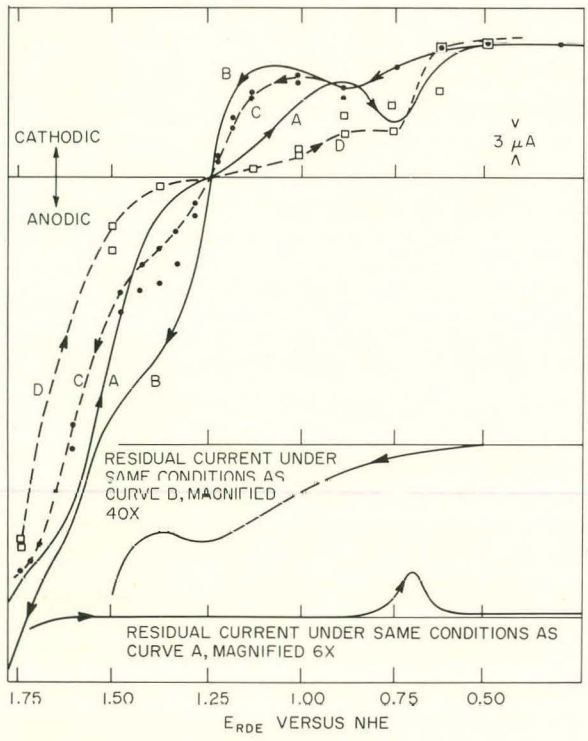


Figure 8. Current-voltage curves for a platinum RDE in Tl(I) and Tl(III) solutions. All curves at platinum RDE at 600 rpm in 1 *M* $HClO_4$, 10^{-3} *M* in Tl(I) and Tl(III). Curves *A* and *B* and residual currents: automatic polarograms at 3 mV/sec. Curves *C* and *D*, manual polarograms.

served before the attainment of the limiting cathodic current are most unusual. It is thought that these "pre-waves" can be explained by postulating certain potential-dependent changes in the platinum surface and a strong adsorption of Tl^+ on the platinum, also potential-dependent. Predictions based on these postulates have been tested experimentally and confirmed.

Mechanism of Graphite Formation. Resistively heated graphite filaments were used to measure the sublimation temperature of graphite and to study the reaction of graphite and hydrogen at temperatures >2000°K. Below 3000°K the reaction is a surface reaction which is proportional to $P(H_2)$ and $\sqrt{K_D(H_2)}$, where $K_D(H_2)$ is the dissociation constant of H_2. This relation holds for reaction rates varying by a factor of 10^4 for pressures between 0.01 and 1.0 atm. At the higher pressure CH_4 is the primary product. Above 3000°K graphite vaporizes and reacts with hydrogen in the vapor phase to form C_2H_2 as the principal product.

Chemical Technology

Volatility Process Development. The fluidized-bed pilot plant was operated to demonstrate decladding and uranium recovery with stainless steel-clad UO_2 fuels of the power reactor type. Assemblies of Yankee-type reactor fuel containing as may as 49 fuel rods 30 in. long were decladded by using the $HF-O_2$ reactant. In about half the runs, decladding was followed by reaction with gaseous fluorine to determine removal of uranium, as volatile UF_6, from the alumina bed material. Uranium recoveries of ≈99% were obtained.

Experiments were also carried out in which Zircaloy-clad UO_2 fuel assemblies were decladded by using essentially the same procedure as with the stainless steel-clad fuels. Reaction rates with the Zircaloy were higher and uranium recovery was satisfactory.

Release of Fission Products From Nuclear Fuels. Fission product iodine, potentially hazardous because of the I^{131} isotope, may exist in many forms. One form of particular concern for reactor safety is CH_3I, the stability of which is currently under study. At concentrations ranging from 10^{-8} to 10^{-6} *M*, CH_3I was found to decompose with a pseudo first-order reaction when exposed to a combined oxidizing and radiation environment. The half-life in terms of total absorbed dose varied from 3.0×10^4 to 1.3×10^5 rads, depending on the moisture content in the system.

A continued investigation of the iodine states released from metallic uranium and hypostoichiometric UC shows that varying proportions of two uranium subiodides and atomic iodine are released within the temperature range 1200° to 2500°C.

An analytical study dealing with the behavior of iodine in sodium-cooled reactors indicates that iodine will exist primarily as NaI if the total fission product concentrations in sodium are of the order of parts per million. Experimentally, NaI was found to be stable in an oxidizing environment in the presence of excess Na_2O_2.

Nitrofluor Volatility Process. The dissolution step of the nitrofluor process for treating various types of reactor fuel to recover uranium and plutonium was successfully demonstrated with a third type of fuel (the other two were described in last year's report). More than 96% of a full-size U-Al alloy assembly was dissolved in the nonaqueous solvent NOF · 3HF during a 12-hr contact period

at 116° to 127°C in Monel equipment. In the uranium separation step, for gram amounts of the same fuel, 99.85% recovery was attained by using refluxing BrF_3 to volatilize UF_6 from the solids isolated by evaporation of the dissolver solution. The nickel equipment for dissolving UO_2 fuel assemblies in NO_2-HF solution and separating uranium with BrF_3 was readied for testing.

In other volatilization studies, the fuel dissolution product $NOUF_6$ was vaporized in the presence of NOF gas and quantitatively reacted with a bed of NaF pellets. The uranium was not removed by simple heating, even in the presence of NOF gas, but was effectively volatilized as UF_6 by treatment with F_2 gas at 300°C. The plutonium dissolution product, tentatively identified as $NOPuF_5$, does not have the volatile character of $NOUF_6$; hence another method of uranium-plutonium separation is available.

Ultimate Waste Disposal. During the past year pilot-plant operations at Brookhaven have been carried out to obtain information necessary for the operation of the waste solidification prototype at Pacific Northwest Laboratory (Battelle Memorial Institute). The performance of the new shell-and-tube evaporation unit was studied with a number of simulated Purex wastes. In 40 evaporator runs heat transfer rates were determined and denitration, volume reduction, and viscosity values were optimized against operation temperature and retention time. With satisfactory performance demonstrated, the evaporator was coupled with the melter and the integrated glass-forming process was carried out with several types of Purex waste.

The phosphate glass process was successfully demonstrated for Purex 2 and Purex 1 wastes with bench-scale equipment and burnups of 20,000 MWD/tonne, and on the laboratory scale with burnups of 40,000 MWD/tonne. A more comprehensive investigation of the physical and chemical stability of platinum as the material of construction for the high-temperature crucible has been initiated. High-temperature, low-stress creep measurements have been in progress for several thousand hours at Battelle Memorial Institute under a subcontract arrangement. Studies are being set up to determine the extent of migration into the platinum, if any, of waste component elements such as Hg, Ag, Ru, and Pd.

Development was continued of methods applicable to the ultimate disposal of wastes generated during fluidized-bed volatility fuel reprocessing. It has been demonstrated that the solid waste (alumina beds) arising from such processes can be dispersed in inexpensive glass matrices to give a product that is considered suitable for transporting and long-term storage. With this technique, the product has a tenfold increase in thermal conductivity over that of the original bed material, as well as greatly increased resistance to chemical or mechanical degradation. The scope of the investigation has been expanded to include the study of methods for treating gaseous and liquid wastes produced in fluidized-bed volatility processes.

Chemical Engineering

Heat Transfer Research. The heat transfer research program consisted of 6 experimental and 4 analytical projects, all primarily concerned with liquid-metal heat transfer.

One of the major projects was an investigation of convective boiling and 2-phase flow with potassium. Heat transfer and fluid-dynamic information is required for design of liquid-metal Rankine systems. Measurements were obtained in a pumped loop at boiling temperatures of 1370° to 1515°F, vapor qualities of 1.9 to 9.4%, and heat fluxes of 5000 to 91,500 Btu/hr-ft^2. The results confirmed the existence of a nonequilibrium, inverse temperature profile in the vapor-liquid stream. Figure 9 illustrates the measured temperature profiles for both single-phase and 2-phase heat transfer, and shows the profile inversion in the 2-phase case.

In the second project, heat transfer coefficients were measured for 90° cross flow of NaK through a staggered rod bundle. The geometry of the test section and the locations of the nine test heaters are shown in Figure 10. Data were taken (a) with equal heat fluxes on all rods, and (b) with heat flux on only the test rod. The results are shown in Figures 11 and 12, where Nusselt number (Nu) is plotted against Peclet number (Pe) as defined in the figures. This is the first study of its kind in which there was heat flux on *all* rods, and this apparently makes a significant difference at the lower Peclet numbers. In the Peclet ranges in which commercial heat exchangers normally operate, the Nu vs Pe correlation appears to be essentially the same in the two cases.

In the third project, velocity and temperature profiles, surface temperatures, and heat fluxes were measured for flow of mercury through concentric annuli with heat input at the inner wall. The results are being analyzed to obtain local heat

transfer coefficients and profiles for the eddy diffusivities of heat and momentum transfer.

In two other experimental studies, local heat transfer coefficients will be measured for (a) 45° cross flow of NaK through a rod bundle, and (b) in-line flow of mercury through an eccentric rod bundle. Test sections for both projects have been fabricated.

A new experimental project was initiated to study experimentally the fundamentals of heat and mass transfer processes in liquid-metal condensation. A forced-convection facility for tests with potassium at 1300° to 1800°F is being designed for this work.

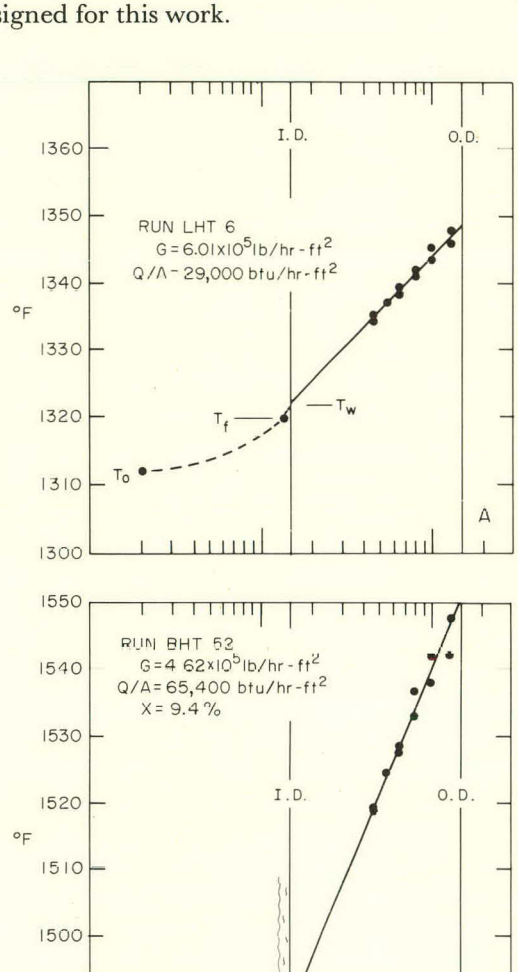


Figure 9. Temperature profiles for single-phase and 2-phase potassium flow with heat input. (*A*) Liquid heat transfer; (*B*) boiling 2-phase heat transfer.

In the analytical part of the program, the following subjects were studied: (1) heat transfer to liquid metals flowing in eccentric annuli, (2) heat transfer to liquid metals in flow past stacked spheres, (3) entrance-region heat transfer with axial conduction, and (4) nonequilibrium, boiling, 2-phase flow.

Rotating Fluidized Bed. Qualitative studies to determine performance characteristics of the rotating fluidized bed were completed.

For a rotating fluidized bed reactor for application in rocket propulsion, it is estimated that particle-to-fluid heat transfer coefficients as high as 1000 Btu/hr-ft²-°F will be required. Therefore experiments were performed to determine whether sufficiently high coefficients could be adequately predicted for such systems.

In the first series of experiments, particle-to-fluid heat transfer coefficients were measured at high mass flow rates in packed beds by use of the cyclic heating method. The outstanding advantage of this method is that only the temperatures of the inlet and outlet gas need to be measured. Mass flow rates with air were varied from 700 to 96,400 lb/hr-ft². The maximum heat transfer coefficient obtained was 1310 Btu/hr-ft²-°F. For nuclear rocket application with H_2 as coolant, heat transfer coefficients of >3000 Btu/hr-ft²-°F would be expected. Experiments have been completed to determine particle-to-fluid bed transfer coefficients in fluidized beds by using this same technique.

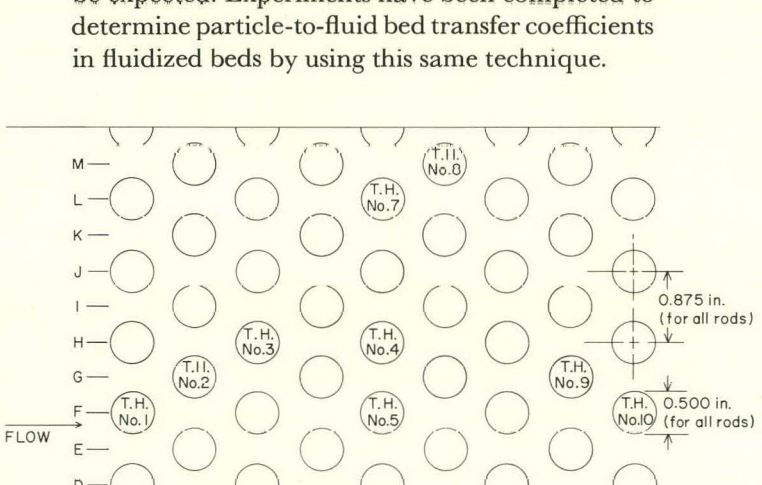


Figure 10. Plan view of tube bank showing locations of test heaters.

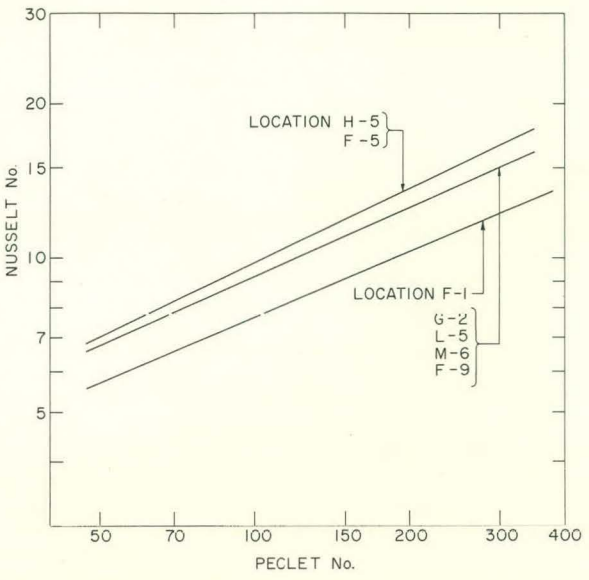


Figure 11. Rod-average heat transfer characteristics for NaK flowing 90° across a staggered rod bundle with only the test rod heated. Nusselt No. $=\bar{h}D/k$, Peclet No. $=Dv_{max}\rho C_p/k$, where $\bar{h}=$ av heat transfer coefficient for a rod, $D=$ rod diameter, $k=$ fluid thermal conductivity, $\rho=$ fluid density, $C_p=$ fluid specific heat, and $v_{max}=$ av velocity through minimum cross section area. See Figure 10 for lattice locations represented by curves.

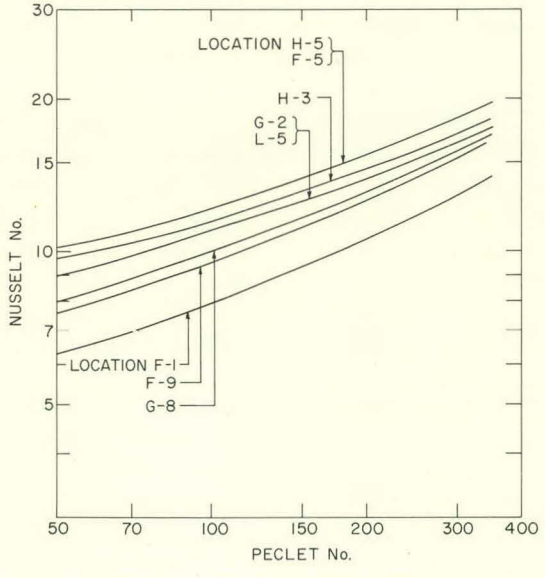


Figure 12. Rod-average heat transfer characteristics for NaK flowing 90° across a staggered rod bundle with equal heat rates from all rods. Definitions the same as for Figure 11. See Figure 10 for lattice locations represented by curves.

Table 1

Ethyl toluene*	Dinitrotoluenes
Tolunitrile*	Dinitrobenzene
Cresol*	Hydroxybenzonitrile
Toluidene*	Nitrobenzonitrile
Mesitylene**	Nitrobenzene
Tolualdehyde**	Benzonitrile
Nitrotoluene**	Acetonitrile
Ethyl benzene**	

*Previously reported. **Recently completed.

A rotating vessel with a diameter of 10 in. and a length-to-diameter ratio of one is being constructed to further determine performance characteristics. The vessel is designed to operate at a maximum of 3500 g and a mass flow rate of 15 lb/sec-ft^2 of nitrogen gas through the bed.

RADIATION RESEARCH AND DEVELOPMENT

Basic Research

Radiation Chemistry of Aromatic Compounds. With toluene used as the basic compound, the three isomeric forms of various substituted toluenes and other related aromatics have been studied. Table 1 lists the compounds that have been or will be included in this study.

In all cases studied, the *ortho* isomer of an electron-attracting substituent and the *meta* isomer of an electron-repelling substituent are least stable. A very large yield of nitrogen from *meta*-tolunitrile has prompted investigation of acetonitrile and benzonitrile to determine the mechanism of nitrogen formation.

Radiation-Induced Reactions in Organic Solids. Rapid oxygen quenching of the electron spin resonance (ESR) spectra of irradiated straight-chain amides, lower rates of quenching in branched amides, and no such quenching in unsaturated amides demonstrate the relative ability of oxygen to diffuse through the layerlike lattice of the first group, as distinct from the second. Acrylamide is an apparent exception to this rule, but in this molecule the lattice spacing is 11% less than that in the smallest saturated amide, propionamide, and hence the effect is readily understandable.

It has been shown that many of the solid-state polymerizations that have been termed topotactic are not really so. Trioxane and trithiane have been shown to produce crystalline polymer at

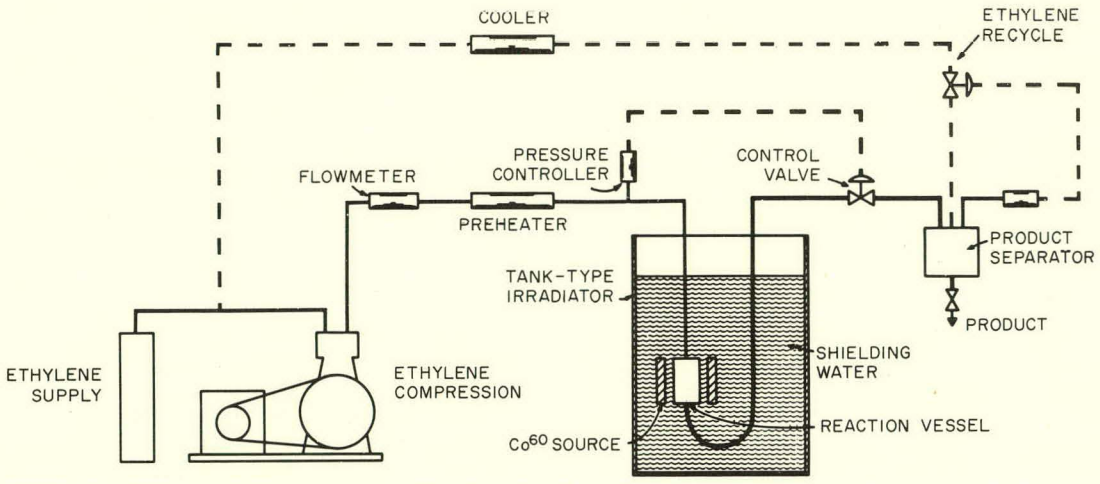


Figure 13. Schematic diagram of ethylene radiation polymerization process.

orientations that are random with respect to the monomer crystal lattice.

Mechanisms of Vinyl Polymerization in the Liquid State. As the purity and dryness of styrene are increased, the rate of polymerization increases by a factor of as much as 10^4. While this is happening, the dose-rate dependence of the rate changes from the classical value of ½ to unity and, as the absolute value increases, to 0.70. It has been established that these effects are peculiar to the radiation-induced reaction and are not shown by either the thermally initiated or the ultraviolet-initiated polymerization. In addition, water has been shown to be the "impurity" that accounts for the novel kinetic features. The changing dose-rate dependence, the almost constant average molecular weight, and the small negative temperature coefficient of both the rate and molecular weight are most readily interpreted in terms of several ionic contributions.

Similar dose-rate dependence of the rate of polymerization of α-methylstyrene has been observed. In this system, at the highest rates of polymerization, the dose-rate dependence has decreased to 0.5.

Pulse radiolysis studies (performed in cooperation with Argonne National Laboratory) have revealed the presence of several transients ranging in half-life from several microseconds to hours.

Radiation Chemical Processing

Ethylene Homopolymerization. *1. Kinetics.* The experimental program for studying the kinetics of Co^{60} gamma-radiation-induced polymerization of ethylene was extended by a series of "fall-through" constant-pressure experiments in a partially irradiated vessel.

Information on the removal of polymer and its characteristics was obtained. Experiments were performed under conditions of pressure ranging from 170 to 1000 atm, of temperature from 20° to 200°C, and of radiation intensity from 7.0×10^4 to 3.9×10^5 rads/hr. At a temperature of 200°C and a pressure of 680 atm, a half-power dependence of the radiation intensity on rate was observed. The dependence of pressure on rate was determined at the same temperature to be $\approx$2.7 for the pressure range 170 to 680 atm, which confirmed previous measurements in static capsule experiments. For the pressure range 850 to 1000 atm, a much larger effect was observed. The apparent breakpoint, which occurred at a pressure of $\approx$800 atm, is thought to be due to the increased solubility of ethylene gas in the molten polymer under these conditions.

2. Engineering experiments. To advance the engineering development of a radiation-induced polymerization process, a small flow experiment based on the polymerization of ethylene has been built and operated. The unit, a schematic of which is shown in Figure 13, was designed to operate at pressures of up to 2000 atm, temperatures to 250°C, and radiation intensities to 10^6 rads/hr. The reaction vessel is operated under water in a pool-type gamma facility containing $\approx$10,000 Ci Co^{60}. Experiments have been carried out at a ra-

diation intensity of 2.8×10^5 rads/hr, pressures from 340 to 880 atm, and temperatures from 150° to 200°C.

Polyethylene Characteristics. The density, melt index, molecular weight distribution, and methyl group content of polyethylene have been correlated as a function of the radiation conditions for the "fall-through" experiments. The density decreases with increasing temperature, the melt index increases, and the molecular weight distribution becomes narrower. Polymer characteristics from flow experiment batches are being measured.

Ethylene–Sulfur Dioxide Copolymers. The Co^{60} gamma-radiation copolymerization of ethylene and sulfur dioxide has been investigated over a range of conditions including temperatures from 20° to 152°C, pressures from 34 to 680 atm, and an intensity of 1.78×10^5 rads/hr. Elemental analyses of the polysulfones formed in the liquid SO_2 phase indicated an equimolar composition of ethylene and SO_2. The yield appears to go through a maximum of $\approx$500 g/liter-hr in the temperature range 50° to 60°C.

In the gas phase the composition of the copolymer appears to depend mainly on the initial ratio of ethylene to SO_2. The SO_2 reactivity was found to be extremely high; thus a large change in the initial ethylene-SO_2 ratio is required to produce a small change in the polymer ethylene-SO_2 ratio. Copolymers containing from 5 to 48 mole % SO_2 have been made in the gas phase. A "ceiling temperature" of 156° ±3°C for the gas-phase mixtures rich in SO_2 has been found. Above this temperature no polymer was formed, which indicated a temperature-dependent depropagation mechanism. At 175°C and 680 atm a spontaneous decomposition occurred. The polymer obtained in both phases was in the form of a white powder and apparently of high molecular weight. X-ray diffraction patterns of powdered samples indicate that the material is crystalline and the crystallinity decreases with increasing SO_2. Equimolar ethylene-SO_2 copolymers were found to depolymerize completely into ethylene and SO_2 molecules at 375°C with no residue. Because of the relative inertness, high molecular weight, and low cost of the monomers, producing a new material by the application of high energy radiation appears of interest.

Chemonuclear Program

Fission Fragment and Radiation Chemistry.

1. Fixation of nitrogen. An extensive series of in-pile capsule experiments has been carried out. The yields of NO_2, N_2O_4, and N_2O have been measured as a function of dose in a 77.3% N_2–22.7% O_2 gas mixture at a pressure of 65 atm, with thin U-Pd foils used as a source of fission fragments. A yield-dose curve is shown in Figure 14. At very high doses sufficient NO_2 is produced so that liquid N_2O_4 condenses in the capsule during irradiation. At this point a marked increase in $G(NO_2)$, as noted by differential values of 3 to 9, is observed, while the N_2O concentration remains essentially at steady state. The $G(NO_2)$ and $G(N_2O)$ values have also been determined as a function of the nitrogen-to-oxygen ratio in the mixture.

2. Ozone synthesis. In a study of the radiolysis of oxygen, the yield of ozone has been measured as a function of dose-rate and temperature with use of Co^{60} gamma radiation. The $G(O_3)$ value increased with decreasing temperature. However, the $G(O_3)$ value found by extrapolation to zero dose was constant $[G(O_3)=6]$. At room temperature the ozone steady-state concentration ($[O_3]_{ss}$) depended markedly on dose rate, as shown in Figure 15. Concentration up to 0.2% by volume was observed. It was found that O_3 can be formed by fission fragment radiation with no significant differences in yields or G values. The influence of additives such as CO, NO_2, and CF_4 on the $G(O_3)$ value and the steady-state concentration of ozone is being investigated.

3. Radiolysis of liquid ammonia. A study of the radiolysis of liquid ammonia has continued, and the yields of H_2, N_2, and N_2H_4 have been measured in detail over the dose range 10^4 to 1.5×10^8 rads. The yields of these products are complex functions of absorbed dose. Additional products have been identified as NH_4N_3 and, tentatively, a mixture of N_2H_2 di-imide, N_4H_4 (tetrazene), and N_3H_3 (triazene). The molecular product yields of H_2 and N_2H_4 appear to be greater than the radical yields, and experiments using the "scavenging" technique are in progress to determine these yields.

Chemonuclear In-Pile Research Loop. Construction of the chemonuclear in-pile research loop B-CIRL, a facility for the study of the chemistry of chemonuclear reactions under dynamic conditions, is nearing completion. Installation of the loop and its auxiliary equipment at the Brookhaven Graphite Research Reactor has begun. Figure 16 shows part of the out-of-pile section of the loop being prepared for installation in its unitized contamination containment.

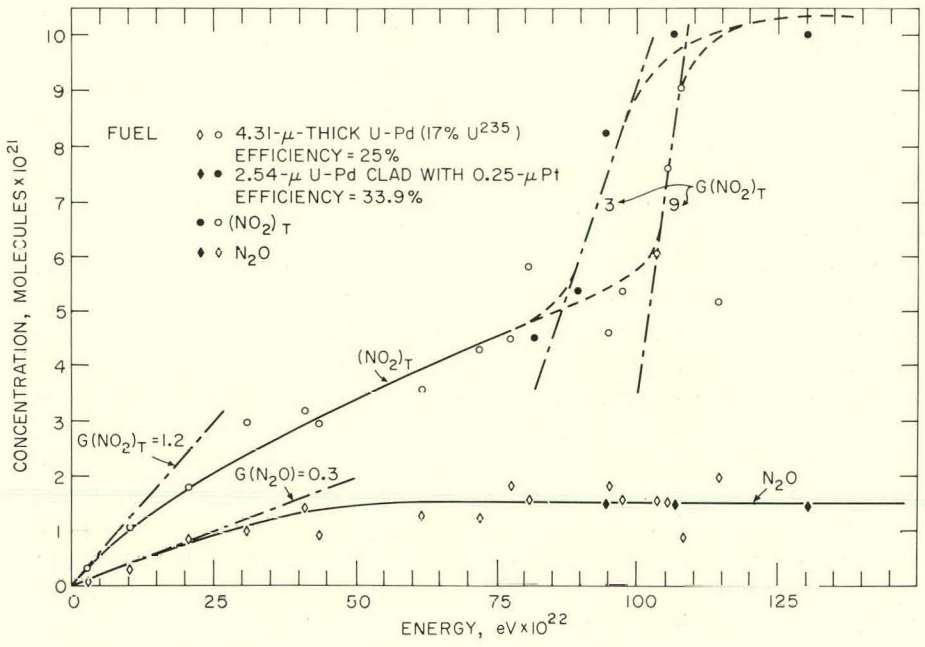


Figure 14. Yield-dose curve for fission fragment and reactor irradiation of a nitrogen-oxygen mixture. Flux, (0.8 to 1.1) $\times 10^{13}$ n/cm^2-sec; vessel volume, $\approx$32 cc; weight of U^{235}, $\approx$10 mg; pressure, 65 atm; temperature, $\approx$35°C.

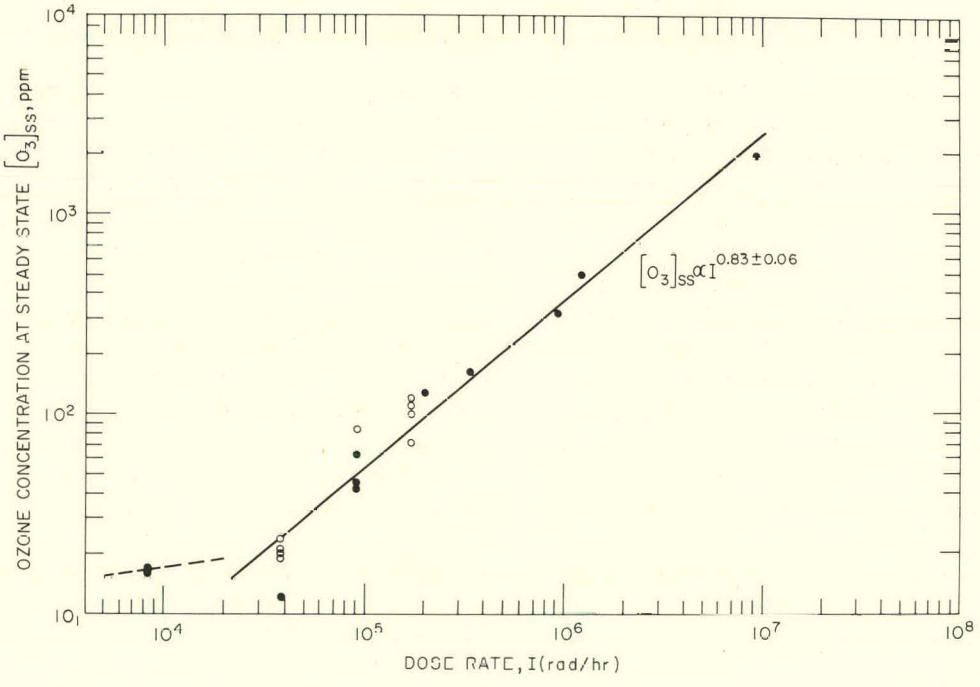


Figure 15. Yield-dose curve for gamma irradiation of oxygen in quartz or Pyrex at 12°C and 300 to 700 mm Hg.

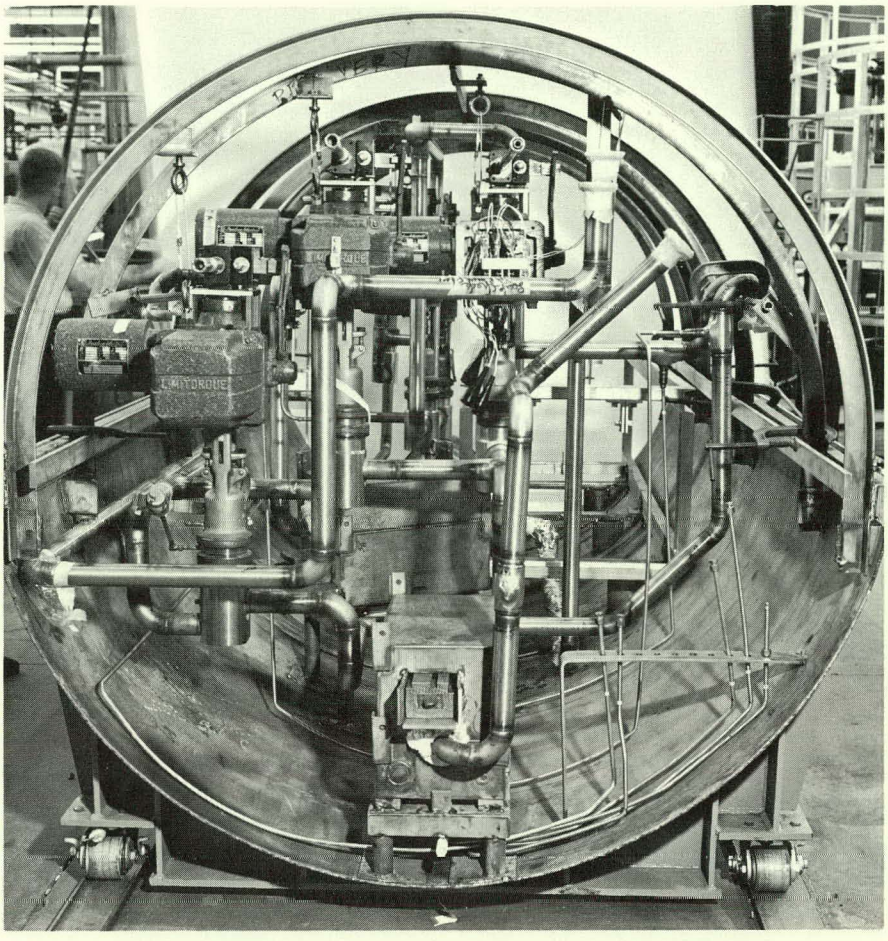


Figure 16. Part of out-of-pile section of the B-CIRL loop under construction. Completed unit will be moved into one of the contamination containments.

Chemonuclear Fuel Development. Technology has been developed for producing thin foil from 20 wt % enriched uranium–80 wt % palladium alloy clad on both sides with platinum. Platinum sheet and a slab of pure alloy are bonded by being clamped together and heated in vacuum. The resultant composite is rolled in a series of mills until it is 0.0001 in. (2.5 μ) thick. The cladding on each side is $\frac{1}{10}$ as thick, 0.00001 in. (0.2 μ). This is adequate to fully protect the U-Pd alloy from attack in corrosive atmospheres.

Clad foil is being fabricated with honeycomb fuel elements for use in the B-CIRL. Elements 1.5 in. in diameter and 5 ft long are being made from honeycomb in three different cell sizes: 1 mm, 3 mm, and 6 mm.

A second method of fuel element fabrication now under development at Pacific Northwest Laboratory (Battelle Memorial Institute) involves coextrusion of alloy and cladding around a sacrificial metal core that is subsequently dissolved away.

Design and Evaluation Studies. Analyses have been made of the feasibility of chemonuclear reactor systems for the production of ozone for water treatment purposes, of dual-purpose reactors for nitrogen fixation and power production, and of generalized methods for the estimation of the cost of producing basic chemicals by chemonuclear means.

Radiation Engineering

High Intensity Radiation Development Laboratory. *1. Operations and services.* Seven hundred thousand curies of Co^{60} of the Mark I type of BNL standard source were received from the Savannah River Plant (SRP), encapsulated, and leak-tested and are now in use. The HIRDL conveyor system,

containing a 860,000-curie plaque (Figure 17), was tested in a series of production runs for certification by U.S. Army Quartermaster personnel for possible use in the irradiation of 15 tons of canned bacon. Approximately 60,000 curies of Co^{60} irradiated at the Engineering Test Reactor were installed in two shipboard irradiators, and 7400 curies were shipped to Unidynamics, Inc., in support of contracts administered by the AEC's Division of Isotopes Development. Nineteen singly encapsulated SRP-BNL standard sources were furnished to the Lockheed-Georgia Corp. for installation in the mobile grain irradiator.

2. Irradiator design. Two portable irradiators were inspected, loaded with 60,000 curies of Co^{60}, and characterized. A 2-patient extracorporeal blood irradiator (Figure 18) was completed and loaded with 3400 curies of Co^{60}. Two additional blood irradiators, each with 4000 curies of Cs^{137}, were completed and calibrated.

3. Source development. Qualifying tests on the BNL Mark II standard bonded Co^{60} source, in which the first stainless steel encapsulation is metallurgically bonded to the cobalt, were successfully completed. Ninety-six pieces were sent to SRP for reactor irradiation. One hundred eighty-eight pieces were sent to Oak Ridge National Laboratory (ORNL) to fulfill their cobalt requirements.

Low-level Sr^{90} beta sources were received from the Minnesota Mining and Manufacturing Company and evaluation studies were initiated. A cooperative program with ORNL was started for the purpose of developing safe, efficient Sr^{90} sources for general application (Figure 19).

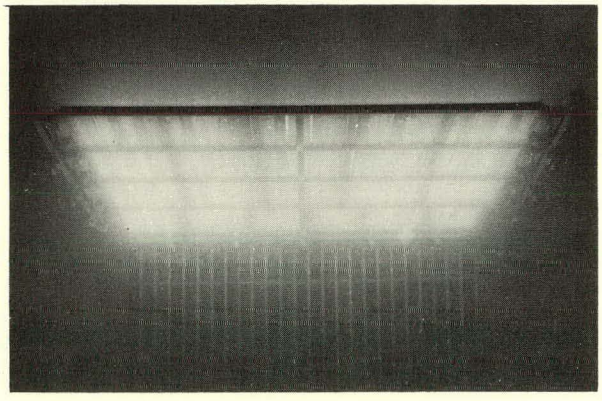


Figure 17. Source plaque containing 860,000 curies of Co^{60} for use in the High Intensity Radiation Development Laboratory.

4. Dosimetry. Evaluation studies of the ultraviolet-transmitting Lucite dosimeter show no severe bleaching problems up to 40°C and accuracies of $\pm 3\%$ in the dose range 10^5 to 3×10^6 rads.

A miniaturized Fricke dosimeter containing 0.3 ml of solution in a special polyethylene container was developed.

The blue cellophane dye dosimeter was evaluated and found to be linear up to 6 megarads and accurate to within $\pm 5\%$. Thermal bleaching studies indicate that the system is stable up to 100°C.

5. Calorimetry. The Mark II gamma calorimeter was calibrated against an electrical heater with an accuracy of $\approx \pm 5\%$. A temperature-controlled chamber was constructed to house the calorimeter to achieve true adiabatic conditions and better accuracy in subsequent calibrations.

An adiabatic cylindrical beta calorimeter to measure source contents of high-level Sr^{90} sources was designed and fabricated of aluminum.

6. Bacon irradiation. The HIRDL facility was used for characterization studies for the irradiation of bacon. Dose distributions in standard bacon cans were determined by cross-comparing the results obtained with the Lucite, Fricke, and ceric sulfate dosimeters. A uniformity ratio of 1.27 and a production rate of 250 lb/hr with a minimum dose of 4.5 megarads was found, based on

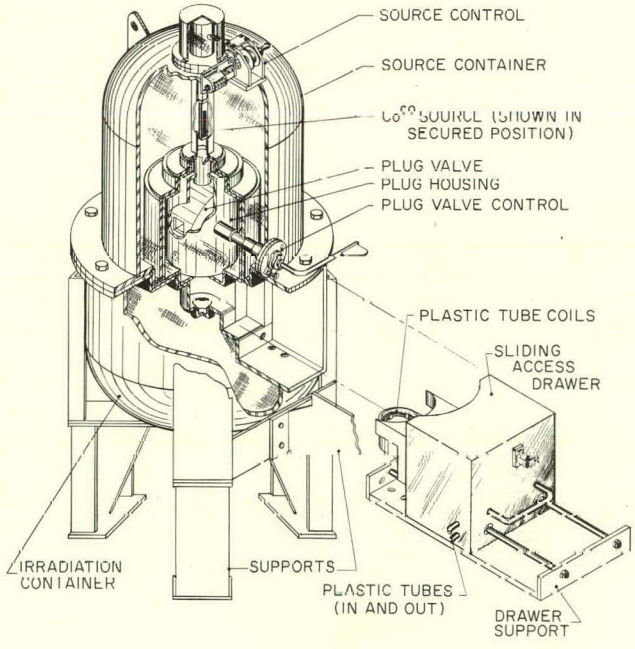


Figure 18. Blood irradiator.

measurements with the Lucite dosimeter and a source plaque containing 860,000 curies of Co^{60}.

7. Self-absorption studies. Theoretical calculations were made to compare self-absorption in various types and shapes of gamma sources. The results are being verified experimentally.

8. Cobalt-cesium comparisons. Analytical calculations comparing specific dose rates and dose distributions in finite targets of three densities were performed. Experimental measurements to verify these calculations have been initiated.

9. Heterogeneous studies. A series of experiments was conducted in which heterogeneous targets consisting of arrays of standard food cans were used. Dose distributions in the target were measured with Lucite dosimeters. The source consisted of a uniform Co^{60} plaque. Results were compared with those for homogeneous targets of the same geometry and with analytical calculations made with use of the FUDGE 4 code.

Direct Conversion. *1. Magnetohydrodynamic studies.* Nonequilibrium plasma studies have continued, with primary emphasis on long-lived plasmas ($\approx$10 msec) energized by excited species produced by fission fragments in a reactor. Nitrogen seems the most suitable gas; excitation energy can be stored as free nitrogen atoms, as metastable electronically excited molecules ($A\ ^3\Sigma_u^+$), or as vibrationally excited ground-state molecules ($X\ ^1\Sigma_g^+$). The nitrogen atoms can liberate 9.76 eV on recombination; the $A\ ^3\Sigma_u^+$ molecules, 6 eV on collision; and the $X\ ^1\Sigma_g^+$ molecules, 0.28 eV on collision. If an inert gas–nitrogen mixture is seeded with a small quantity of cesium, the excited spe-

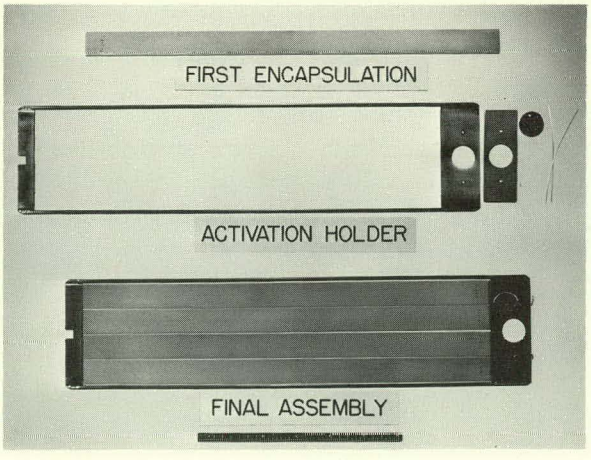


Figure 19. BNL Mark II bonded Co^{60} source, assembly.

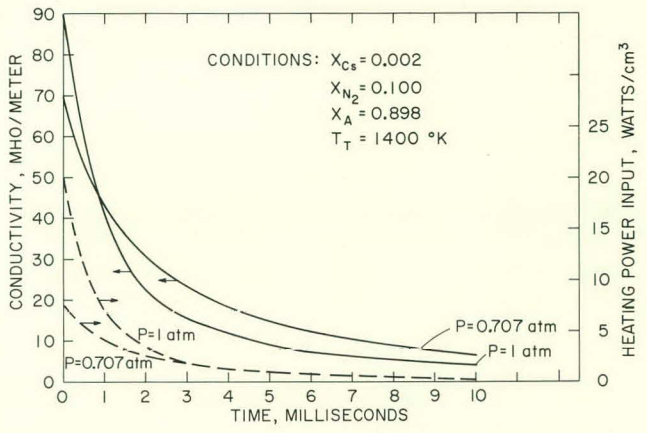


Figure 20.

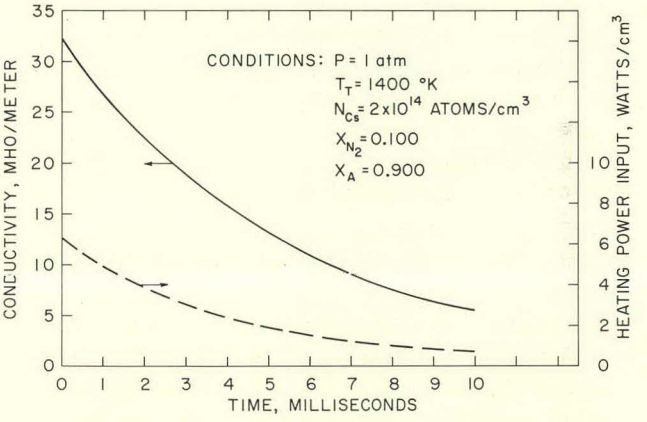


Figure 21.

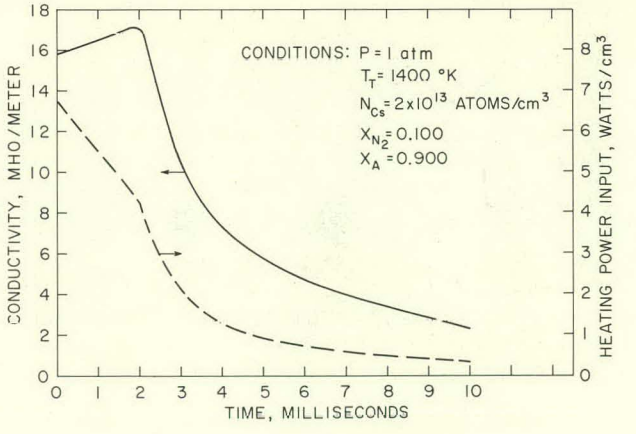


Figure 22.

cies can transfer energy only to cesium neutrals or electrons. The steady-state electron density is a function of the energy transfer rate and the recombination coefficient.

Figures 20, 21, and 22 show the conductivity excited by the above three modes [$N = N_{atom}$; $N_2^* = A\ ^3\Sigma_u^+$; $N_2^{**} = X\ ^1\Sigma_g^+$ (vib)] normalized to an initial excitation energy of 5×10^{-14} ergs/molecule (10% of the thermal energy necessary to raise the gas to 1500°K). The gas is Ar–10% N_2. All modes offer satisfactory conductivity (>10 mho/meter) for an MHD generator, but storage in the $A\ ^3\Sigma_u^+$ mode gives the longest lifetime and the least variation of conductivity.

Actually, most of the fission fragment energy will initially appear as nitrogen atoms, which will quickly recombine in the reactor at pressures >1 atm to form the $A\ ^3\Sigma_u^+$ state. Experiments on rf plasmas containing large concentrations of this state show that its effective lifetime is several hundred milliseconds, much greater than needed. The effective lifetime can be reduced to the desired value by adjusting the cesium concentration.

A cell to measure the equilibrium electrical conductivity of uranium halide vapors has been constructed and tested to 2500°K with use of CsI vapor. Conductivities of several mho/meter were obtained.

2. Closed-cycle electrochemical converter. Work continued on the development of the lead bromide converter, a direct conversion device. $PbBr_2$ was electrolyzed at temperatures up to 900°C. The experiment was conducted over a period of 1400 hr and gave consistent results, with no corrosion or other materials problems. Bromine anodic current density of 1.5 amp/cm² was obtained with a bromine overvoltage below 0.1 V. No gases other than bromine were found at the graphite electrode. The overpotential required for deposition of liquid lead was negligible. Current efficiency decreased with increasing temperature and increased with current density. The highest yield at 800°C was 43%, obtained at a current density of 1.5 amp/cm². The use of porous separators is indicated for current yield improvement.

HOT LABORATORY

Analytical Chemistry Research

From a study of mixed chloride-bromide and mixed iodide-bromide complexes with palladium have come the stepwise formation constants, the relative amounts, the spectrophotometric absorption maxima, and the molar absorptivities of the various species in the two systems.

Studies of the extraction of Cu^{++} by six selected β-diketones, singly and in pairs (all possible combinations), showed that any given pair extracted to an extent greater than the sum of the two individually. Surprisingly, however, no interaction was found between thenoyltrifluoroacetone and either tributyl phosphate or tri-*n*-octylamine.

Stability constants in molten dimethyl sulfone were measured for the nitrate complexes of lead and cadmium and the chloride complexes of nickel and palladium.

A quantitative relationship was found between the current, time, and kinetic parameters and the intensity of light emitted during chemiluminescence produced by the electrogeneration of anion and cation radicals of aromatic hydrocarbons at a single electrode; and a method was devised for distinguishing between triplet-triplet annihilation and direct singlet formation in such electrogenerated chemiluminescence.

Mechanisms and rate constants were determined for the disproportionation of U(V) in acetate buffer without and with added ethylenediaminetetraäcetic acid, which changes the disproportionation from second to first order.

The computer continues to be used to calculate electrokinetic relationships which are too complicated to be solved by hand but which when calculated are verifiable.

Isotope Research and Development

The development of new tellurium "isomer" generators and the improvement of present I^{132} generators requires more knowledge and better understanding of the chemistry of tellurium. A study along these lines showed that at *p*H 13 to 14 adsorption of (anionic) Te(VI) on Dowex 50 (cation exchange resin) under certain conditions is >98% complete, while Te(IV) adsorption is negligible. Te(VI) adsorption decreases with reduced residence time, increasing resin mesh size, and higher resin purity. The adsorption of Tc(IV) on alumina is shown in Figure 23. Yields of I^{132} milked from tellurium on alumina over a long time remained relatively constant with some fluctuation; they were consistently higher from Tc(IV) than from Te(VI). A high degree of internal conversion of the 50-keV gamma ray of Te^{132} leading to an internal redox reaction accounts for the in-

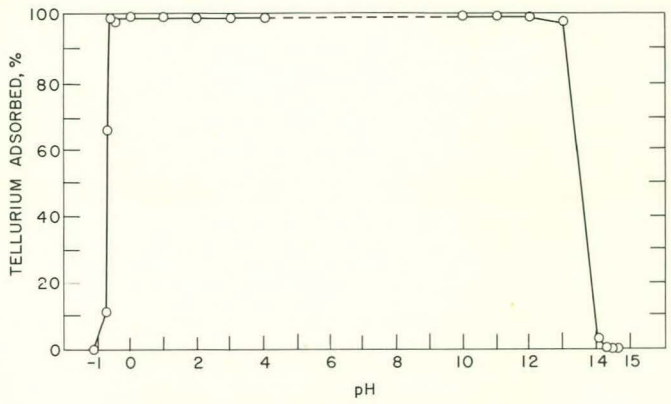


Figure 23. Adsorption of Te(IV) on alumina.

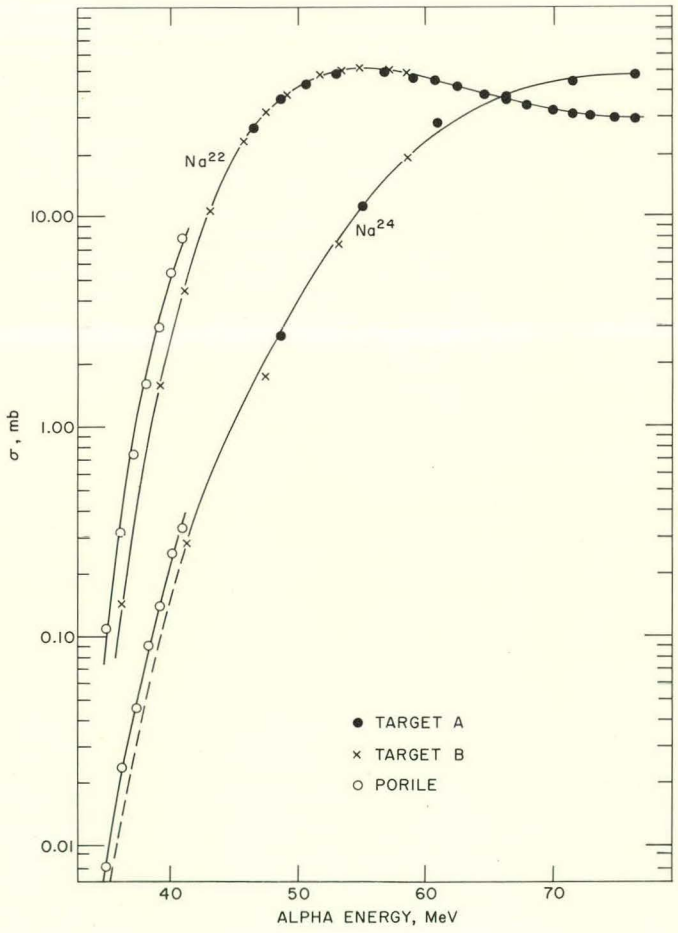


Figure 24. Excitation functions (preliminary results) for the formation of Na^{22} and Na^{24} by the alpha bombardment of Al^{27}.

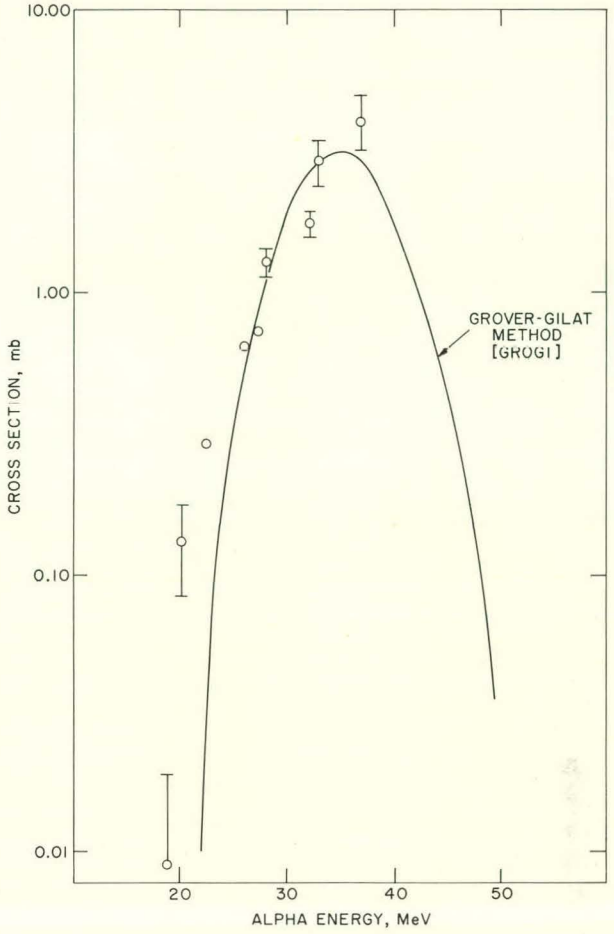


Figure 25. Excitation function of the $Ar^{40}(\alpha,2p)Ar^{42}$ reaction.

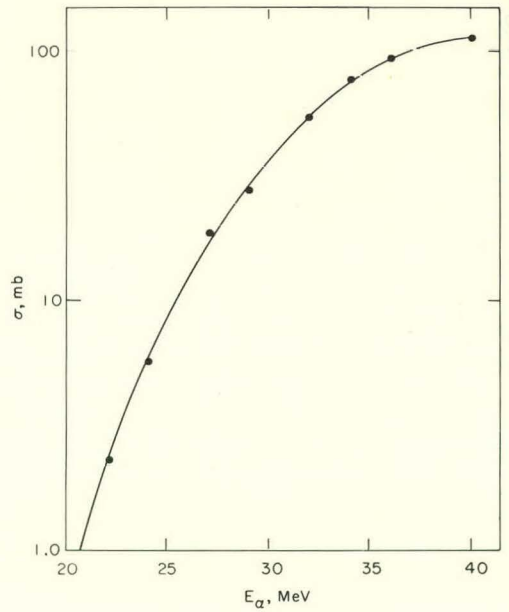


Figure 26. Excitation function of the $Ca^{48}(\alpha,p2n)Sc^{49}$ reaction.

Table 2

Production of Special Isotopes by Hot Laboratory Division

	Fiscal 1966		Fiscal 1965		Fiscal 1964	
	No. of shipments	Activity, mCi	No. of shipments	Activity, mCi	No. of shipments	Activity, mCi
Ar^{38}	—	—	—	—	5[a]	0.24[b]
Cu^{67}	—	—	1	1	1	1
Ga^{68} generators	—	—	—	—	1	0.5
I^{132} generators	70	730	74	800	76	1,220
I^{133}	11	202	5	100	3	60
K^{43}	—	—	—	—	19	16
Mg^{28}	131	22	135	21	172	24.5
Mo^{99}	18	4,550	28	10,720	23	2,210
Sr^{87m} generators	18	53	23	28	1	1
Tc^{99m} generators	661	117,460	597	85,880	116	11,450
Te^{132}	9	106	10	72	7	70
Xe^{128}	—	—	—	—	1	0.02[b]
Y^{90} beads	4	1,600[c]	1	200[d]	4	65[d]
Y^{90} generators	—	—	1	100	3	250

[a]Production discontinued February 1964; customers referred to Physikalisch-Chemisches Institut der Universität, Zürich, Switzerland.

[b]Ar^{38} and Xe^{128} are stable; unit is cc, not mCi.

[c]Not mCi, but number of individual beads; unirradiated.

[d]Not mCi, but number of individual beads; activity per bead controlled by length of irradiation requested by customer.

Table 3

Foreign Distribution of Special Isotopes

	Fiscal 1966		Fiscal 1965		Fiscal 1964	
Isotope	Country	No. of shipments	Country	No. of shipments	Country	No. of shipments
Ar^{38}		—	—	—	France	3
I^{132}	—	—	—	—	Japan	1
I^{133}	England	1	—	—	—	—
Mg^{28}	France	31	France	32	France	40
	England	4	England	7		
	Canada	1	Canada	1		
Mo^{99}	Canada	14	Australia	4	Canada	2
			Canada	2	Mexico	1
			Japan	1		
Tc^{99m}	Canada	36	Canada	15	Germany	7
	Japan	10	Argentina	9		
	Argentina	8	Japan	7		
	South Africa	11				
	Australia	7				
	Peru	1				
Y^{90} generator	—	—	—	—	Japan	1
Y^{90} beads	Switzerland	1	Switzerland	1	—	—
	Netherlands	1	—	—	—	—

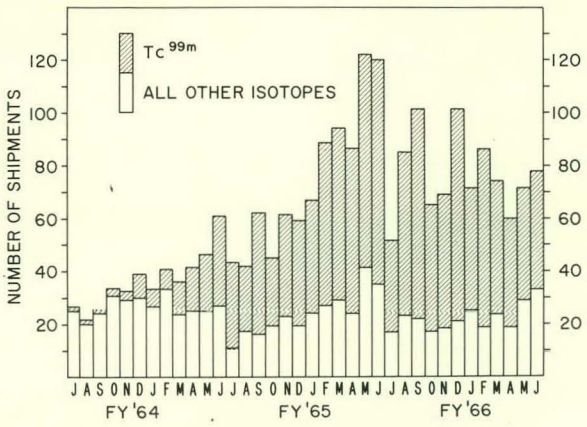


Figure 27. Isotope shipments.

creased yield of I^{132} (VII) when the parent tellurium is polymerized; the iodine oxidation state is not a function of solution temperature during growth.

The chemistry of technetium is being studied with use of paper chromatography, electrophoresis, and coulometry. Thus far two compounds have been found which behave differently physiologically from previous forms. The Tc(III) and Tc(IV) states were produced electrolytically. Tc^{99m}-labeled iron ascorbate was characterized and its preparation method improved.

The specific activity of radioactive hafnium and zirconium isotopes can be increased by Szilard-Chalmers reactions on the respective phthalocyanines. Effects due to mass and to the amount of spin change between product and reactant were observed.

Preliminary results of the excitation functions for the formation of Na^{22} and Na^{24} from 40 to 80-MeV alpha bombardment of Al^{27} are shown in Figure 24. Experimental results for the $Ar^{40}(\alpha,2p)Ar^{42}$ excitation function are compared in Figure 25 with values calculated by the (unpublished) method of Grover and Gilat, and Figure 26 shows the observed excitation function for the $Ca^{48}(\alpha,p2n)Sc^{49}$ reaction.

Unsuccessful attempts to produce Sc^{48m} by the V^{51}(14-MeV n,α)Sc^{48m} reaction indicate that if this isotope emits 0.2 to 2-MeV gammas and has a reasonable formation cross section, its half-life is either <1 min or very long.

Production of Special Isotopes

The remarkable demand for the special isotopes supplied by BNL is illustrated in Figure 27 and Table 2. Table 3 illustrates the extent to which the use of BNL-developed generators coupled with improved air transportation has eliminated geographical limitations on the use of short-lived isotopes. The Tc^{99m} generator was improved by substituting physiological saline solution for the 0.1 N HCl used previously as the eluant.

Physics

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

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

PARTICLE PHYSICS

The number of universities and laboratories sharing in the particle physics research at Brookhaven National Laboratory clearly demonstrates its national nature. About two-thirds of the work at the Alternating Gradient Synchrotron (AGS) and the Cosmotron is done by groups from these organizations. During fiscal 1966 more than 450 guest scientists participated in the program, including representatives of all the AUI institutions:

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

The following organizations were also represented:

Brown University
California Institute of Technology
Carnegie Institute of Technology
Case Institute of Technology
City University of New York
Duke University
Florida Atlantic University
Florida State University
General Electric Company
Institute for Advanced Study
Iowa State University
Naval Research Laboratory
Oak Ridge National Laboratory
Ohio University
Rockefeller University
Rutgers University
Stanford University
State University of New York at Stony Brook
Syracuse University
USAF School of Aerospace Medicine
University of Arizona
University of California at Berkeley
University of California at La Jolla
University of California at Los Angeles
University of Chicago
University of Colorado
University of Illinois
University of Maryland
University of Massachusetts
University of Michigan
University of Notre Dame
University of South Carolina
University of Tennessee
University of Washington
University of Wisconsin
Vanderbilt University
Washington University
Western Reserve University
William Marsh Rice University

Guest scientists also included representatives of the following foreign laboratories: CERN, Geneva, Switzerland; Chalk River Nuclear Research Laboratories, Canada; McGill University, Montreal,

Canada; University of Manitoba, Canada; Oxford University, England; Queen Mary College, England; Rutherford High Energy Laboratory, England; Woodstock College, England; CEN, Saclay, France; University of Caen, France; University of Bologna, Italy; University of Padua, Italy; University of Pisa, Italy; University of Rome, Italy; University of Delhi, India; University of Tel Aviv, Israel; and Weizmann Institute of Science, Rehovoth, Israel.

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

General

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

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

Research at the Cosmotron

For financial reasons, operation of the Cosmotron is scheduled to end early in 1967, and a long and fruitful program of high energy research with this pioneering accelerator will be brought to a close.

One Cosmotron project that will be arrested is a promising investigation of nuclear structure with BeV protons which has just begun to yield results for a Brookhaven group. The experiments require very high energy resolution, and at the start the energy spread of the Cosmotron was estimated to be a few MeV, at best perhaps 1 MeV. The first step was to investigate the machine characteristics with a high-resolution magnetic spectrometer using wire spark chamber hodoscopes. Surprisingly, the energy spread of the accelerator was found to be <1 MeV, with a long-term stability over periods of 24 hr of about 1 to 1½ MeV. At present the group is making nuclear measurements with a single-arm spectrometer with an over-all instrument resolution of about 2½ MeV, due mainly to multiple scattering in the helium bags in the magnetic spectrometer. A special vacuum chamber with very thin windows should allow a resolution of 1 to 1½ MeV. Preliminary results of measurements of the angular distributions of elastic and inelastic scattered protons from light nuclei have revealed a large deuteron production. Further investigation of the momentum distribution of these deuterons showed that the observed peak corresponded very closely to proton scattering from what appeared to be free deuterons inside the carbon nucleus. It is difficult to visualize free deuterons inside carbon, but the results are probably indicative of strongly correlated neutron-proton pairs inside the carbon nucleus. The incoming proton seems to interact very strongly with these pairs, and the deuteron is probably formed as the neutron-proton pair escapes from the carbon nucleus. A more definitive measurement of this process will be undertaken soon when a second spectrometer is ready and a coincidence measurement can be made between the outgoing deuteron and protons or other light particles.

In the area of particle physics, research involving both counter systems and hydrogen bubble chambers was carried out. An experiment using cosmic rays as a source of high energy particles was also performed. The report on this work follows.

The ρ meson is an unstable particle that decays into two pions. Recently there has been considerable speculation about the nature of its production process. A group from Princeton University now reports the analysis of an experiment to measure the dipion mass spectrum from the reaction $\pi^- +$

$p \rightarrow \pi^- + \pi^+ + n$ at an incident momentum of 1.5 BeV/c. The spectrum was observed between 450 and 1000 MeV, with π-π scattering angles at $90° \pm 30°$. With >6000 events obtained, the only structure observed is a peak at $\approx$750 MeV with a width $\Gamma \cong 130$ MeV, corresponding to the ρ meson. The result supports the so-called one-pion-exchange (OPE) process. Other features of the data fit the OPE predictions fairly well.

A group from Indiana University has completed analysis of photographs of $\pi^+ + p$ interactions taken some time ago with the BNL 14-in. liquid-hydrogen bubble chamber. At 751-MeV/c incident pion momenta, 2000 events were obtained. Partial cross sections measured were: $(\pi^+ + p \rightarrow \pi^+ + p) = 9.5 \pm 0.5$ mb, $(\pi^+ + p \rightarrow \pi^+ + p + \pi^0) = 9.3 \pm 0.5$ mb, $(\pi^+ + p \rightarrow \pi^+ + \pi^+ + n) = 2.15 \pm 1.7$ mb. Angular distributions were obtained for the elastic channel, and energy and angular distributions for the single-pion production channels. The decay distribution of the $(\pi^+ p)$ isobar is suggestive of ρ exchange.

It is surprising that, although there are particle states that have quantum numbers corresponding to multiple charges, multiple pions, and multiple spins, no double nucleon states are known with the exception of the deuteron, which may be considered a composite nuclei. A search for a dibaryon state was made by a group from the University of Rochester and BNL using the apparatus designed to measure a final-state interaction in the (Λ,p) system described in last year's report. They have analyzed the momentum spectra of π^+ and π^- mesons produced at 0° and 17° in the laboratory system in p-p collisions. Incoming proton energies of 2.85, 2.4, and 2.0 BeV were investigated. An upper limit for the production of a possible B^{+++} state, viz., $p + p \rightarrow B^{+++} + \pi^- \rightarrow p + p + \pi^+ + \pi^-$, is obtained $[\sigma(B^{+++}) \lesssim 100\ \mu b]$.

A group from the University of Michigan completed an experiment on elastic proton-deuteron scattering. This interaction provides a method of observing the collective interactions of nucleons at high energies and a test of some current dynamical theories of particle interactions. As a function of the four-momentum transfer, $-t$, the cross sections at 1.0, 1.3, and 1.5 BeV are approximately exponential in character. The behavior is typical of single-particle exchange processes.

The group from the University of Michigan also finished their experiment on proton-proton polarization. At 1.7 BeV, where previous results from Saclay and Berkeley were in disagreement, the present data favor the results from Saclay. The general behavior of the polarization as a function of angle and energy could be explained on the basis of a simple potential model with a real spin-orbit potential at low energies which becomes imaginary as inelastic processes become predominant.

The demonstration at the AGS by a Princeton University group of apparent CP (charge conjugation, parity) violation in the 2-pion decay of the long-lived K^0 meson has stimulated much theoretical and experimental work. A University of Rochester group has completed a Cosmotron experiment to detect the interference between the decay amplitudes of the long-lived and short-lived components of the K^0 from about 9 to 14 K_S lifetimes downstream from a target in an external beam. The data are being analyzed.

A group from the University of South Carolina and BNL conducted a survey experiment to measure the pion-production cross sections for Be, C, Cu, and B bombarded with 1.0, 2.0, and 3.0-BeV protons. The momentum spectra of positive and negative pions were measured at laboratory angles of 0°, 17°, and 32°. Some cross sections for inelastically scattered protons, H^3, He^3, and deuterons were also obtained.

Two cosmic-ray experiments were completed by a group from Yale and BNL. Since the experiment by the Princeton University group suggests that time-reversal invariance is violated, a search was made for heavy magnetic monopoles whose existence also violates time-reversal invariance. Monopoles created by cosmic rays high in the atmosphere could diffuse along magnetic field lines and be accelerated and focused on a nuclear-emulsion array by a large solenoid magnet, the final trajectory being defined by coincidence counters and a spark chamber. No monopoles were found, and the result places an upper limit for the flux of monopoles in the atmosphere at $\lesssim 3 \times 10^{-15}$/cm^2-sec. Assuming a specific model for monopole production in very high energy nucleon-nucleon collisions, an upper limit of $\sigma \lesssim 2 \times 10^{-36}$ cm^2 for the production cross section of 15-BeV/c^2 monopoles is derived.

It is attractive to speculate that the known, strongly interacting, "elementary" particles are, in fact, composites of a triplet of more fundamental particles. In one particular scheme the triplets would have charges of ⅓ and ⅔ that of the electronic charge. Measurements have been made of

the flux of particles with these charges which reach sea level from the vertical with relativistic velocities. The apparatus, which consisted of six scintillation counters with an acceptance of 650 cm²-sterad, was in operation for about 3500 hr. Particles with fractional charge were identified through their characteristic energy loss in each of the six counters. The flux of particles with a charge of ⅓ was determined to be $2.6^{+2.1}_{-1.3} \times 10^{-9}$/cm²-ster-sec. The flux of particles with a charge of ⅔ was determined to be $2.1^{+1.8}_{-1.5} \times 10^{-9}$/cm²-ster-sec. There is thus a suggestion that these particles exist.

Research at the Alternating Gradient Synchrotron

In an experiment carried out at the AGS, a group from the University of Pennsylvania has measured $\pi^{\pm}$ proton scattering at backward angles, in the "nucleon-exchange" angular region, at 4 to 10 BeV/c. This experiment was designed to study the structure of the nucleon (and its excited states) when the nucleon acts as the object *exchanged* in a particle reaction. The behavior of the nucleon in these circumstances can give important information on the question of whether the nucleon is an "elementary" (structureless) particle or instead behaves like a compound system. These two possibilities give distinctly different predictions for the energy- and angle-dependence of nucleon-exchange scattering.

Clear nucleon-exchange peaks (peaks in the angular distribution, at backward angles) were found and unexpected large differences were found in these peaks for the π^+-p and π^--p cases. These differences, and the detailed energy- and angle-dependence of the peaks, may be explained in terms of Regge-pole behavior of the exchanged nucleon. Regge-pole behavior may be thought of as corresponding to the transfer of a nonelementary particle. Thus this experiment indicates that the proton, the lightest member of the baryon family, is in a certain sense not a structureless elementary particle. If indeed the proton is a composite of other particles, it is not clear just what those other particles are. One possibility is that the proton is made up of quarks. Another is that the proton and (an infinite number of) other nucleon states are "made up of each other."

Following up their work on pion-proton total cross sections, a BNL counter group, joined by guest scientists from Europe, have measured the total scattering cross sections for K^- mesons by protons and deuterons at the AGS. The technique of precise measurements previously developed was applied to this work with the added feature of a purified beam of K^- mesons provided by an electrostatic separator. The measurements were made in the momentum range 1.0 to 2.45 BeV/c at intervals of 50 MeV/c. The momenta were determined to a relative accuracy of 1%. The statistical accuracy of the measurements in the region of the observed structure was 0.3%. Preliminary analysis indicates two new K^--nucleon resonances in the isotopic spin 0 state and very likely three in the isotopic spin 1 state above the Y_0^* (1815 MeV) resonance, as follows:

Resonance	Mass, MeV	Full Width, MeV
Y_0^*	2100±20	160
Y_0^*	2340±20	105
Y_1^*	1915±20	65
Y_1^*	2040±20	150
Y_1^*	2260±20	180

Since other Y^* resonances have been discovered with lower mass values, it is speculated that these Y^* resonances may fit the Regge model which predicts recurrences of resonances at higher mass values with higher spin assignments.

A Brookhaven group in collaboration with a group from Carnegie Institute of Technology carried out a rather extensive study of inelastic p-p interactions over the full range of AGS energies with use of a new technique. Approximately 300 momentum spectra of emergent p's and π's were measured at five incident energies and at fixed laboratory angles covering the range from 9 to 260 mrad. In all, some 10^7 events were recorded and analyzed during the data-taking. The apparatus used was a precision spectrometer connected on line to the BNL PDP-6 computer; the spectrometer consisted of a set of 12 wire spark chambers (see the section on Instrumentation) and two 72-in. bending magnets. The system was capable of recording up to 200 events per AGS beam pulse; the precise angle and momentum of each event and the sorting into angle and momentum bins was calculated by the PDP-6 for the events in the 2.5-sec period between AGS pulses. This system, developed by this group at Brookhaven during the previous two years, represents the first application of a wire chamber system to a full-scale high energy physics experiment. It established the digitized wire chamber as a useful and reliable device for high energy research.

With this system differential cross sections for the reaction $p+p \rightarrow p+N^*$ were obtained covering a wide range of energy and scattering angles. Here N_1^* represents any one of the nine known excited states of the proton. The data for the production of one isobar, N^* (1.69), as a function of momentum transfer, t, are summarized in Figure 1. From this figure it may be seen that two rather distinct types of interaction seem to exist, separated by a value of t of ≈ 1 (BeV/c)^2. Below this value the cross sections are exponential, but the different isobars have slopes that differ from one another and from the elastic channel. Perhaps the most remarkable fact that emerged is the lack of energy dependence in this region for all but the N^* (1.24) channel, with the consequence that the total cross sections for these other channels are constant in the 10 to 30-BeV range.

In the region above $t \approx 1$ (BeV/c)^2, N^* (1.52) and N^* (1.69) show behavior similar to that of the elastic channel, and all channels show strong energy dependence. Thus the behavior in this region suggests a statistical-type model for the interactions, in contrast to the behavior in the low t region, where peripheral interactions involving simple particle exchanges are indicated.

Theoretical predictions based on $SU(3)$ and other symmetries have predicted a branching ratio for the decay of the long-lived K_L^0 meson into 2 γ's and into 2 π^0's. A group from the University of

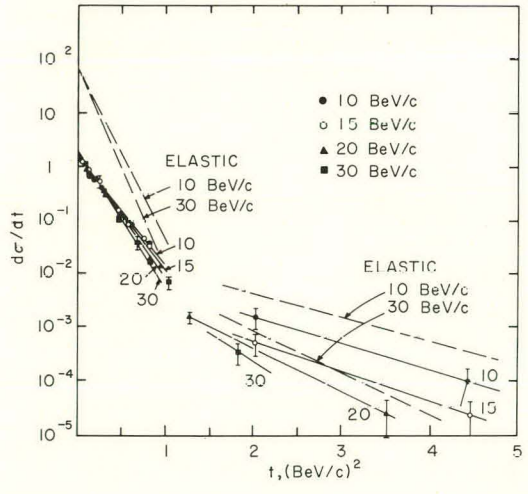


Figure 1. Cross section for the production of the N^* (1.69) isobar by p-p scattering as a function of the momentum transfer, t. Note the change in the character of both elastic and isobar dependence at $t \approx 1.25$ (BeV/c)^2. Similar data exist for other isobars.

Illinois has determined these two decay rates experimentally. Figure 2 shows the arrangement of spark chambers and scintillation shower detectors used.

The neutral K mesons were produced by 30-BeV protons on an internal beryllium target at the Brookhaven AGS and collimated at 30°. Photons were filtered out of the beam with 4 cm of lead located close to the target; charged particles were removed with a sweeping magnet following the lead. Decay photons were converted in two spark chambers measuring 30 × 30 cm × 25 cm deep, each containing two radiation lengths of lead. The energies of the resultant showers were measured (to an accuracy of about 30%) with lead-and-scintillator shower detectors (S_L and S_R) behind each spark chamber. A total of 79,000 pictures were scanned and 4000 were selected for further analysis. These had one photon shower in each spark chamber and shower configurations allowing the reconstruction of the initial photon directions. Each of these events was considered to be a 2-photon decay of a single particle. The analysis was carried out by comparing the invariant masses associated with the two observed photons with those computed for 2γ, $2\pi^0$, and $3\pi^0$ decays simulated by a Monte Carlo program and satisfying identical triggering and scanning criteria.

After correction for a background due to $3\pi^0$ decays, 29 candidates for the $K_L^0 \rightarrow 2\gamma$ mode remained and 6 events may be ascribed to the $K_L^0 \rightarrow 2\pi^0$ mode. These numbers together with the calculated direction efficiency give (rate $K_L^0 \rightarrow 2\gamma$)/(rate $K_L^0 \rightarrow$ all modes) $= (1.35 \pm 0.6) \times 10^{-4}$, and (rate $K_L^0 \rightarrow 2\pi^0$)/(rate $K_L^0 \rightarrow$ all modes) $= (1.0 \pm 1.2) \times 10^{-3}$. This result may be compared with the theoretical predictions for $K_L^0 \rightarrow 2\gamma$, which range from 5×10^{-3} to 1.5×10^{-5}, and for $K_L^0 \rightarrow 2\pi^0$, which range from 3.2×10^{-5} to 0.8×10^{-3}.

It is of fundamental importance to the theory of weak interactions to confirm or refute the postulate that there exists a particle, the intermediate boson (W), which mediates these interactions. The W would thus play a role similar to that of the photon in electromagnetic interactions and the meson in strong interactions. Experiments searching for the W previously carried out at Brookhaven and at CERN with use of high energy neutrinos have established that if it exists it has a mass >2 BeV.

Recently a Columbia-BNL team has extended the search by measuring the yield of high energy

muons emitted at large angles when a proton beam with a momentum of 20 or 30 BeV/c collides with the nucleons in a tungsten target. It has been recognized that such large-angle muons would be evidence for a heavy W because of the large transverse momentum given to them in the decay process $W \rightarrow \mu + \nu$. Thus for a W of mass 2 to 6 BeV the transverse momentum of the emitted muon can vary from 1 to 3 (BeV/c)^2. This is much larger than is typically found in secondary particles emerging from high energy interactions.

The experiment was performed at the AGS with the fast-extracted proton beam transported in a vacuum pipe up to the 82-ft steel shield of the BNL neutrino facility. A counter array was buried in the steel shielding. The beam struck an 18-in. block of Hevimet (90% tungsten), which absorbed the bulk of the beam and its secondary particles. In this way the usual source of muons was largely "turned off," because the "parent" particles, pions and kaons, undergo relatively fast absorption by strong interaction in dense matter ($\approx$4 in. in tungsten) as compared to their mean free path ($\approx$1800 ft at 10 BeV) for decay into muons. Thus the rate of muon counts observed at large angles, relatively easily reached by W decay, is an upper limit to the product $\sigma_W B$, where σ_W is the W production cross section by AGS protons (per nucleon), and B is the rate for the decay $W \rightarrow \mu + \nu$. The experimenters concluded that $\sigma_W B < 2 \times 10^{-34}$ cm^2 (99% confidence level) for proton-nucleon collisions in the mass range $\approx 2.5 < m_W < \approx 6$ BeV/c^2. The interpretation of these data in terms of the *existence* of bosons $m_W < 6$ BeV/c^2 must await a better theoretical grasp of the production of heavy particles.

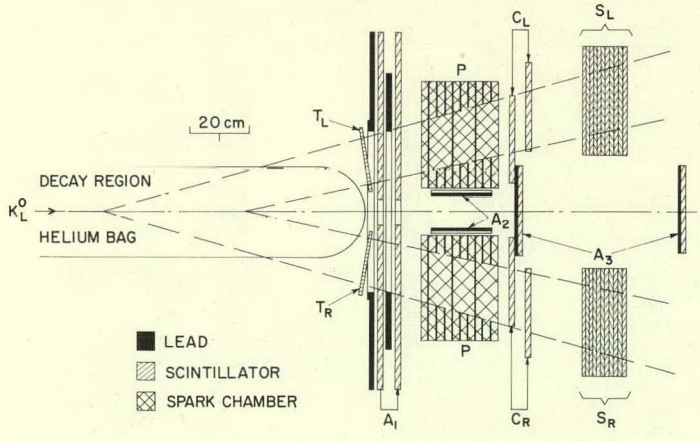


Figure 2. Diagram of setup to determine the decay rate of the K_L^0 meson with two γ rays. Spark chambers P convert γ's in shower and measure angle of emission of γ rays. S_L and S_R are scintillation-lead detectors which measure roughly the energy of γ rays. A_1, A_2, and A_3 are anticoincidence counters.

It is well known that the CPT theorem which follows from very general principles of Lorentz invariance predicts equal masses, equal lifetimes, etc. for both particle and antiparticle. In view of the recent discovery of small CP violations, a group from the University of Rochester and BNL checked the validity of CPT in strangeness-violating weak interactions such as the decay of the K^- meson. Since the lifetime of negative particles (with the exception of the μ^- meson under very special conditions) cannot be measured at rest, a beam of K^+ and K^- mesons was formed at the AGS by using one stage of electrostatic separation. The K mesons were contained over considerable distances (up to 2000 in.) with the help of quadrupole triplets. The geometric collection efficiency of the system into a 1½-in. counter was always better than 0.996. This was measured by using both protons and antiprotons. The momentum of the K mesons was measured separately to $\frac{1}{1000}$, and seven completely independent sets of data (for each type of particle) were taken. The final analysis of the data is now in progress, the statistical error on the ratio being

$$\sigma[\tau(K^+)/\tau(K^-)] = 0.0006 .$$

The random deviations of the independent runs are compatible with such an error. From the preliminary analysis it was possible to set the upper limit for a possible deviation:

$$\left| \frac{\tau(K^+)}{\tau(K^-)} - 1 \right| < 0.002 .$$

Figure 3 shows the experimental setup.

A group of physicists, mainly from Harvard University but including members from Yale, McGill, Cornell, and the Stanford Linear Accelerator Center, used a carbon plate spark chamber in a 12-BeV/c π^- beam to examine the spectrum of μ pairs emerging from the chamber (see Figure 4). The effective mass, $m_{\mu\mu}$, of the (μ^+,μ^-) system can be calculated if measurements are made of the opening angle between the pair of μ's and the energy of each muon. Of interest is the question of whether the μ pairs result from a resonant state

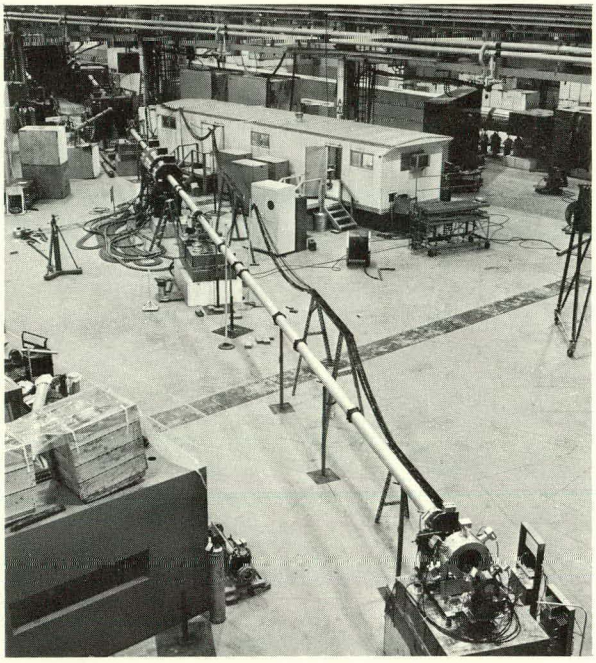


Figure 3. Flight path and detection system used to compare the mean lifetimes of the K^+ and K^- mesons.

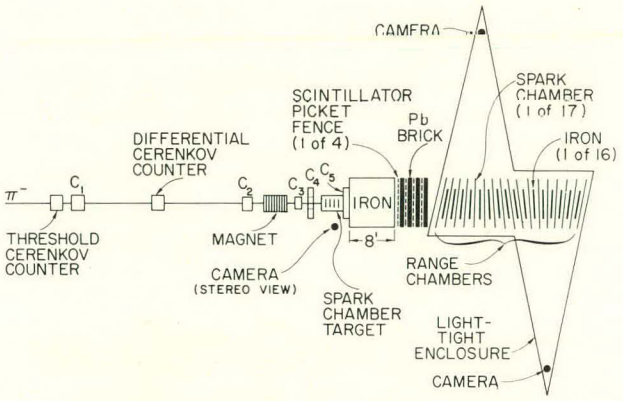
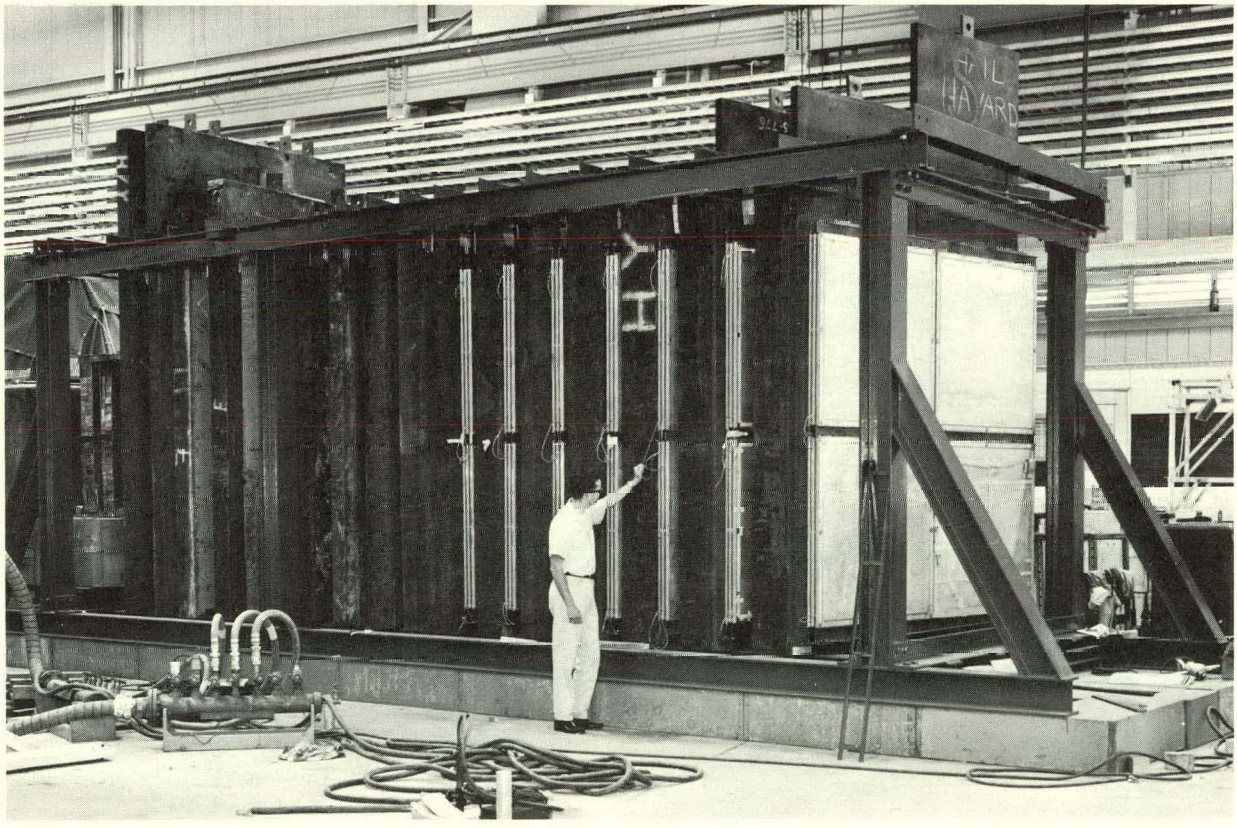


Figure 4. Experimental arrangement for measuring the spectrum of μ pairs. These pairs are produced in the spark chamber target, pass through the iron filter, through the picket-fence triggering counters, and into the range chamber. The iron filter absorbs the large background of pion pairs produced in the target chamber, and uninteresting triggers are thereby avoided.

Figure 5. Device used to measure the energy of the μ-meson pairs produced in a carbon target by 12-BeV/c π^- mesons. It consists of 6-in. steel plates alternating with large spark chambers.



such as the ρ, ω, or ϕ mesons, or any other state with quantum numbers $J^P = 1^-$. This question is particularly important in understanding the electromagnetic structure of the nucleon because the simplest model of elastic μ^--p scattering, for example, supposes that the muon emits a virtual photon which couples to the kaon and pion clouds of the proton through a resonant state of quantum numbers 1^-. In this experiment the equivalent process of producing the 1^- meson which decays into a pair of muons via an intermediate photon was investigated. From spark chamber photographs of the carbon target chamber the opening angle of the μ pair is measured. The energy of each muon is obtained by allowing the muons to enter the range chamber, which consists of the spark chamber modules sandwiched between large steel plates. The range chamber will stop a 10-BeV muon. (See Figure 5.)

Figure 6 is a histogram of the number of events having an effective mass $m_{\mu\mu}$. These events are selected from the data as being "energy conserving" events, i.e., all the pion energy goes into the (μ^+,μ^-) system. This constraint makes it possible to improve the mass resolution of the experiment by avoiding the error due to straggling in the range chamber. It is apparent from Figure 6 that a strong enhancement of the $m_{\mu\mu}$ spectrum is occurring at about the mass of the ρ meson (765 MeV). In addition, there seems to be no structure at high mass values (although the equipment is sensitive to masses up to 1500 MeV), which indicates that there are no further resonant states similar to the ρ which could contribute to the pion form factor. If it is conjectured that the pion form factor is entirely due to the ρ meson, then the electric radius of the pion can be calculated to be about 0.6 fermis. Whether there is an ω contribution on top of the ρ peak must be determined by a Treiman-Yang test of the data. The mass resolution is 25 MeV, which is marginal for seeing an ω peak. There is also no obvious structure at the ϕ-meson mass value because the cross section for pion production of ϕ's is extremely small.

A group from the University of Wyoming, with assistance from the BNL staff, has performed an interesting emulsion experiment (see Figure 7). A stack of emulsions was exposed to about 10^6 separated K^- mesons by being placed behind the 80-in. bubble chamber during a run involving these particles. An event was found which can be interpreted only as resulting from the K^- production of a Ξ^- particle which interacts with C^{12} by the process $\Xi^- + C^{12} \rightarrow Li^7 + {}_{\Lambda\Lambda}He^6$ (a helium nucleus

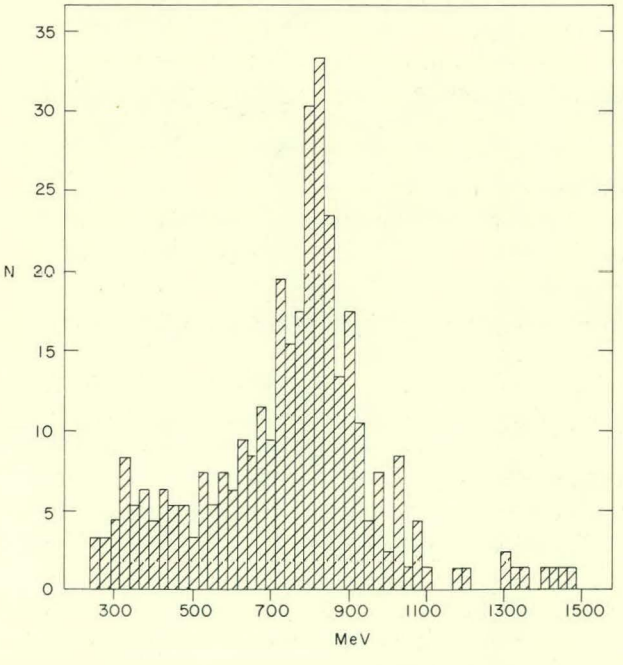


Figure 6. Mass distribution of the particles decaying into two μ mesons.

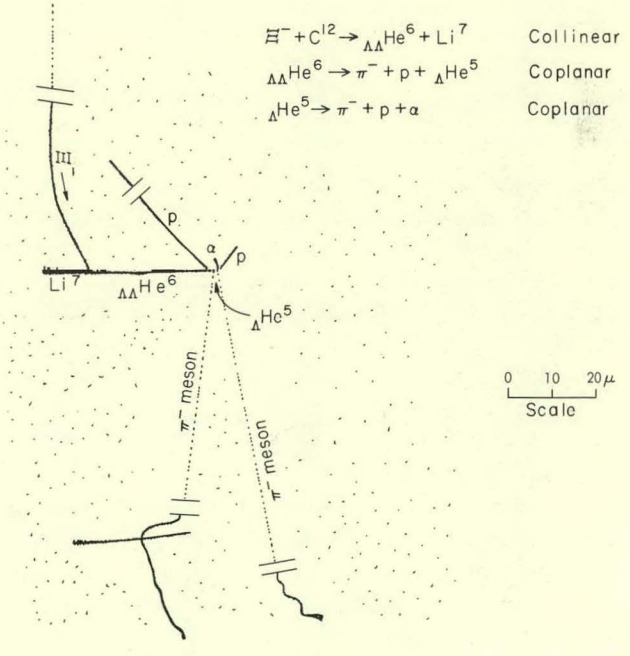


Figure 7. Drawing of an emulsion event showing the production and decay of a double hyperfragment.

containing two Λ particles and two instead of four neutrons). One Λ of the ${}_{\Lambda\Lambda}He^6$ then decays by the process ${}_{\Lambda\Lambda}He^6 \rightarrow \pi^- + p + {}_{\Lambda}He^5$. The second Λ decays by the process ${}_{\Lambda}He^5 \rightarrow \pi^- + p + \alpha$. These events confirm the existence of double hyperfragments and yield a value for $\Lambda\Lambda$ binding of 4.6 ± 0.5 MeV.

One of the principal areas being investigated by the Bubble Chamber Group and the Nuclear Interaction Group at BNL is the discovery and study of the properties and production mechanisms of new particles via strong interactions.

The mass spectrum of such particles has been codified into families of 8 and 10 members. Experiments are being performed and proposed in a search for resonances that require larger member representations, namely 27 or higher. The results of such studies have enormous implications with respect to composite models of elementary particles, i.e., as to which models have a greater or less validity.

In an experiment carried out by a BNL–Syracuse University team, seven Ω^- events have been found to date. A total of 350,000 pictures have been scanned and measured in exposures to 5.0-BeV/c K^- interactions in the 80-in. hydrogen bubble chamber. This corresponds to a cross section of 1.3 μb. Four of these Ω^- hyperons decay via the mode $(\Xi^0 + \pi^-)$, two via $(\Lambda + K^-)$, and one via $(\Xi^- + \pi^0)$. The world total of Ω^- events is now 12.

Using these same photographs, the BNL–Syracuse group has now observed the decay mode $f^* \rightarrow K^+ + K^-$. The discovery of this resonance (mass 1500 MeV and width 85 MeV) by the same team was reported last year.

A peak has been observed in the (K_1^0, K_1^0) mass spectrum from the reaction $\pi^- + p \rightarrow K_1^0 + K_1^0 + n$ at 6 BeV/c. This enhancement, called the S^*, is centered at 1068 ± 10 MeV with a width of 80 ± 15 MeV. Analysis shows that the quantum numbers of the S^* are $I^G = 0^+$ and $J^P = 0^+$. Because of its scalar nature, the S^* can be identified as an isosinglet member of a scalar multiplet in the framework of $SU(3)$ symmetry.

In the continued study of about 20,000 two-prong events and 12,000 strange-particle events, clear evidence is seen for G-meson ($\approx$1675 MeV) production from the reaction $\pi^- + p \rightarrow \pi^+ + \pi^- + n$. Progress is being made in determining the isospin and the spin-parity of this resonance from (π^-, π^0, p) and (K, K, n) final states. This study is being done by a BNL–CUNY group.

The study of hyperon-antihyperon production in interactions of 7-BeV/c antiprotons with protons has been completed. This study was undertaken by a BNL group and the high energy physics group at Yale University. A total of 80,000 pictures taken with the BNL 80-in. liquid-hydrogen bubble chamber have been analyzed for all possible final states involving the production of a hyperon and/or an antihyperon. The total cross section for events in this category is 1.3 ± 0.1 mb. Reactions leading to 2-, 3-, or 4-body final states involving Λ or Σ hyperons (or their antiparticles) were produced highly peripherally. The angular distribution of the $(\Lambda, \bar{\Lambda})$ final state can be fitted to K^* (888 MeV) exchange when the absorptive effect of competing channels is taken into account. Ratios among cross sections of various hyperon-antihyperon pair states agree with predictions from $SU(3)$ symmetry if a dominant K or K^* exchange and an F-type coupling are assumed. Charge ratios of events with $\Sigma^{\pm}$ hyperons and $Y_1^{*\pm}$ (1385 MeV) resonances are also consistent with single-particle exchange models. The mass spectra of all possible mass combinations of all possible final states have been examined. The Y_1^* (1385) was by far the most prominent resonance produced, and production of Y_0^* (1405), Y_1^* (1520), and Y_1^* (1765) was also observed. Although the energy available in the production center-of-mass system is 3.86 BeV, there was no statistically significant evidence for the production of any new meson or baryon resonance. A thorough search has been made for Ω and $\overline{\Omega}$ particles, but no event was found to be consistent with their production and decay.

The film is currently being used to study the interference between Coulomb and small-angle nuclear scattering. The data are taken from the film by an automatic scanning program which uses the Hough-Powell Flying Spot Digitizer (FSD), and each track is then examined for kinks by a subsequent program. From this analysis the experimenters expect to obtain a measurement of the real part of the proton-antiproton scattering amplitude.

About ¼ of the film has been copied and sent to Tohoku University in Japan, where a high energy group is being formed; a study of pion production by antiprotons will be one of their first experiments.

A search by BNL physicists for a (K^+, K^+) resonance with mass of $\approx$1250 or 1050 MeV has been completed with a negative result. A total of

120,000 pictures were taken in the BNL 80-in. hydrogen bubble chamber exposed to a 3-BeV/c K^+ beam. A total of $\approx$100 (K^+,K^+,Λ) or (K^+,K^+,Σ^0) events were obtained, which gives a (K^+,K^+) mass distribution fitting phase space rather well. If all the world data on this effect, namely those from CERN, the University of Wisconsin and BNL, are combined, there is no evidence for any (K^+,K^+) resonance where previously there had been some indication.

Approximately 60,000 photographs were taken with the 80-in. chamber filled with hydrogen with a 28.5-BeV proton beam. The reaction $p+p\rightarrow p+N^*$ is currently under investigation by a BNL group to determine the isospin, spin-parity, and elasticity of the N^* (1400 MeV) isobar which has been observed in proton and counter experiments. Single and double isobar production in general will also be studied.

In an exposure of the 30-in. hydrogen bubble chamber to a beam of K^+ mesons which were brought to rest in the chamber, a study by another BNL group of the space properties of pions from τ decay has been completed, and a preliminary result of the spectrum of electrons from K_{e3} decay will soon be presented. In earlier experiments in which the decay chain $\tau^+\rightarrow\pi^+\rightarrow\mu^+\rightarrow e^+$ was investigated, correlations between the π^+ and μ^+ directions were observed. Such a result would imply that the "pion" has nonzero spin. This decay chain has been re-examined and shows no anomaly. The decay rate of $\tau^+\rightarrow\pi^+ +$(Dalitz pairs) has also been measured in an unsuccessful attempt to establish anomaly in the "π^0" from τ' decay.

A further run in the 30-in. hydrogen chamber has just been made to study the reaction $K^- + p\rightarrow \Lambda+\eta$ at threshold. The improved separated beam (S-2) is expected to yield sufficient data to establish definitely the character of this threshold enhancement.

Studies of the reactions leading to Σ-hyperon production by K^- mesons on protons in the range 600 to 840 MeV/c are near completion and a report should be available this fall.

A number of results from $K^- + p$ interactions at 2.24 BeV/c obtained in several exposures of the 20-in. bubble chamber at the AGS have previously been reported. Data reduction and analysis of 40 separable reaction channels carried out both at BNL and at Syracuse University over a 4-year period is now complete. Many results of unusual interest, such as the discovery of the η^* (960), ϕ (1020), and Ξ^* (1530) resonances, have appeared in past annual reports. These earlier results have been updated with use of more complete samples. In addition, a considerable range of new results is now available, for example the decay branching ratio of η^* (960), ϕ (1020), etc., as well as cross sections for all reaction channels.

A total exposure of 320,000 pictures, 200,000 of $\pi^- + p$ and 120,000 of $\pi^+ + d$, both at incoming pion momenta of 1.68 BeV/c, were taken in the BNL 20-in. chamber and studied by a BNL–Carnegie Institute of Technology team. This energy is such that other known resonances such as the K^* (890) cannot be produced with an accompanying hyperon. A total of 170 clean Y_0^* (1405) events were obtained, clean in the sense that they were free from background interference or contamination from other resonances. A study of the production and decay distributions indicated that the Y_0^* spin was $J=\frac{1}{2}$. In principle it is possible to measure the parity of Y_0^* (1405) from a measurement of the Σ^* polarization in the chain Y_0^* (1405) $\rightarrow\Sigma^+ +\pi^+$; $\Sigma^+\rightarrow p+\pi^0$. However, the present paucity of events (35) in this channel precludes such a determination. Low energy kaon-nucleon interactions were analyzed in terms of Dalitz-Tuan effective range formalism and it was deduced that the Y_0^* (1405) is an $S_{1/2}$ bound state of $(\bar{K},N)$, i.e., $J^P=\frac{1}{2}^-$. In addition, in this same exposure the Y_1^* (1385) resonance was observed and its spin measured to be $J=\frac{3}{2}$, in agreement with the results of many other experiments.

The investigation of ρ and ω production and decay as produced by $\pi^+ + n$ and $\pi^- + p$ interactions was completed with use of these same photographs. The ρ and ω are produced peripherally, the former by π exchange and the latter by ρ exchange. However, it was found that absorption effects must also be included in the initial and final states in order to explain the ω production-angle distribution, which is not as sharply peaked as predicted by the simple Sakurai-Stodolsky model. If the dipion mass spectrum from the 3-body final states is examined, a distortion at a mass slightly higher than the ρ mass is observed, occurring mainly at intermediate energy (q^2), with both π^+ and π^- mesons as incoming particles, and one of the interpretations of this effect is that it may be the 2π decay mode of the ω. On the whole, these investigations add further weight to the general observations that pseudoscalar exchange agrees quite well with a single-particle exchange model and that vector exchange works poorly.

Analysis by a Brookhaven group continued on an exposure of the 20-in. bubble chamber to about 65,000 $\pi^- + p$ interactions at 3.5 BeV/c. In the latter part of fiscal 1966, 10,000 of these events were successfully measured on the FSD over a period of 2½ months. This sample has been studied for ρ, ε, and f^0 physics. Measurements on a further sample of 20,000 events are in progress.

The dynamics of the $\bar{p} + n$ interactions were studied via the production of $(\bar{N}^*, N)$ final states in the BNL 20-in. deuterium chamber by a team from BNL and Carnegie Institute of Technology. The production and decay distributions agree with the predictions of the OPE model as calculated by Ferrari and Selleri. However, the measured cross section of 5.1 ± 0.5 mb was low by a factor of two, which indicated the importance of absorption effects as proposed by Gottfried and Jackson.

The problems being pursued in the weak interaction study by the Nuclear Interaction Group are threefold: (a) do $\Delta S = -\Delta Q$ currents exist, (b) what is the sign and magnitude of the (K_1^0, K_2^0) mass difference, and (c) what is the magnitude of CP violation in $K_S^0 \to 3\pi$ decay? These problems are being studied via the decay and interaction of K^0 mesons produced by K^+ charge exchange in deuterium.

To date $\approx$300,000 pictures have been taken in the BNL 30-in. deuterium chamber exposed to a 600-MeV/c K^+ beam. Since the discovery by a Princeton University group working at the AGS of CP violation in $K_L^0 \to \pi^+ + \pi^-$ decay, extreme interest has been generated in studying such violation in other reactions. To this end the decay $K_S^0 \to \pi^+ + \pi^- + \pi^0$ was looked for, and in a sample of $\approx$50 such decays within 10 K_1^0 mean lives all were found consistent with being due to $K_L^0 \to \pi^+ + \pi^- + \pi^0$. In addition, an investigation has been made to determine whether the $\Delta S = -\Delta Q$ current exists. A total of 200 leptonic decays have been found ($K^0 \to \pi + e + \nu$; $K^0 \to \pi + \mu + \nu$). From a study of time distribution of these leptonic decays the ratio, X, of the $\Delta S = -\Delta Q$ and $\Delta S = +\Delta Q$ amplitudes is determined.

$$X = \frac{A(\Delta S = -\Delta Q)}{A(\Delta S = +\Delta Q)} = |X| e^{iy},$$

$$X = 0.5 \pm 0.2, \quad y = 50° \pm 20°.$$

Finally, the magnitude of the (K_L^0, K_S^0) mass difference can in principle be measured from the distribution of K^0 secondary interactions. The best value for this number is 0.6 ± 0.3 for 75 events.

The analysis of part of the data on the 2-pion decay mode of the K_L^0 and on K_S^0 regeneration by K_L^0 mesons in the 80-in. chamber has been completed and published. This experiment was a collaboration between the Yale University and BNL Bubble Chamber Groups. The results are in agreement with spark chamber results, where the regeneration occurred in heavier materials, and show that

1. In contradiction with theories that explain the CP violation in K_L^0 decay by postulating a "fifth force," the branching ratio to the 2-pion decay mode of the K_L^0 meson shows no marked dependence on the laboratory momentum of this meson.
2. The phase difference between the amplitudes for the 2-pion decay modes of the K_S and K_L mesons is $30° \pm 45°$.

The 3-pion decay mode has also been analyzed and found to yield a branching ratio of (π^+, π^-, π^0) to final states containing no neutral particles, which is in agreement with the $\Delta T = ½$ rule. This is consistent with previous measurements.

With reference to the discovery, mentioned above, of a violation of CP invariance, theorists have conjectured that this violation might actually be due to a violation of C invariance in quasi-strong interactions. The strength can be estimated to be of the order of 10^{-2} to 10^{-3} with respect to the strong interactions, but $\approx 10^{10}$ with respect to the weak interactions. A previous experiment to test C invariance in strong interactions by a Columbia group at BNL had confirmed C invariance of the usual strong interactions to an accuracy of about 1 part in 100.

The decay of the η meson, $\eta \to \pi^+ + \pi^- + \pi^0$, can proceed via the electromagnetic interaction but not through the usual strong interaction. If the above C noninvariance interaction were to contribute to the η-meson decay, then sizable C noninvariant effects might be expected. In particular, the decay energy spectrum of the positive pion could be different from that of the negative pion, and such a difference would constitute proof of C noninvariance.

Define N^+ to be the number of events for which the π^+ is more energetic than the π^-, and N^- the corresponding number for which the π^- is more energetic. The result of an experiment can be expressed in terms of the asymmetry parameter A, where

$$A=\frac{N^{+}-N^{-}}{N^{+}+N^{-}}.$$

Using η mesons produced in the reaction $K^{-}+p\rightarrow \Lambda+\eta$ in the BNL 30-in. hydrogen chamber, a Duke University group has reported a value of $+0.087\pm0.053$ for this asymmetry parameter. In another experiment in the 30-in. chamber, physicists from Columbia University and the State University of New York at Stony Brook used the reaction $\pi^{+}+d\rightarrow p+p+\eta$ to obtain η mesons for study. Their published result is $A=+0.072\pm 0.028$.

Because of the importance of this effect, other measurements of the asymmetry in η-meson decay, using a variety of techniques, are planned or in progress at BNL and at other laboratories.

Theory

During the past year the work of the theoretical group has covered a number of areas. In the area of fundamental theory, a Lagrangian field theory model of the ρ meson was considered in the "bootstrap" limit in which the ρ becomes strictly a multipion system. It was found that if such a limit exists the theory becomes anomalous in the sense that any finite set of skeleton graphs, along with the radiative corrections, gives a trivial S-matrix.

A calculation of the γ-ρ direct coupling, γ_{ρ}, has been completed. An explicit value of $\gamma_{\rho}/\gamma_{\rho\pi\pi}$ is obtained from the Zachariasen and Zemach model of the ρ. How an approximate value of γ_{ρ} can be obtained in a more general context has also been observed.

Electromagnetic and weak properties of the neutron-proton system have been calculated in the strong coupling model. An extension of the strong coupling theory to $SU(3)$ is being attempted with a general orientation toward the weak and electromagnetic properties of the baryons.

Studies of the properties of the solutions of field equations and commutation relations and the related matrix elements have covered such matters as

1. The consistency conditions imposed on commutators and matrix elements by the assumptions of the conserved vector and partially conserved axial vector currents.

2. The peculiar features required of a quantum field theory of particles carrying magnetic charge (monopoles) as well as electric charge. The problem of crossing symmetry in this theory is now under study.

3. A program to reconcile apparently mutually inconsistent analyses of the neutron-proton electromagnetic mass difference within the framework of quantum field theory.

An alternative derivation, which is not based on the Gell-Mann algebra of current commutators, has been given of the Alder-Weisberger and similar sum rules.

The numerical solution of the Bethe-Salpeter equation in the ladder approximation has been examined. A method of solution was found which could be extended above the first inelastic threshold, but the solution was then nonunitary. When self-energy corrections were included a unitary solution was obtained, but with modified behavior even below the inelastic threshold.

In the area of strong interactions, the high energy scattering of particles off deuterons has been studied, and it was shown that the size of the Glauber shadow correction in π-d scattering up to 20 BeV/c is not in accord with any Regge picture of pion-nucleon scattering.

The effect of Fermi motion on the scattering of particles off deuterons in the resonance region was considered. This technique was subsequently applied to the $K^{\pm}$-d total cross section data obtained here, with some success in that more new resonances were found. To provide a thorough check of the procedure some new $\pi^{\pm}$-d total cross-section measurements are now being analyzed in the same manner.

Incidental to this work, the Glauber correction for π-d scattering was shown to violate charge independence, and a new formula was derived which does not suffer from this defect.

Attempts to explore the generalized diffraction concept have resulted in a study of the photoproduction of ρ mesons and a study of interesting "regeneration" effects in ω-ϕ production. Further work along this line will relate the analogous but more complicated situation with incident hadrons, such as the $p+p\rightarrow N^{*}+p$ reaction studied at Brookhaven. Related questions under study include possible electromagnetic effects in regeneration of K mesons, application of the ρ-photon analogy to production of $\frac{3}{2}^{-}$ isobars, and high energy final-state interaction theory.

Calculations of the real part of the neutron-proton scattering amplitude by means of the forward dispersion relations and charge exchange data are in progress.

The decays of strongly interacting systems with $J^{P}=1^{-}$, $J^{C}=1^{-}$ (vector mesons and $\bar{p}$-p annihila-

tion at rest) were analyzed to obtain values of coupling constants, in particular the ratio of symmetric to antisymmetric couplings of vector mesons to baryons and of η^* (960 MeV) mesons to nucleons.

Previous work on linear mass relations for the strongly interacting particles has been extended, particularly in connection with several recently discovered resonant states. Three observed particle states with baryon number $B=2$ satisfy simple mass relations which give support to the compound (quasinucleus) model discussed in earlier work.

With respect to electromagnetic interactions, a phenomenological investigation of decay modes of η (550) and a possible C violation in strong and/or electromagnetic interactions was made, and it was concluded that the present experimental values for the neutral branching ratios and the shape of the Dalitz plot distribution require the existence of a $|\Delta \mathbf{T}|=3$ contribution to the amplitude for $\eta^0 \rightarrow \pi^+ + \pi^- + \pi^0$. The consequences of specific isospin behavior of a possible C-violating interaction for various Dalitz plot configurations were also discussed.

Calculations were made of the momentum transfer and energy dependence of μ^- bremsstrahlung off carbon and hydrogen. Calculations are in progress on the effect of the Coulomb interaction between the outgoing electron-positron pair on the process $\gamma + \text{nucleus} \rightarrow \text{nucleus} + e^+ + e^-$. A semiclassical argument has been given suggesting that this might explain ⅓ to ½ of the experimentally observed deviation from the well-known Bethe Heitler theoretical cross section.

In the study of weak interactions, the decay of the W meson into two pseudoscalar mesons and into a baryon-antibaryon pair was calculated. Estimates were made for the direct decays of $J^P=0^-$ mesons into lepton pairs.

A course of lectures on the properties of scattering amplitudes was given to members of the Department. A general computer program for handling the complicated algebra of γ-matrices and evaluating traces, producing analytic expressions for transition probabilities, was successfully modified for the CDC 6600 computer. Assistance was provided to experimental groups on theoretical questions raised in their experiments.

80-in. Bubble Chamber

During fiscal 1966, the 80-in. chamber has taken a total of 1,474,000 pictures. This may be compared with 996,000 pictures taken during the previous year. These pictures were distributed over 26 separate experiments performed by 17 experimental groups.

A significant improvement was made in the performance of the dc separated beam (S-3) by the installation of a "kicker" magnet which swept the beam away from the chamber after the desired number of particles had traversed the chamber and thus gave an extremely stable beam intensity. During the second half of the year, the chamber was operated in the rf separated beam (S-4) for the first time. This beam ran quite reliably, requiring less surveillance and adjustment than beam S-3, and was used to take photographs of K^- and K^+ mesons at 7.4 and 12.8 BeV/c, π^- mesons at 9, 16, and 25 BeV/c, and protons at 29 BeV/c. The chamber can be moved from one beam station to the other in one day, but since this move entails emptying the liquid hydrogen from the chamber, an additional day is required for refilling. A hydrogen Dewar will soon be connected to the chamber and will shorten considerably the time required for refilling.

The CEA disaster in July 1965 prompted an extensive safety review of the 80-in. installation. Most of the specific criticisms leveled at the CEA installation were found not to apply to the 80-in. bubble chamber. However, many possible improvements were suggested, and most of them have been completed. Despite the *a priori* precautions, a hydrogen-oxygen ignition occurred in March in the expansion system cryogenic purifier and resulted in considerable damage to the purifier. All the recommendations made by the subsequently appointed investigating committee have been complied with, and no recurrence is expected.

Installation of new equipment and replumbing in preparation for deuterium operation accounted for a large part of the effort during the year's shutdowns. One very short deuterium run was made preceding the AGS shutdown in June 1966. This was instructive, and further deuterium operation is contemplated early in the next running period.

An alternate camera system for the 80-in. bubble chamber using 46-mm film has been developed at the Lawrence Radiation Laboratory (LRL) to provide a film format compatible with scanning and measuring machines for the LRL 72-in. hydrogen bubble chamber. This camera is operational and is now available as an option for the experimenter.

Good progress has been made in the development of a prototype "multipulse" camera designed to advance film at sufficiently high speed to permit taking two or more pictures per AGS pulse. This could eventually result in a considerably increased over-all picture-taking rate. It is hoped that a set of multipulse cameras will be ready for use during the second half of fiscal 1967.

Data Processing

The 3-view geometry program TVGP, prepared at LRL, has been put into production use on IBM 7094 and IBM 7044 computers, with minor modifications appropriate to Brookhaven bubble chambers. More extensive changes have been made in a version for the CDC 6600 computer, and test calculations have been performed. Use of KICK for kinematic fitting on the IBM 7094 has continued. For the CDC 6600 a new program has been prepared; it combines many routines from the LRL program SQUAW with a more automatic mode of operation in which the sequence of hypotheses to fit is generated by the computer if desired. Tests of this program have been started. On the CDC 6600 a later fit selection program will combine information from kinematic fits and densities of ionization to choose the best hypothesis following procedures used for experiments analyzed with use of the FSD and the IBM 7094. The data display program for the CDC 6600 will provide a flexible and convenient means of summarizing output in the form of histograms and scatter diagrams. Fit selection and data display programs are essentially complete but not yet in use on the CDC 6600.

To provide improved access to the main data storage medium, more flexible display capabilities, and more efficient data input to the CDC 6600 central computer, a data terminal network has been designed which incorporates a satellite computer. Specifications for this computer were prepared, and from bids received the SDS Sigma-7 was selected. Cathode-ray-tube displays will use a video display of a bit pattern from a refresher drum. Study of the need for a large photostore unit has continued, but it has not been possible to acquire such a unit during the present fiscal year.

Conventional measuring equipment has continued to bear the principal burden of analysis for the Bubble Chamber Group. Four machines capable of measuring 80-in. chamber film have been connected on line to a PDP-5 computer, and the system is now operating very satisfactorily. Extension of the system to all active machines is planned, together with installation of incremental magnetic tape output equipment. Improved film transports and frame-number-indicating systems have been installed on all three Hermes machines.

Scanning facilities have been supplemented with three Vanguard scanning projectors of improved design. One of these is now in operation and the remaining two soon will be. A modified film control, designed and built at Brookhaven, has been installed, and the projectors will be equipped with new "road-makers" for guidance of the FSD. Two of the new road-makers are now in operation with good results, and all seven 80-in.-type Vanguard scanners will be so equipped by the end of calendar 1966.

A long and difficult period of development of a new system for measurement of bubble chamber film based on the FSD is approaching a satisfactory conclusion. Both the 35-mm and the 70-mm FSD's are producing reliable measurements for physics experiments. To date, about 20,000 events in the 80-in. chamber have been measured by the 70-mm FSD and about 10,000 events in the 20-in. chamber by the 35-mm machine. The monthly rate of measurement by the new system has exceeded that of the conventional analysis system of the Bubble Chamber Group (which uses six manually operated measuring projectors). An increase by a factor 3 to achieve the design rate of 5000 events/week is expected in the fall of 1966. Further increases in rate can be expected subsequently.

Measurements by the 70-mm FSD (Figure 8) have yielded strong evidence for the existence of a new resonance, the G meson, of mass 1670 MeV, produced in an exposure of 6 BeV/c π^- mesons in the 80-in. hydrogen chamber.

Bubble density measurement by the FSD has been shown to be more reliable than estimation by physicists at the scan table for events in both the 80-in. and 20-in. chambers. For the latter chamber, where more experience has been accumulated, the machine measurement error is more than three times smaller. In the first two experiments using the FSD's a large part of the event identification procedure was performed by a computer program that combined the machine bubble-density information with the results of kinematic fitting. This new technique reduces significantly the amount of mechanical labor required of physicists in the performance of a large experiment.

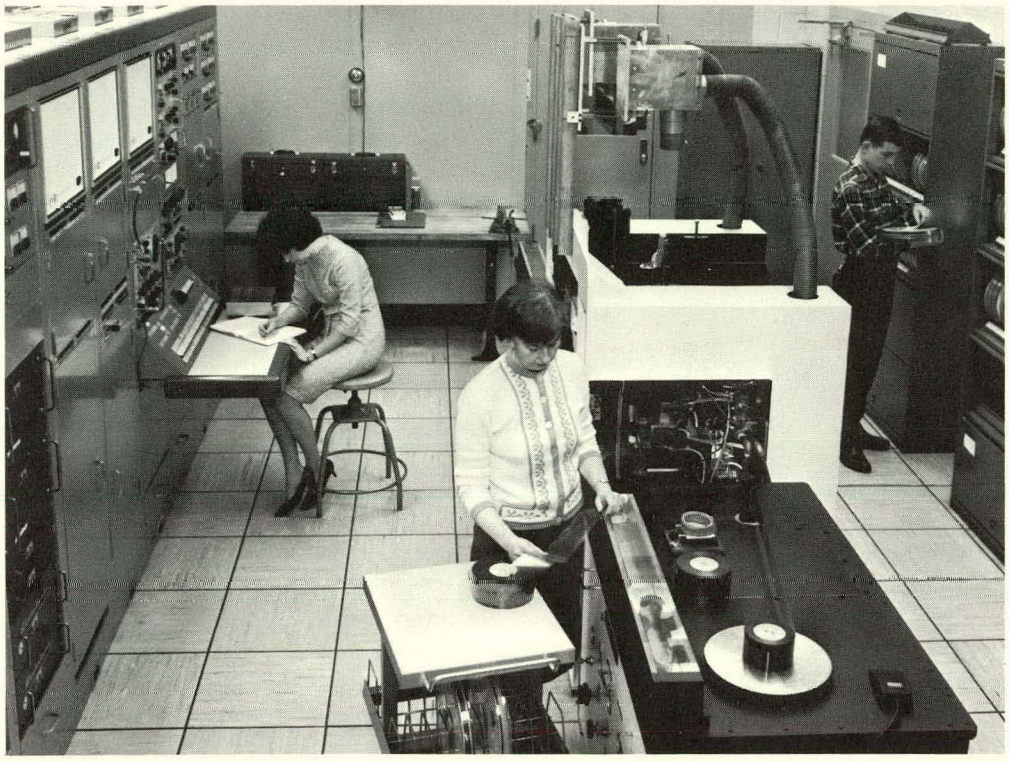


Figure 8. The BNL 70-mm Flying-Spot Digitizer, which has recently completed its first high-volume experiment and has contributed to the knowledge of the dipion mass spectrum near 1700 MeV.

As described in last year's report, the basic measuring computer program (FILTER) for the FSD was rewritten with the aim of reversing an initially unfavorable performance of the FSD system when compared with conventional measuring systems, especially with respect to measurement mistakes. This work has been successful, and extensive evidence now exists to show that FSD measurements contain a smaller fraction of mistakes than measurements from manually operated projectors. They also show a significantly higher accuracy in the track points for correctly measured tracks.

The most important FSD development work during fiscal 1967 will consist of application of the new methods in a variety of experiments and development of procedures for reliably processing several experiments concurrently at an aggregate rate of >5000 events/week. Work will also be started on the application of programs developed by the Applied Mathematics Department for reduction of the amount of human guidance ("road-making") which so far must be provided at the scan table.

In a program to improve the quality and quantity of measurements of bubble chamber film, the Nuclear Interaction Group has connected an SDS 920 computer on line to five measuring tables. The computer directs the process of measuring, requesting, and receiving information from the measurer, checks the data for completeness and correctness, and, after doing a partial reconstruction, calculates momenta and effective masses.

The system serves several purposes, including increasing the quality of the measurements, increasing the amount of film processed, improving bookkeeping, machine diagnostics, and measurer training, and making available geometric and kinematic quantities such as locations in the chamber, momenta, and effective masses usually not available to the scanner.

Use of the computer ensures that $>95\%$ of the measurements pass through the full reconstruction programs without error; much of the remaining 5% fails for reasons that could be checked by the on-line computer, but only after a substantial programming effort. Before the computer was at-

tached, ≈75% of the events passed. The increase in the number of usable events measured by any given machine per unit time is greater than indicated above, because remeasurements take longer per event than do original measurements.

Four of the five machines now on line are fast image-plane digitizers (mangiaspagos) which measure as fast as a measurer can move her arm, with an accuracy of 15 μ on film. These machines, coupled with computer encouragement and feedback to the measurers, have made the average time per event 6 min for a mangiaspago and 8 min for a conventional machine, compared with the 10 min previously required for conventional machine-handling of similar events.

The result of using both computer and machines is that twice as many events can be processed in a given time as by the same number of unaided conventional machines.

Improvements are still being made in the system: the output has been put on magnetic tape rather than on paper tape and cards; four additional machines are being added; the memory, flexibility, and capability of the computer are being increased with the addition of a rapid-access disk; the image-plane digitizers are being improved in accuracy through a redesign; and a device using a cathode-ray scanner is being developed to measure ionization of tracks while the conventional measurements proceed.

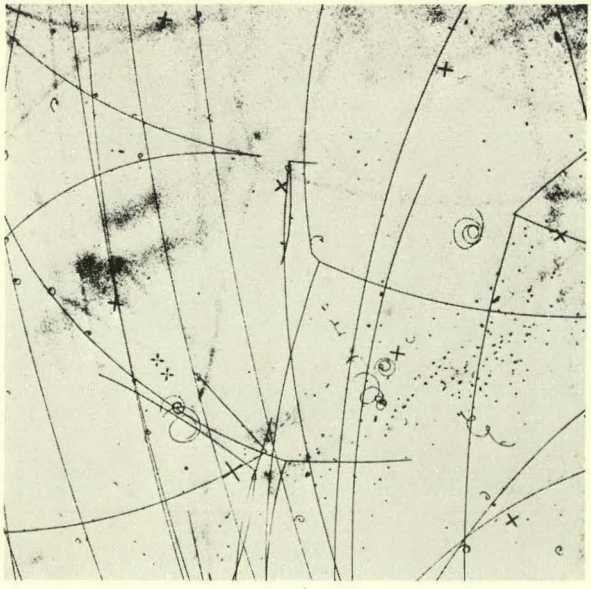
Data Analysis

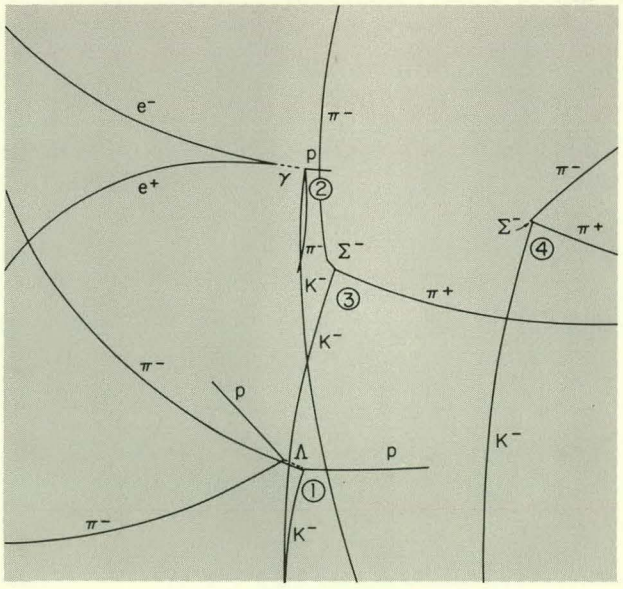
The PDP-6 computer, designed for on-line use with counter experiments, has been improved through the addition of a time-sharing system that makes it possible on a priority basis for several experimenters to utilize every instant of the computer's time. The addressable memory has been increased to 65,000 words, and additional accessories such as tape transports have been added. For the past year and a half this system has been in use, serving as a vital part of two on-line, high-counting-rate experiments that represent a new generation of counter experiments.

Particle Physics Apparatus

During the 10 months preceding the June shutdown, the 30-in. bubble chamber took 2,550,000 pictures, a record for production of photographs

Figure 9. K^- mesons stopping in a mixture of hydrogen and neon in the BNL 30-in. bubble chamber. The neon concentration is about 5% of the number of atoms. Three examples of K^- interactions with neon and one with hydrogen are shown in the drawing. Reaction 1 shows the production of a Λ hyperon as well as a proton and a π^- meson. Since there are at least two baryons in the final state, the reaction must have been with neon. Reaction 2 yields two prongs plus a γ ray which converts nearby to an e^+-e^- pair. Reaction 3 is common in hydrogen capture but is here identified as a neon event, since the π^+ meson and Σ^- hyperon in the final state are not collinear. Reaction 4 has the same final state as reaction 3 but probably results from hydrogen capture, since the π^+ and Σ^- appear to be collinear.





by any BNL bubble chamber, and very possibly more than have been taken at any laboratory during a comparable period. Some of these pictures were of Ne-H_2 and Ne-D_2 mixtures with the neon concentrations ranging up to 5 at. %. Figure 9 shows tracks in $\approx$5 at. % neon. A system was completed for purifying deuterium gas and separating neon gas from hydrogen or deuterium gas. A chamber liquid fill system was installed which should reduce the time required to fill the chamber. The magnetic field for the bubble chamber was remapped with use of a semiautomatic device constructed for the purpose. The Scotchlite optical system was redesigned. The new system, which uses toroidal lenses to reduce the shadowgraph effect, has been bench-tested and appears to be clearly superior to previous 30-in.-chamber Scotchlite systems.

All major components of the 31-in. bubble chamber were received. The control panels and the reservoir system have been completed, and the bubble chamber body and expansion system are being assembled in the vacuum tank. The 31-in. bubble chamber magnet was assembled and powered. The magnetic field was mapped with use of the device constructed for the 30-in. bubble chamber magnet. Assembly of the electronic control console is continuing.

The new separated beam (S-4) has been placed in successful operation, and as of July 1, 1966, has been used for >612,000 pictures taken with the 80-in. chamber. The separators, of the radio-frequency type, have operated as expected, and with good reliability. The beam, after the usual trial period, behaved as well as expected or better. The K^--meson beam appears to have a very low background of μ and π mesons. A set of integrating counters was developed that gives adequate sensitivity and stability for operation of the beam.

The proposal for construction of a 14-ft-diam cryogenic bubble chamber has been resubmitted. A Pre-Title I report on this project was completed last fall and more detailed design work is now proceeding. A major decision was made to provide the magnet with superconducting field coils but with no iron flux-return yoke. The coils are expected to produce about 30 kG. In addition to large electric-power savings, an increased useful volume ($\approx$48,000 liters) results from this decision, as well as improved optics and greater flexibility of assembly and maintenance. Furthermore, because of its much reduced weight, the chamber can now be made mobile on rails, which will permit optimum experimental beam arrangements. A research and development program is in progress to explore some aspects of the planned expansion system, the superconducting magnet, optics, instrumentation, and future data processing problems. This program will culminate in a test facility permitting exploration of operational and engineering details of very large chambers. Figure 10 contrasts the proposed 14-ft chamber and the 80-in. chamber.

Work has continued on the development of reliable, stable, superconductor–normal conductor cables for use in bubble chamber magnets.

Measurements were continued of the resistance of various copper samples at helium temperature as a function of magnetic field and of stress in the sample. The 24-in.-bore helium test cryostat was assembled and is being tested at cryogenic temperatures. The coil forms and support structure for the 8-in. bore, 60-kG split-pair superconducting magnet were completed. Stabilized superconducting cable for this magnet is being stranded on a machine constructed for the purpose. A 650-A power supply for this magnet was also assembled. A sample magnet coil clamp and various turn-to-turn spacer configurations were fabricated to examine the feasibility of their application to larger magnets.

A "magnetic finger" particle-focusing system has been designed at BNL and is ready for construction by outside vendors. The system is expected to be mechanically complete in the fall of 1966, and electrical testing should take about two months. The finger system will be used to improve the intensity of neutrino beams for use in bubble chamber and spark chamber experiments at BNL. Neutrino beams are produced by allowing a parent beam of π and K mesons to decay in flight, after which a shield stops all decay products except the neutrinos. The better the parent particles of all momenta are focused, the more intense the resultant neutrino beam. The "magnetic horn" focusing device designed at CERN was considerably improved during its use at both CERN and BNL. However, its focusing power was restricted to a limited momentum region. The magnetic finger system, so called because of its pointed shape, focuses over a wider momentum range; with such a system, neutrino fluxes are expected to be more intense by a factor of 3 than those obtained with magnetic horns.

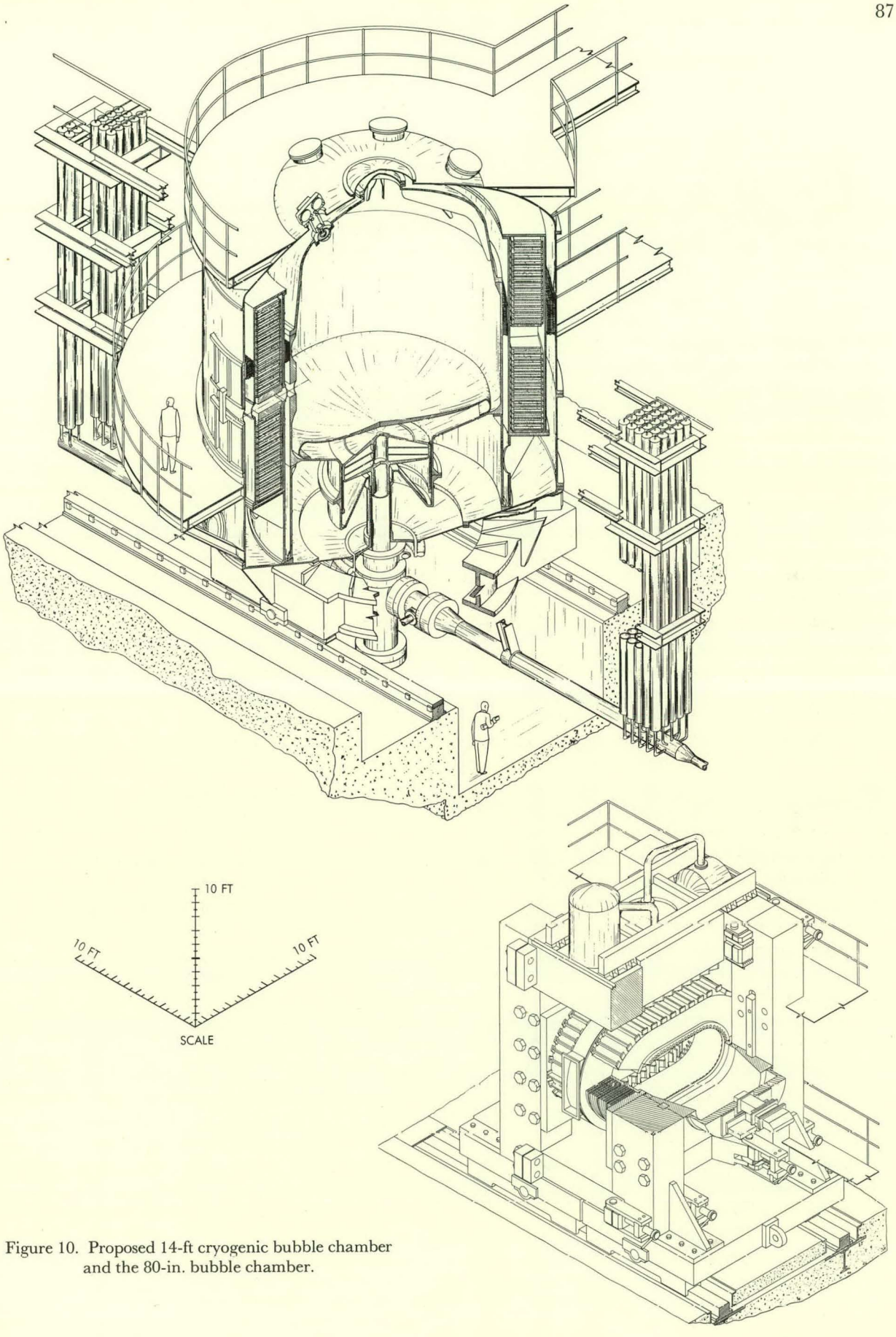


Figure 10. Proposed 14-ft cryogenic bubble chamber and the 80-in. bubble chamber.

SOLID STATE PHYSICS

The research program in solid state physics is concerned with the understanding of the physical nature of condensed systems, with emphasis on imperfections in crystals and on the structure and dynamics of solids. Some representative research studies are described briefly below.

Theory

Calculations on point defects in metals carried out on high-speed computers have been extended to a study of carbon impurities in martensite, a body-centered tetragonal phase of iron. The carbon migration energy was found to increase with carbon concentration, e.g., from 0.86 eV in pure α-iron to 1.00 to 1.09 eV for 1 wt % carbon in martensite, depending on the direction of motion. The di-carbon binding energy showed little change, and the carbon-vacancy binding energy decreased with increasing carbon concentration. No carbon reorientation internal friction peak is predicted by these calculations. The model for the tempering of martensite that emerges from these studies is consistent with available experimental data and suggests some new experiments.

A combination of analytical and computational techniques was applied to several problems of defects in alkali halides. For the *H*-center, which consists of four collinear halogens occupying three halide sites in the [110] direction, it was found that for a wide range of pertinent parameters the [110] orientation of this molecule was unstable with respect to a [111] configuration. The [110] orientation became stable (by $\simeq$0.2 eV), in accord with experiment, only after the sharing of the hole among all four ions was taken into account.

Neutron diffuse scattering from a simple cubic lattice containing an interstitial has been studied with a computer model which includes the distortion around the defect. Results show that the scattered intensity is greatest near the reciprocal lattice points, with relative maxima on either side of each lattice point and relative minima at each lattice point. A comparison with previously reported calculations for a similar polycrystalline sample shows that care must be exercised in deducing a defect configuration from neutron diffuse scattering experiments alone. The best hope of obtaining meaningful results appears to lie in combined neutron, x-ray, and volume change measurements on single crystals. Even then, it may be possible to deduce only the concentration of defects and the strength of the relaxation.

A kinetic model of biological radiation response has been developed which postulates that upon irradiation a series of reactions takes place, some of them reversible, leading to a final product that is lethal to the system. Such a kinetic theory is a generalization of the "hit" and "target" theories and contains them as special cases. The limitations of these earlier theories have been examined. The kinetic model can describe, in a natural way, such features as the general shapes of survival curves, dose-rate dependence, and simple and retrogressive recovery behavior. An important prediction of the model is the presence of intermediates (or precursors) with their characteristic growth and decay.

A model for first-order phase changes in magnetic systems was devised and applied to the case of UO_2, in which such a transition has been observed experimentally by neutron diffraction. The Weiss molecular field theory of ferromagnetism predicts a second-order transition from the ferromagnetic to the paramagnetic state. The model proposed is a generalization of the Weiss molecular field and assumes a nonmagnetic energy level which lies below the magnetic levels. Depending on the relative magnitudes of the energy separation of the nonmagnetic and magnetic levels and the exchange splitting of the magnetic levels, either no magnetic ordering, a first-order transition, or a second-order transition is found. Quantitative agreement with the UO_2 measurements is found.

The theory has been extended in two directions: first, to include the effects, in the ferromagnetic case, of an external magnetic field, and second, to cover the situation in which both the lowest-lying and excited ionic energy levels have magnetic moments. It is found that the magnetization-temperature curves in the second case can take a variety of unusual forms (so far unobserved), depending on the ratio of the exchange coupling to the level separation and on the ratio of the magnetic moments of the two levels. A set of typical curves of this type is shown in Figure 11. In the presence of the external field the magnetization-temperature curves resemble the volume-temperature curves of a van der Waals gas, with the external field playing the role of the pressure. There is a critical field above which no phase transition occurs. An example of this is shown in Figure 12.

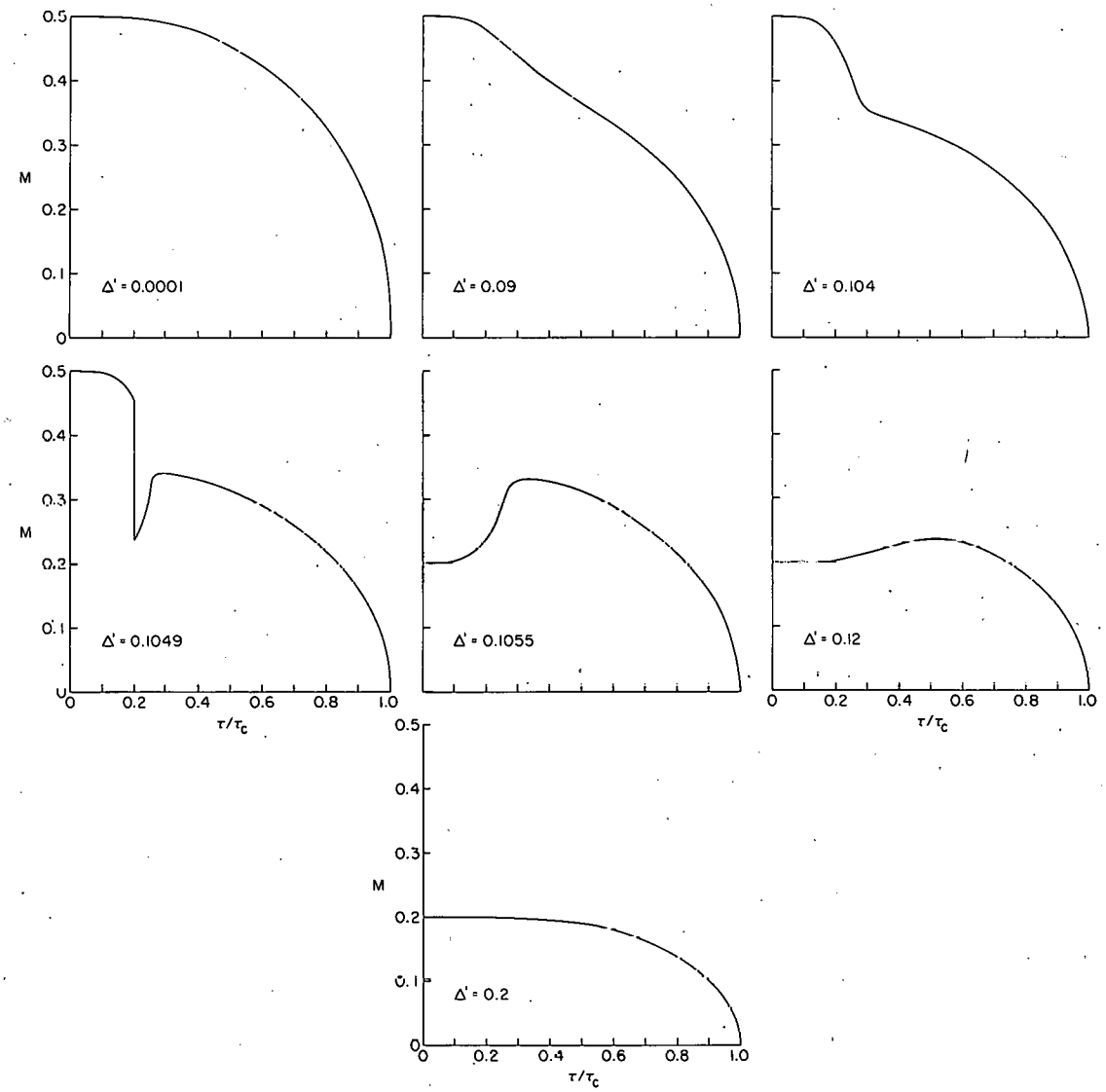


Figure 11. Calculated magnetization-temperature curves for the situation in which both the lowest-lying and excited energy levels have magnetic moments. M is the magnetization, τ/τ_c the ratio of the temperature to the critical temperature, and Δ' the ratio of the ionic level splitting to the exchange coupling.

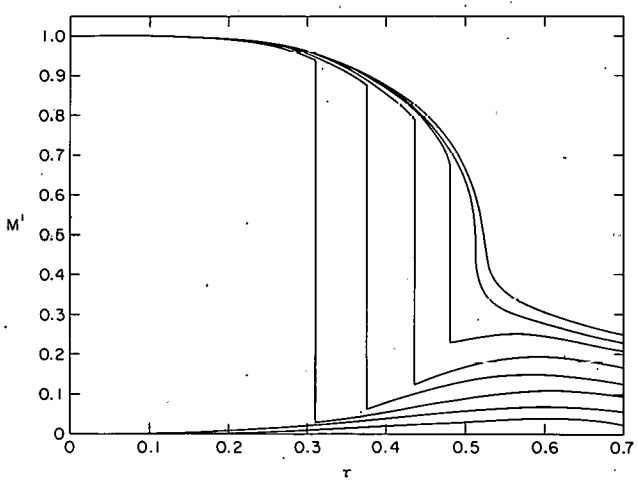


Figure 12. Calculated magnetization-temperature curves for the ferromagnetic case with the inclusion of the effect of an external magnetic field. M' is the magnetization and τ a variable proportional to the temperature. Individual curves are shown for various values of the external magnetic field. These curves resemble the volume-temperature curves of a van der Waals gas, with the external field playing the role of the pressure. A critical field is seen to exist above which no phase transition occurs.

Several aspects of the interaction of a metal's conduction electrons with local magnetic moments have been studied quantitatively. Emphasis has been placed on the spin density induced in these electrons. The effects of the exchange potential produced by the local moment and those from the process in which a conduction electron resides on the magnetic site (and vice versa) have been examined. These couplings differ analytically from the assumption traditionally made in theories of the induced spin densities, which causes significant quantitative changes in what is predicted. Results have been obtained for iron series and rare-earth local moments which show substantially improved qualitative agreement with neutron diffraction and hyperfine interaction experimental results. The extent of the agreement is surprising in view of the crudities still remaining in the theory.

Neutron scattering experiments on MnF_2 had been interpreted as showing covalency effects in the magnetization density of the Mn^{+2} ion. This interpretation was incomplete in that it did not explain the observed intensity of several neutron reflections for large sin θ/λ. It was shown that these reflections can be accounted for on the assumption that the e_g and t_{2g} orbitals in Mn^{+2} are of different radial extent. The difference necessary to account for the experimental observation is in good agreement with a calculation by Watson and Freeman based on a point charge model.

Crystal Imperfections

The study of defects in crystals continues to be a major research activity. Investigations of charged-particle interactions with crystals and of the formation and subsequent behavior of color centers in inorganic solids are in progress. Studies of the electron transport properties of organic crystals have become an important part of the over-all research effort. Other areas of investigation include precipitation kinetics in alloys and diffuse x-ray scattering in irradiated single crystals.

Work has continued on the orientation dependence of the interaction of charged particles in single crystals. The direction and energy distribution of protons with energies in the MeV range passing through thin silicon and germanium single crystals were studied at high angular resolution. Results agree well with the predictions of a model in which anisotropic effects arise from correlated small-angle scattering of charged particles in the average field of the arrays of atoms in the crystal. At these high energies, and for sufficiently thick crystals, atomic planes play a more important part in "channeling" than atomic rows. Even when incidence is along a crystal axis, the channeled beam is found to emerge from the crystal in directions parallel to the low-index planes containing the particular axis. This process gives rise to the characteristic "star pattern" observed. The role of valence electrons in silicon and germanium in limiting the minimum energy loss of well-channeled particles was investigated in detail. Results indicate that interactions of the particles with core electrons are effectively shielded and that the minimum energy loss results from interactions with the weakly bound valence electrons.

A variety of color center and electron spin resonance (ESR) measurements on $NaClO_3$ were completed. Irradiation produces two broad absorption bands, one at 3300 Å and one at 4300 Å, and causes a pronounced shift of the apparent absorption edge to longer wavelengths. Ultraviolet, x, and γ rays all produce the same absorption bands and similar growth kinetics. Both bands are twofold anisotropic, with the axis of maximum absorption in the (110) plane. The twofold anisotropy also appears in the ESR spectra. Bleaching with 4300-Å light decreases the 4300-Å band and increases the 3300-Å band and the edge absorption. Light of 3300 Å decreases the 3300-Å band, does not increase the 4300-Å band, but does increase the edge absorption. The bleaching studies indicate that the centers corresponding to the three absorption bands have the same charge. In addition, none of the observed ESR centers can be produced by uv light, while all three optical bands are produced by uv irradiation. Thus, it is most likely that these color centers contain an even number of electrons or holes. Heating unirradiated $NaClO_3$ does not produce either the 3300 or 4300-Å bands; i.e., these bands are not produced by thermal decomposition. However, heating uncolored crystals does cause a pronounced shift of the apparent absorption edge toward long wavelengths. Thus this absorption is the result of a thermal process such as decomposition. Annealing irradiated crystals to a temperature of 160°C causes both absorption bands to decrease simultaneously. This is accompanied by an increase in the apparent edge absorption which overwhelms both bands when 160°C is reached.

ESR measurements on $NaClO_3$, made by using both X and K band spectrometers, show that at

least five different paramagnetic centers are present. All five are produced by either x- or γ-ray irradiation, but none by uv irradiation. Hence, they have not been correlated with any of the optical absorption bands described above. One of the five centers exhibits hyperfine interaction with two spin ½ nuclei, and the principal axes of the hyperfine and *g* tensors are coincident. Another center does not have any hyperfine interaction. Each of the remaining three centers shows hyperfine interaction with a single nucleus having spin ½. Some of these have the twofold symmetry found in the color centers.

Two problems of interest to geologists were attacked by methods developed for radiation damage studies. An essentially new method of age determination in which trapped charge and other pertinent parameters are measured with ESR techniques was applied to the crucial question of whether natural crystals contain ESR active centers. A survey of typical minerals showed that 22 of the 24 minerals tested did exhibit suitable ESR signals. Furthermore, these signals were shown to be radiation induced, i.e., they are not due to chemical contaminants.

The second geology-related problem involves the mineral calcite ($CaCO_3$). This substance has been used as a dating tool, much in the manner described above, except that the trapped charge is measured by thermoluminescence. To relate the height of the glow-curve peaks to the total trapped charge, the details of the charge-release mechanism must be known. With methods originally developed for radiation-damage studies, specifically by optical bleaching, it was demonstrated that charge retrapping is a controlling factor in the charge-release mechanism. This result should make it possible to re-evaluate published dating data, which have been analyzed, almost without exception, by assuming that retrapping does not occur.

The organic-crystal program has yielded new results concerning the electron-transport properties of phenanthrene. Very high purity single crystals of phenanthrene have been produced, and measurements show electrical behavior much different from that of naphthalene and anthracene. An anomaly in the resistivity at 72°C was found; it consists of a charge release superposed on the normal current increase with increasing temperature. Whereas phenanthrene is a poor photoconductor below 72°C, the photoconductivity increases by about 2 orders of magnitude at temperatures above 72°C. Specific heat measurements made on powdered phenanthrene showed an anomalous absorption of heat of 380 cal/mole at 72°C. However, measurements of thermal expansion and dielectric constants show no anomaly corresponding to those found in electrical conductivity and specific heat. The specific heat anomaly and the behavior of the electrical anomaly suggest enantiamorphism in the phenanthrene molecule and the existence of a racemic state in the crystal above 72°C. To determine the effect of irradiation upon this material, single crystals of phenanthrene were irradiated at 35°C with γ rays from a Co^{60} source. No change was found in the infrared absorption spectrum (0.7 to 2.5 μ), but three new peaks were found in the visible region. The annealing kinetics of these peaks are being examined and their correlation with the above anomaly is being studied.

Preliminary measurements of the diffuse scattering of x rays in single crystals of neutron-irradiated diamond have been made in the neighborhood of the (111) and (220) reflections. These measurements are in qualitative agreement with a recent theory for the scattering of x rays from partially ordered binary alloy containing atoms of different atomic size. The model assumes an elastically isotropic medium containing centers of pure dilation. The atomic displacements are proportional to C/R^2, where C is the strength of the defect and R the distance from it. The diamond structure can be considered as an ordered array of normally occupied and normally vacant sites. Neutron irradiation produces interstitials and vacancies analogous to those in a partially disordered alloy. The model predicts a diffuse scattering in terms of the strengths of a vacancy and interstitial and essentially the transform of a $1/R^2$ displacement field. The measurements indicate that the displacement field is not completely symmetric. This may be due to lack of crystal isotropy, defect clusters of low symmetry, failure of superposition of the displacements, or simply point defects with less than spherical symmetry.

Point defects with lower symmetry which might exist in irradiated diamonds are being studied. It has been suggested that the four broken bonds associated with a vacancy re-form into bonds along the edges with no common vertex of the tetrahedron of four neighbors of the vacancy. Such bonding would introduce a pair of double forces

acting at right angles and separated by half a lattice constant. The axis of any such pair would be oriented parallel to any of three cube axes at random to produce only a uniform dilatation. However, the scattering from a random array of such double forces is different from that from an array of defects having spherical symmetry.

The 3-MeV accelerator is in the final stages of testing. A number of tests, including tests of the beam-pulsing electronics, were performed successfully without the beam transport system. The quadrupole magnet, bending magnet, and one drift tube subsequently were installed, and a beam was steered into one of the target areas. Experimental equipment for the research programs at the accelerator is being assembled. A controlled-temperature cryostat for radiation damage studies at liquid helium temperature has been designed and constructed. Internal friction and resistivity apparatus designed to fit within the sample chamber of the cryostat is under construction. A vacuum uv scanning spectrometer and a high-vacuum thin-film evaporation system have been received and are undergoing tests. These two units form the major components of the system required to measure optical emission from solids during exposure to charged particles. Finally, a data-acquisition system for radiation-effects experiments at the accelerator has been designed and ordered.

Structure of Solids

Another major experimental activity is the use of neutron diffraction in studies of the structure and dynamics of solids. Principal emphasis has been placed on magnon scattering problems and on spin density distribution in antiferromagnets. Although the work reported here was carried out mainly at the Brookhaven Graphite Research Reactor (BGRR), the selection of problems has already been strongly influenced by the schedule of the new High Flux Beam Research Reactor (HFBR), which is now in regular operation. Preliminary results obtained at the HFBR are very promising.

A study of magnon dispersion relations in $3d$ metals has continued. Accurate measurements of the relation between the magnon energy and the wave vector are essential to the understanding of magnetic properties of solids. The experiments were carried out by measuring the size of the diffuse spot as a function of the deviation from the Bragg angle. The magnon scattering was distinguished from other scattering contributions by use of a polarized neutron beam.

Magnon scattering measurements have been extended to hexagonal cobalt and nickel. Previous measurements on iron revealed considerable deviation from a quadratic law $E=Dq^2$, which would be expected from a nearest-neighbor Heisenberg model over the measured range of $q/q_{max} \leqslant 0.2$. A single crystal of Ni^{60} was used in order to minimize background from nuclear disorder and phonon scattering. The cobalt results show, as for iron, a decided departure from the dispersion law for a Heisenberg ferromagnet. In particular, if the energy is expressed as a sum of q^2 and q^4 terms, then the q^4 term should contribute only 3% to the energy, whereas a contribution of 35% is observed. This was interpreted as resulting from long-range magnetic interactions in the $3d$ transition metals. However, the measurements on nickel follow, surprisingly, the quadratic law closely up to $q/q_{max}=0.2$. The origin of this different behavior among $3d$ metals is not obvious. Further measurements at higher energies will be made with the new triple-axis spectrometer at the HFBR.

Another problem of interest is the spin density distribution in magnetically ordered phases. Polarized neutron techniques have increased the sensitivity of neutron measurements to such a degree that details of spin distributions can be mapped out "between" the magnetic atoms. This technique has mainly been confined to ferromagnets, but it can be applied to antiferromagnets under proper symmetry conditions if there is an unbalanced domain distribution. The technique has been employed in a detailed study of the spin density distribution in anhydrous copper sulfate, $CuSO_4$. The basic magnetic structure of this material was determined in an earlier study with unpolarized neutrons on a polycrystalline sample. The present, more extensive measurements, made on a single crystal with a polarized neutron beam, can be used for an accurate determination of the spin density distribution. Large deviations from the theoretical Cu^{++} free ion form factor have been found. Fourier inversion of the data has shown that these deviations are due to the presence of substantial unpaired spin density located between the Cu^{++} sites of neighboring copper-oxygen chains in the structure. This result is of particular interest, since a superexchange mechanism involving electrons of the SO_4 group should be important in the magnetic ordering of this material.

Another example of a spin density problem is that of $CuCl_2 \cdot 2H_2O$. Proton resonance data indicate that the magnetic moment should be localized predominantly in the space between the copper and chlorine nuclei. In this case the polarized beam technique is not applicable because the magnetic reflections are separated from the nuclear ones. The basic magnetic structure proposed by Poulis and Hardeman has been confirmed. Further details of the problem will be investigated at the HFBR.

The quasi-elastic scattering of slow neutrons by light water and aqueous salt solutions was investigated at the Brookhaven slow chopper. The theory of hydration proposed by Samoilov and verified experimentally by others predicts that certain salts should cause a decrease in the coefficient of self-diffusion of water, while other salts should cause this quantity to increase beyond its value in pure water. Since the quasi-elastic peak width is directly proportional to the coefficient of self-diffusion if the broadening is due to continuous diffusion, Samoilov's theory predicts that the peak width should vary with the nature of the salt in solution. Scattering by solutions of KI and NaCl was compared with scattering by pure water. The comparison was performed at 90°, where the broadening is large. The breadth of the peak for KI was $\approx$10% larger than that for pure water, and that for NaCl was $\approx$25% smaller. The results agree well with existing radiotracer data and suggest that continuous diffusion plays an important role in the quasi-elastic scattering of slow neutrons by water.

NUCLEAR STRUCTURE

Experimental work in the area of nuclear structure consists essentially of the determination of (1) the various properties of nuclear energy levels – their energy, spin, parity, lifetime, and electromagnetic moments; (2) the characteristics of transitions between states of a nucleus or between neighboring nuclei; and (3) the parameters of nuclear reactions, where these are important in testing the validity of current theories of nuclear structure or in guiding their further development. The experiments fall into two general classes, those dealing with unstable (radioactive) nuclei produced at the 60-in. cyclotron or the research reactors, and those concerned with the instantaneous products of nuclear reactions produced by charged particles or neutrons. Some outstanding examples of work carried on during the past year are given below.

The lower limits reported earlier for the lifetime for double β decay of Ca^{48} have been further improved after the separated isotope used was repurified to remove radioactive impurities. A new lower limit of 2×10^{20} yr was established for the neutrinoless Majorana type of double β decay in Ca^{48}. For the 2-neutrino Dirac type of double β decay it was possible to set a lower limit of 5×10^{18} yr. The lower limit to theoretical estimates for the Dirac type is 10^{19} yr, i.e., the experiments are just becoming sensitive enough for comparison with theory. The neutrinoless type of double β decay is a very sensitive test of lepton charge conservation. For example, a possible lepton nonconserving interaction has been proposed which allows double β decay to proceed as a first-order process. The rate of this type of decay should be comparable to ordinary β decay. The present lower limit of 2×10^{20} yr leads to the conclusion that the coupling constant for this decay is 10^{14} times weaker than the Fermi coupling, or that lepton charge is conserved. These experiments thus are accumulating strong evidence for lepton charge conservation in weak interactions. The Ca^{48} sample will once more be repurified and the experiment will be continued with further suppression of background radiation.

The method of magnetic perturbation of γ-ray angular correlations has continued to be employed in the measurement of the g-factors of excited states of nuclei. Recently the g-factor of the 1+ first excited state of Na^{22}, populated in the $F^{19}(\alpha,n)Na^{22}$ reaction, was determined by this means. The 1+ first excited state in Na^{22} is of interest because the $E2$ transition between it and the 3+ ground state is highly retarded – by a factor of 1600 in comparison with the strength of a similar transition in F^{18}. Accordingly, it is worth while to gain additional data which would clarify the character of this state. The experiment was unusual in that instead of a helium ion beam from an accelerator, α particles from Po^{210} dissolved in HF were utilized to produce excited Na^{22}. This not only was convenient, but also provided an environment for the Na^{22} nuclei that minimized possible attenuations of the angular correlation arising from quadrupole interactions. The value obtained for the g-factor of the 1+ state is $g = +0.535 \pm 0.010$. New measurements of the energy and half-life of the state gave values of 583.0 ± 0.5

keV and $(243\pm2)\times10^{-9}$ sec, respectively. The g-factor of the 3+ ground state is known to be $g=+0.582\pm0.001$, in good agreement with the predictions of both the shell model and the rotational model for a 3+, $K=3$, $T=0$ ground state. Similarly, the newly measured g-factor of the 1+ excited state is consistent both with a shell model description in which the configurations of the 1+ and 3+ states are similar and with the rotational model for a $K=0$ state. A determination of the quadrupole moments of the 1+ and 3+ states of Na^{22} would provide a basis for distinguishing between the rotational and shell model descriptions.

An indication of possible parity mixing in an electromagnetic transition (a phenomenon predicted by the current-current theory of weak interactions) was observed in the highly K-forbidden 57-keV $E1$ transition in Hf^{180m}. The L_I conversion coefficient is substantially higher, and the L_{II} conversion coefficient somewhat higher, than the values predicted by theory. This anomaly cannot be explained by an $M2$ or $E3$ admixture but is compatible with the assumption of an $M1$ admixture of 9.5%. If this were indeed the case, a circular polarization of 56% would be expected for the γ ray. To determine whether parity mixing is the cause of the observed anomaly, the circular polarization of the 57-keV γ ray was measured by observing its Compton scattering from polarized iron. The transmission method was employed because it allows interpretation of the results in a more direct manner than the more efficient forward or backward scattering methods. A polarization $Pc=(+6\pm6)\%$ was observed, which showed that most of the anomaly in the L_I and L_{II} conversion coefficients arises from the nuclear penetration effect rather than from parity admixtures in the initial and final states of the transition. This result is in agreement with an independent measurement performed at the University of Heidelberg with use of the forward scattering method, which gave $Pc=(-2.3\pm3)\%$.

The analysis of the moments of inertia of deformed odd-odd nuclei, carried out earlier, has been extended as new experimental results have become available. In this analysis the moment of inertia of the odd-odd nucleus is treated in terms of the moments of inertia of the even-even core $(A-2)$ and of the neighboring odd-proton and odd-neutron nuclei $(A-1)$. The values for all the moments of inertia used are the experimentally determined ones. So far 20 rotational bands in odd-odd nuclei have been analyzed in this manner: 12 ground-state bands and 8 bands built on excited states. The results of the analysis suggest that the odd proton and neutron contribute almost independently to the moment of inertia of an odd-odd nucleus.

A new experimental investigation of the level scheme of Mo^{93} has been carried out. Recent shell model calculations of the level locations and transition probabilities in Mo^{93}, aimed at an understanding of the transitions observed following the decay of the $^2\frac{1}{2}+$ isomeric state, have prompted this new work. The $^2\frac{1}{2}+$ state, a well-known example of "core isomerism," is formed by the coupling of the odd neutron, probably in a $d_{5/2}$ state, to an excited $g_{9/2}^2$ proton pair from the even-even core. γ Rays from the decay of Mo^{93m} (7 hr), Tc^{93m}(44 min), and Tc^{93}(2.8 hr) were examined with a Ge(Li) detector and with Ge(Li)-NaI coincidence techniques. A new, 114-keV transition, observed in the decay of Mo^{93m}, was found to populate a level in Mo^{93} at 1365 keV. The experimental results indicate a spin and parity of $\frac{7}{2}+$ for this level. The theoretical calculations predict such a level at approximately the observed energy. A new γ ray at 2.734 MeV was observed, and a previously reported 1.5-MeV γ ray was shown to consist of a doublet at 1.477 and 1.521 MeV. The 1.521-MeV transition is probably a ground-state transition, giving a new state at the same energy. This new state, with an apparent spin and parity of $\frac{7}{2}+$, is not predicted by the shell model calculations.

The properties of several of the excited states of Pr^{143} have been investigated. The energies and intensities of both γ rays and internal conversion electrons were determined with the use of semiconductor detectors. Angular correlation measurements gave spins and parities of $\frac{5}{2}+$, $\frac{3}{2}+$, $\frac{5}{2}+$, and $\frac{3}{2}+$ for the 57.4, 351.0, 490.5, and 722-keV states, respectively. Half-lives of $(4.2\pm0.1)\times10^{-9}$ sec and $(6\pm1)\times10^{-11}$ sec were determined for the 57.4 and 351.0-keV states, respectively, and a limit $T_{1/2}\leqslant10^{-11}$ sec was established for the 722-keV state. The half-life of the 351.0-keV state and the intensity and $E2/M1$ mixing ratio of the 294-keV transition to the 57-keV state give an enhancement factor of ≈35 for the $E2$ component. This suggests that the 351-keV state is the $\frac{3}{2}+$ member of a core-excitation multiplet built on the 57-keV state. Similarly, the 490 and 722-keV states are probably members of a ground-state core-excitation multiplet on the basis of the ob-

served transition intensities and lifetime limit. The precession of the 294 – 57 keV γ-γ angular correlation in a magnetic field was measured. The rotation is $21.2° \pm 1.0°$ for Ce^{143} sources in aqueous solutions at 295°K in a magnetic field of 7350 gauss.

A detailed investigation has been made of the properties and decay modes of the 146 and 68-keV states of Sc^{44} populated by the decay of Ti^{44}. The 146-keV crossover transition was observed, with an intensity of 0.1%. $E2$ admixtures of $(7.0 \pm 2.0)\%$ and $\leqslant 1.2\%$ were deduced for the 68 and 78-keV transitions, respectively. A $(1.9 \pm 1.5)\%$ electron capture branch to the 68-keV state was observed. The g-factor of this state was determined to be $+0.342 \pm 0.006$ in a measurement of the precession of the angular correlation in a magnetic field. The $E2$ component of the 68-keV transition is enhanced by a factor of 16, and all other $M1$ and $E2$ transition rates are strongly hindered. Of these, the 146-keV $M1$ transition has a remarkably large hindrance factor, $>6.6 \times 10^9$. The many exceptional properties of the 68 and 146-keV states are not given by the coupling of ordinary neutron and proton configurations but may be evidence for core excitation.

A direct determination has been made, for energetic germanium atoms stopping in a germanium crystal, of the fraction of the total energy loss that goes into the production of hole-electron pairs. Inelastic neutron scattering in a Ge(Li) detector was used to excite the 690-keV state of Ge^{72} and the 596-keV state of Ge^{74}. The conversion-electron line of the 690-keV state and the γ-ray line of the 596-keV state are both broadened by the summing of the ionization produced by the interaction of the electron or γ ray in the crystal with the ionization produced by the recoiling atom. In this method the contribution from a single germanium isotope is uniquely identified by the energy of the radiation accompanying the recoil. The widths of the broadened lines, corrected for the finite resolution of the Ge(Li) detector, are equal to the energy lost by the recoiling germanium atom in producing hole-electron pairs. As a check on the validity of the line shape analysis, monoenergetic recoils were selected at several energies by the detection of the scattered neutrons at given angles. The experimental results are in excellent agreement with the theory of J. Linhard.

New studies have been made of the thermal neutron capture γ rays of Cr^{54}, Fe^{55}, and Os^{190}. The Cr^{54} measurements were prompted primarily by the need for a convenient standard for energy and intensity calibrations in studies of (n,γ) reactions. Cr^{54} was chosen because certain fortuitous combinations of γ-ray energies and multiple-energy sum relationships make possible the extension of the energy scale to the neutron separation energy by means of intercomparisons of closely spaced peaks. These measurements give a neutron separation energy for Cr^{54} of 9721 ± 2 keV. Earlier coincidence measurements on the $Fe^{54}(n,\gamma)Fe^{55}$ reaction were confirmed and extended by means of high-resolution γ-ray measurements. A detailed description of the electromagnetic de-excitation of all states below 3 MeV that are excited in the (n,γ) reaction was established, which made possible a comparison with theoretical calculations in progress elsewhere. Both high-resolution γ-ray measurements and Ge(Li)-NaI coincidence measurements were carried out on the $Os^{189}(n,\gamma)Os^{190}$ reaction.

The rapid acquisition of complex γ-ray spectra at high resolution and with high precision, brought about by the recent development of Ge(Li) detectors, has presented the problem of rapid reduction and evaluation of the results. This problem has been met with the development of a computer program that evaluates Ge(Li) spectra fully automatically. Starting with the raw data, the program identifies peaks, performs a least-squares fit to each peak, and lists its relevant parameters. The program identifies and fits doublets automatically.

New equipment for investigations of capture γ rays at the HFBR is under construction. The principal element of this equipment is a crystal monochromator that will provide monoenergetic neutrons with energies up to 15 eV. The neutron beam will be utilized primarily in studies of the γ rays from resonance capture. In providing an uninterrupted source of neutrons with a given energy, the equipment will complement the many neutron time-of-flight devices now in operation.

In the Van de Graaff research program a wide variety of experiments on the properties of light- and medium-weight nuclei were carried out. These studies involved the employment of semiconductor detectors in high-resolution γ-ray and particle energy measurements; multiparameter techniques; lifetime measurements with the use of pulsed-beam, Doppler-shift, and delayed-coincidence methods; and the use of the "multipole meter," an intermediate-image electron spectrometer modified so that the multipolarities of

nuclear electromagnetic transitions may readily be determined from the angular correlations of internal pairs.

A detailed measurement was made of the energy dependence of the cross section for the $Be^7(p,\gamma)B^8$ reaction. The cross section was found to be nearly twice as large as the previously accepted value. This reaction is of considerable importance, for it is one of several leading to the formation of He^4 in stars burning hydrogen via the proton-proton chain. While the reaction plays only a minor role in the termination of the proton-proton chain, the β decay of the product, B^8, is believed to be the primary source of high energy solar neutrinos. The cross section measurements are therefore essential both to estimates of the large stellar energy loss associated with neutrino emission and to the interpretation of experiments currently under way to detect solar neutrinos.

A number of short-lived radioactivities produced by Van de Graaff bombardment were studied. In the decay of N^{12} two new positron branches were found that populate the known C^{12} states at 12.7 and 15.1 MeV. Their logft values are in excellent agreement with previous theoretical calculations which were based in part on the assumption that the 12.7-MeV level of C^{12} has a structure that is related to the ground state of N^{12}.

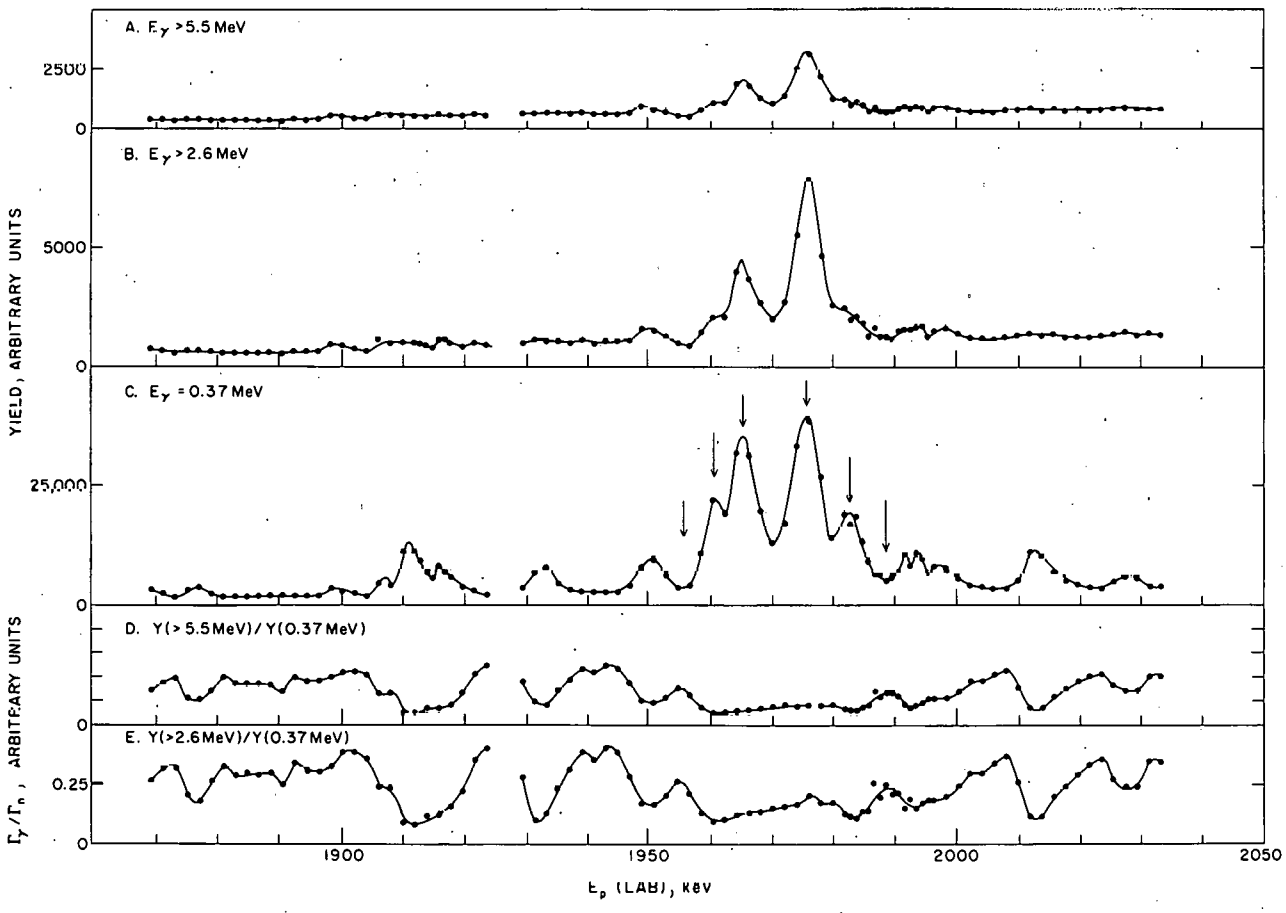


Figure 13. Excitation curves for the analogue states of Sc^{49}. γ-Ray yields are shown as a function of incident proton energy. Curves *A* and *B* show the yield of γ rays with energies >5.5 and 2.6 MeV, respectively. Such γ rays arise chiefly from the $Ca^{48}(p,\gamma)Sc^{49}$ reaction. Curve *C* shows the yield of the 0.37-MeV γ ray from the $Ca^{48}(p,n\gamma)Sc^{48}$ reaction. This curve represents fairly well the total cross section for the latter reaction. Curves *D* and *E* show the ratios of the yields of the higher energy γ rays in curves *A* and *B* to the yield of the 0.37-MeV γ rays in curve *C*. These ratios are roughly proportional to Γ_γ/Γ_n, the ratio of the probabilities for the emission of γ rays and neutrons from the compound nucleus formed by proton capture.

The heavy particle emission from the first two excited states of B^9 has been studied. Since the first excited state of B^9 at 2.34 MeV has a spin and parity of $\frac{5}{2}-$, its decay to the $0+$ ground state of Be^8 would have to occur by the theoretically forbidden process of $l=3$ proton emission. No detectable proton emission to the Be^8 ground state was observed, with a limit of $\theta^2_{l=3}<5\times10^{-3}$ established for the reduced width of $l=3$ proton emission. Recent results on the neutron decay of the mirror state in Be^9 at 2.43 MeV, obtained elsewhere, give a reduced width of 2×10^{-2} for neutron emission to the ground state of Be^8. Future theoretical interpretation will be required to determine the reason for the substantial differences in the decay properties of these mirror states in B^9 and Be^9.

An accurate determination of the energy of a recently discovered excited state in O^{15} was carried out because of the proximity of the level to the proton binding energy and the resulting possibility of its importance in the stellar formation of O^{15} in the $N^{14}(p,\gamma)O^{15}$ reaction. The energy of the level was found to be 7275.8 ± 0.6 keV, which is 15.2 ± 1.9 keV below the proton binding energy; this removes it from consideration with respect to stellar reaction cycles. A Doppler shift measurement gave a mean lifetime of $(1.25\pm0.3)\times10^{-12}$ sec for the level.

The recently discovered 0.44-sec, 12.4-keV state of Sc^{45} is thought to be an example of a $d_{3/2}$ hole state. In an attempt to confirm this assignment, the K-conversion coefficient of the transition from

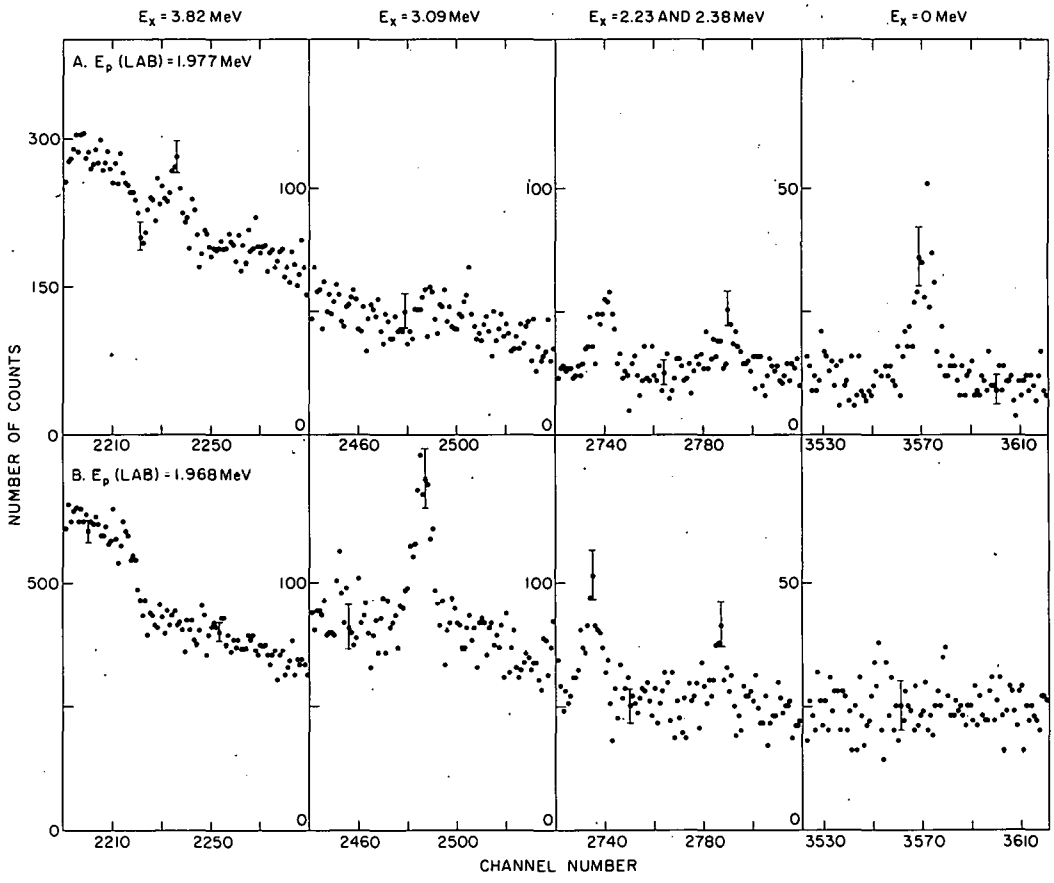


Figure 14. Selected portions of spectra of γ rays from the $Ca^{48}(p,\gamma)Sc^{49}$ reaction. These results were obtained with a 30-cm^3 coaxial Ge(Li) semiconductor detector. The upper and lower portions of the figure correspond to the two principal peaks in the excitation curves of Figure 13, or to the two principal levels making up the $\frac{5}{2}-$ analogue state in Sc^{49}. The energy of the final state for each γ transition is given at the top of the figure. A marked difference between the two spectra is seen to exist, which suggests a substantial difference in the structure of the two levels.

this state to the $\frac{7}{2}-$ ground state of Sc^{45} was measured. In this measurement the intensities of x and γ rays were compared with the use of a proportional counter. The value $\alpha_K = 413 \pm 37$ was obtained, in agreement with the expected theoretical $M2$ conversion coefficient and a spin and parity of $\frac{3}{2}+$ for the 12.4-keV state.

The γ-ray spectra resulting from the Coulomb excitation of Ru^{99} and Ru^{101} have been studied. These were so complex that the high resolution provided by Ge(Li) detectors was an essential feature of the experiment. Many of the $E2$ transitions in both nuclei were found to be strongly enhanced. This result and the fact that the even Ru isotopes are known to possess large quadrupole deformations point to a predominantly collective character for the states involved. However, the properties of these states are not in accord with the predictions of the core excitation model.

Isobaric analogue states have recently been the subject of a number of investigations. Few experiments, however, have been concerned with the electromagnetic decay of these states, although the transition rates from such states should be valuable in determining their structure. At Brookhaven the γ rays from the two states in Sc^{49} that carry the major portion of the $\frac{3}{2}-$ analogue state strength have been studied in the $Ca^{48}(p,\gamma)Sc^{49}$ reaction. The excitation curves for the states in question are shown in Figure 13. Curves A and B show the yield of high and low energy γ rays, respectively, from the (p,γ) reaction and indicate clearly the two analogue states. Curve C shows the yield of the 0.37-MeV γ rays of Sc^{48} from the Ca^{48} reaction, which also proceeds through these analogue states. In addition to the two principal states, two satellite states are seen. Curves D and E show the ratio of the yield of the high and low energy γ rays, respectively, to that of the 0.37-MeV γ rays. It was possible to obtain spectra of the γ rays emitted following excitation of the two principal analogue states; the yield of γ rays (other than 0.37 MeV) from the two satellite states was too small to be useful. Selected portions of the results for the two principal states are shown in Figure 14. An unexpected feature of these spectra is the marked difference in the γ-ray branching of the two states. Ordinarily, these states might be expected to be dominated by the strength of the analogue of the Ca^{49} ground state, and the normal isotopic spin states with which the analogue state is mixed might be expected to have complex structure, leading to comparable branching ratios. Such behavior is known for the $Cl^{37}(p,\gamma)Ar^{38}$ reaction, in which the analogue of the $5-$ first excited state in Cl^{38} is split by ≈ 4 keV. In the present case it is necessary to postulate some mechanism that will lead to the cancellation of certain otherwise strong transitions to low-lying levels in Sc^{49}. If the $T = \frac{1}{2}$ states with which the analogue state is mixed are of comparatively simple character and have large matrix elements for transitions to the single particle states, interference with the analogue state might lead to such cancellations.

The 60-in. cyclotron was shut down for conversion to variable-energy, sector-focusing operation on October 1, 1965. Prior to this several experiments were completed. The 31-MeV He^3 beam of the cyclotron was used in a study of the $O^{16}(He^3,\alpha)O^{15}$ pickup reaction. This work was prompted by the recent suggestion that the $p_{3/2}$ hole state in O^{15} is split between two levels, at 6.18 and 8.98 MeV, respectively. Contrary to this suggestion, at least 90% of the strength of the $p_{3/2}$ hole state was found to be concentrated in the 6.18-MeV level, and no evidence was found for a $p_{3/2}$ hole state admixture in the 8.98-MeV level.

Several recent studies of the levels of Be^6 excited in the $Li^6(p,n)Be^6$ reaction have given conflicting results. In one experiment the existence of nine narrow levels, three of them below 5 MeV, was reported. In another experiment only one level, at an energy of 1.6 MeV and with a width of 1.1 MeV, was found in the region below 5 MeV. In an attempt to resolve this question the analogous $Li^6(He,t)Be^6$ reaction was studied. A single broad state was observed at an excitation energy of 1.63 ± 0.10 MeV, with a width of 1.20 ± 0.10 MeV, in excellent agreement with the results of one of the (p,n) reaction experiments. Angular distributions measured for the ground state and first excited state of Be^6 are consistent with expected spins and parities of $0+$ and $2+$ for the two levels.

THEORETICAL PHYSICS

A theory of dilute mixtures of He^3 in liquid He^4 has been developed. The fluid is regarded as a mixture of He^3 and elementary excitations of He^4 and has the feature that the coupling is not weak. By means of a canonical transformation, the Hamiltonian is changed to a form in which it represents a system of fermions to a good approxima-

tion. A detailed discussion of its properties is possible, since they may be calculated by means of an independent pair approximation in both the degenerate and nondegenerate regions. Preliminary experimental evidence indicates that the effective interaction between the fermions is very weak, with mean free times 50 to 100 times larger than in pure He^3. In particular, it is unlikely that mixtures will undergo a fermion superfluid phase transition above 10^{-6}°K, as has been conjectured.

Expressions had been derived previously for the so-called stretching or β parameter appearing in expressions for the energies of deformed or rotational even-even nuclei:

$$E(I)-E(0)=\frac{\hbar^2}{2}I(I+1)+\beta[I(I+1)]^2+\dots .$$

Since then, numerical computations of the β-coefficient have been carried out. Comparison with the experimental β-values indicates a very interesting qualitative agreement. It is particularly noteworthy that the greatest contribution to the theoretical value of β arises not from stretching of the physical shape of the nucleus but from a combination of the Coriolis perturbation and the weakening of the pairing correlations by the rotation.

A number of possible experiments that might be done to detect parity nonconservation in a nuclear electromagnetic transition have been examined theoretically. The use of internal conversion electrons has been examined in detail. A detailed numerical evaluation has been carried through for the currently interesting 57.5-keV $8-\rightarrow 8+$ transition in Hf^{180}; the helicity of the internal conversion electron, while only about ⅓ of the possible circular polarization of the corresponding γ ray, is still of interest. The formalism has been examined in the high energy limit.

The calculation of shell-model properties with realistic nuclear forces has been extended to the $T=0$ levels of two nuclei that possess a closed shell plus a proton and neutron, F^{18} and Sc^{42}. The basic method involves the expansion of the Brueckner reaction matrix in terms of the free reaction matrix. In the cases examined the first term of the expansion appears dominant. In the $T=0$ case the existence of a bound state in the free system leads to a characteristic energy dependence that is apparently observable in the differences between spectra of F^{18} and Sc^{42}; the relative kinetic energy decreases, and this leads through the energy dependence to a weakening of the $T=0$ "residual" interaction. This is in qualitative agreement with the change from a $T=0$ F^{18} ground state to a $T=1$ ground state in Sc^{42}.

A theory of the polarization of nuclei by atomic electrons has been developed. The calculation is carried to second order in the various multipole interactions, but is otherwise exact. The first application has been to the isomer shift between the lowest $0+$ and $2+$ states in rotational nuclei. The calculated result for each level separately is of the order of the difference obtained experimentally in studies of the Mössbauer effect. However, in the adiabatic approximation used in the calculations, the difference is much smaller. Work on the lifting of the adiabaticity requirement is in progress.

The ionic quadrupole antishielding factor γ_∞ has been calculated for the following ions: Al^{+3}, Cs^+, I^-, Pr^{+3}, and Tm^{+3}. The atomic quadrupole shielding factor R has been evaluated for the $4f$ electrons in Pr^{+3} and Tm^{+3}. Numerical values have been obtained for an additional shielding factor, denoted by σ_2, which measures the reduction of the quadrupole part of the crystal field at the location of the $4f$ electrons in the rare earths, due to the shielding effect of the more external $5s$ and $5p$ electrons. The results for σ_2 of praseodymium and thulium are in reasonable agreement with the experimental values. The shielding terms of γ_∞ have been calculated for the case of hydrogenic wave functions.

The reduction of the ionization energy loss of charged particles arising from the polarization of the medium, also called the density effect, has been evaluated for several additional substances, in particular, silicon, germanium, liquid hydrogen, propane, and freon (CF_3Br). An approximate semiempirical expression for the mean excitation potential I as a function of Z has been obtained for use in connection with the Bethe-Bloch formula for the energy loss.

A summer study group concerned with the physics of the Emperor Tandem Van de Graaff region met for four weeks during the summer of 1965. Approximately 25 leading theorists and experimentalists actively involved in this research participated. The range of topics covered included direct-reaction spectroscopy, nuclear models, reaction mechanisms, capture reactions, Coulomb excitation, heavy-ion reactions, and possible new regions of nuclear stability. The *Proceedings* [BNL 948 (C-46), 3 vol.] cover the main points of the discussions.

NEUTRON PHYSICS

The new fast neutron chopper has been completed and put into operation at the HFBR. This equipment is intended primarily for studies of the γ rays emitted from nuclei following resonance neutron capture. The device incorporates a large beam aperture and narrow collimation to provide a high-intensity beam with small angular divergence and a combination of tungsten, nickel, and steel in the rotor to provide efficient shielding between beam bursts. The relatively narrow, high-intensity beam permits the use of separated isotope targets. The flight path, now 22 meters, will soon be extended.

Experiments on the γ rays from resonance neutron capture are currently under way at the new fast chopper. Data from a Ge(Li) detector and the associated neutron flight times are stored on magnetic tape by a computer-controlled system, and the tape is later scanned to give a 2048-channel γ-ray spectrum for each neutron resonance. An example of the results obtained is given in Figure 15, which shows the high energy γ rays from the 7-eV resonance in W^{183}. The strong peak at 7.414 MeV corresponds to the transition to the ground state of W^{184}. The weaker transition at 6.512 MeV populates the $K=2,2+$ state at 904 keV. The 7.305-MeV transition to the $K=0,2+$ level at 110 keV is extremely weak. For the 27-eV resonance the situation is just the reverse, with a weak transition to the ground state and a strong transition to the first $2+$ state. There is no evidence in any of the resonance spectra for a transition to a proposed $0+$ state in W^{184} at 690 eV.

Similar results have been obtained for resonance capture by Tm^{169}. The detailed examination of transitions to low-lying odd-parity states has permitted unambiguous spin assignments to several Tm^{169} resonances. The resonance at 17 eV, for example, is clearly $0+$ and not $1+$ as had been previously reported from cross section measurements, and the spin of the weak 29-eV level is $1+$.

Studies of the interaction of polarized slow neutrons with polarized nuclear targets have continued. Measurements of the spin dependence of the slow neutron cross section of He^3, reported earlier, have been extended and refined. The cross section for the reaction $He^3(n,p)t$ was found to be associated entirely with the $I-\frac{1}{2}=0$ entrance channel, i.e., $\sigma_{I-1/2}/\sigma_0=1.010\pm0.032$, where σ_0 is the cross section for unpolarized neutrons. This result supports current theoretical ideas on excited states in He^4. The measurements also show that the technique employed, in which the He^3 was adsorbed on zeolite powder, will be useful for studying the nuclear susceptibility of He^3 systems. For example, the results indicated that He^3 at approximately monolayer coverage on 13x zeolite could be described either as an antiferromagnet with a Weiss constant of $0.020°\pm0.002°$K or as a Fermi gas with a degeneracy temperature of $0.092°\pm0.005°$K. A study of the susceptibility as a function of coverage is now in progress and should provide new information on the adsorption process.

The spin dependence of the total cross section of U^{235} has been studied in the energy range 0.075 to 2.04 eV. Attempts were made to polarize uranium metal, UFe_2, $U_{0.2}La_{0.8}Cl_3$, and $U_{0.02}La_{0.98}Cl_3$. The polarization attained was very small for the metal, moderate for UFe_2, and substantial for the salt. The nuclear polarization has the same sign in the salt as in uranium metal, but the opposite sign in UFe_2.

The results show that the cross section at the 0.275 and 2.04-eV resonances is primarily associated with one of the two possible spin states ($J=I-\frac{1}{2}$ if the magnetic moment of U^{235} is negative), while the cross section below 0.1 eV and at the 1.14-eV resonance is primarily associated with the other spin state.

Further, the magnitude of the effect below 0.1 eV indicates that at least two levels of opposite spin contribute to the cross section in that energy region. A refinement of these results will aid greatly in the multilevel analysis of the low energy U^{235} cross section, which at present cannot be done in an unambiguous or entirely satisfactory way. The spin assignments so far obtained are in disagreement with previous analyses.

The parameters of the first resonance in thulium at 3.90 eV have been remeasured. The measured partial resonance widths ($\Gamma_\gamma=0.099\pm0.002$, $\Gamma_n=0.0081\pm0.0002$) are considerably larger than the previously accepted values. The spin of the resonance was found to be $J=1$, and the magnetic hyperfine constant for thulium metal, $0.112°$K. A nuclear polarization of at least 4% for Hf^{177} was achieved in a 90% Fe–10% Hf target. An absolute determination of the spins of the first two neutron resonances at 1.10 and 2.38 eV could be made and the spins found to be $J=3$ and $J=4$, respectively. The direction of the hyperfine field is

negative if the magnetic moment is assumed to be positive.

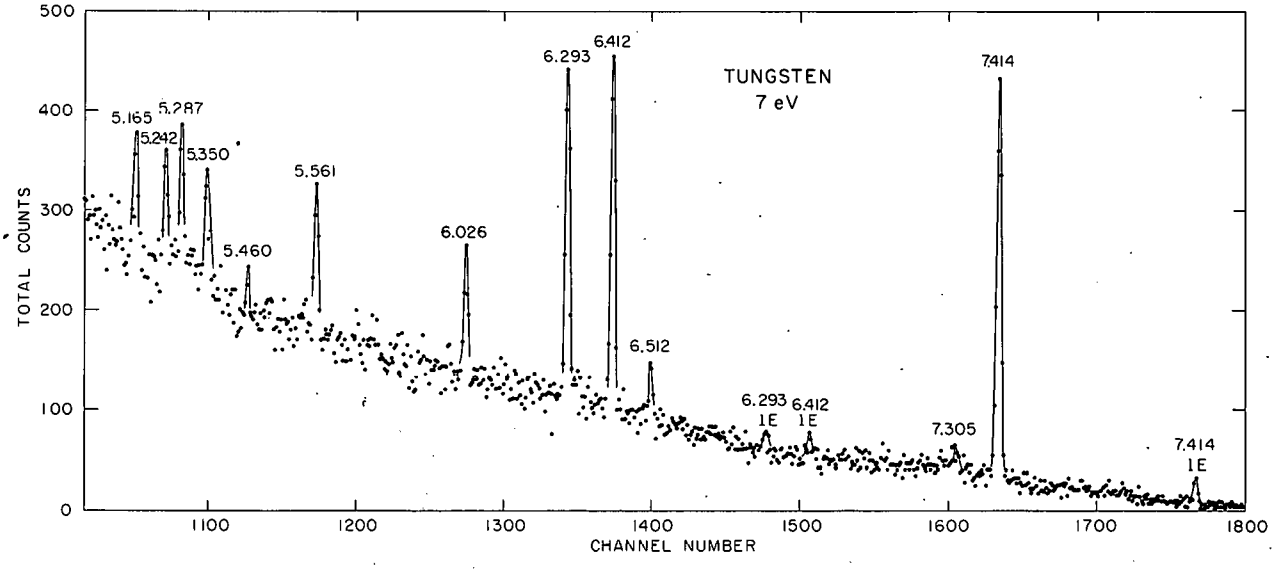
The new polarization spectrometer to be installed at the HFBR is now under construction. This equipment is an improved version of the polarization spectrometer that has been in use for several years at the BGRR. Its main elements are a crystal monochromator for providing a monoenergetic, polarized beam of neutrons, a cryostat with provision for adiabatic demagnetization of targets, and a high-field magnet for orientation of target nuclei. The new equipment incorporates a higher magnetic field for orienting target nuclei, an improved cryostat, and higher energy resolution. These features, along with the high neutron flux available at the HFBR, will permit a substantial improvement in the polarization experiments. This equipment is expected to go into operation at the beginning of 1967.

In a cooperative program with Columbia University, the dynamics of molecular motion in various organic and inorganic compounds in solid, liquid, and gaseous states are being studied with monoenergetic neutrons obtained from a neutron crystal spectrometer at the BGRR. In measurements of the temperature-dependent total cross section and the inelastic differential scattering cross section, the motions of the water molecules in $K_4Fe(CN)_6 \cdot 3H_2O$ have been compared with those in water. The temperature and wavelength dependences of the cross section curves indicate a greater freedom of motion for the H_2O molecule in $K_4Fe(CN)_6 \cdot 3H_2O$ than in water, in accord with evidence from inelastic scattering spectra. The results indicate no significant change in the average rotational or translational freedom of the water molecules when the material passes through its Curie point at 249°K.

The effect of the rotation of large molecules on the scattering cross section was studied in temperature-dependent transmission and inelastic differential scattering measurements on *d*-camphor and ethylene dibromide. Abrupt changes in the cross section were observed for *d*-camphor near −40°C and for ethylene dibromide near −24°C; these changes are thought to arise from the onset of rotation of the entire molecule. Two peaks in the inelastic scattering spectrum for *d*-camphor at 216 cm^{-1} and 48 cm^{-1} at 213°K are assigned to the motion of the entire molecule and to torsion of the CH_3 groups, respectively.

Studies of the Mössbauer effect in dilute alloys of iron in palladium have been extended. A previous investigation on $Fe_{2.65}Pd_{97.35}$ had shown

Figure 15. High energy γ rays from neutron capture in the 7-eV resonance of W^{183}. A Ge(Li) detector of 4-cm^3 volume was used. The strong peaks are all 2-escape peaks. The weaker peaks labeled 1*E* are 1-escape peaks corresponding to the same γ rays. The strong peak at 7.414 MeV corresponds to the transition to the ground state of W^{184}. The weaker transition at 6.512 MeV populates the $K=2,2+$ state at 904 keV. The 7.305-MeV transition to the $K=0,2+$ level at 110 keV is extremely weak.



that the hyperfine field at the iron sites is proportional to the bulk magnetization and that the Mössbauer effect provides a zero-field technique for determining the Curie temperature θ. New Mössbauer spectra have been obtained for samples containing 13.2 and 7.5 at. % Fe in Pd. These spectra were found to become diffuse as the sample temperature approached the transition temperature. The observed spectra could be reproduced by a model that assumes a distribution of the local magnetization. Statistical fluctuations in the iron concentration are assumed to give rise to a distribution in the local magnetization, which produces, for temperatures not far below θ, a distribution of the hyperfine field throughout the sample. The sample is treated as consisting of cells of varying iron concentration which magnetize through a molecular field type of process, with individual cells coupled together through a second molecular field. Two parameters, independent of temperature, are required to fit any single Mössbauer spectrum. The model gives the average hyperfine magnetic field H_1 as a function of temperature. In the range $0.86<T/\theta<0.98$, the field is given by $H_1/H_{sat}=A(1-T\theta)^{\beta}$ with the parameters

% Fe	β	θ(°K)	A
13.2	0.436±0.024	300.6±1.0	1.21±0.05
7.5	0.415±0.04	170.7±1.4	1.21±0.08

Precise measurements have been carried out of the temperature dependence of the dielectric constant in ferroelectric crystals near ferroelectric transitions. This was done as a test of the extensive theoretical calculations made for the analogous case of ferromagnetic materials in the neighborhood of second-order ferromagnetic critical points (Curie points). In some second-order ferroelectric transitions, Curie's law was found to be valid within a few parts in 10^4, although deviations from the law are predicted. The transition in potassium dihydrogen phosphate was found to be first order, rather than second, as previously believed.

ATOMIC AND MOLECULAR PHYSICS

The atomic-beam magnetic-resonance technique has been used to determine the hyperfine structure separation $\Delta\nu$ and the nuclear magnetic moment in the electronic ground state of the radioactive isotopes K^{42} and Rb^{82}. These measurements were performed by observing separated loop resonances for the $\Delta F=\pm 1$ transition in the field-independent region. The results of these measurements and the corresponding hyperfine structure anomalies (relative to stable K^{39} and Rb^{85}, respectively) are as follows.

K^{42} $\quad \Delta\nu = 1258876840(100)$ cps
$\quad \mu_I = 1.1408(5)$ nm (uncorrected)
$\quad {}^{42}\Delta^{39} = +0.0035(5)$.

Rb^{82} $\quad \Delta\nu = 3094082650(200)$ cps
$\quad \mu_I = 1.6372(11)$ nm (uncorrected)
$\quad {}^{82}\Delta^{85} = -0.0027(10)$.

In collaboration with the National Bureau of Standards and the University of Colorado, a study has been made of the dependence of the line width of the 6834-Mc/sec hyperfine transition in Rb^{87} on the buffer gas pressure (argon). To observe this the technique of optical pumping was used. The quantitative theory of Galatril involving Doppler reduction at low pressure (1 mm) and collision broadening at high pressure (>10 cm) was fairly well confirmed.

Applied Mathematics

In mid-February of 1966, the staff of the Applied Mathematics Department moved into the newly completed Applied Mathematics Building. During the following month the Central Scientific Computing Facility operations were moved to the new building.

The Department's activities during the past year in the areas of computer operations, computer engineering, scientific programming, and mathematical research are summarized below.

COMPUTER OPERATIONS

Central Scientific Computing Facility

At the beginning of fiscal 1966 the computer complement of the Central Scientific Computing Facility (CSCF) consisted of an IBM 7094 computer, an IBM 7044, and a CDC 924. In accordance with the CSCF expansion program approved last year, a CDC 6600 computer system was added during the third quarter. A small PDP-8 computer, now being used in the development of a remote-computer interface for the CDC 6600, was acquired at the end of the second quarter.

All permanent computing and support equipment, except the IBM 7094 computer, has been installed in the computing center at the new Applied Mathematics Building. The IBM 7094 remains in its previous location, where it is convenient for continued on-line use with the Hough-Powell Flying-Spot Digitizer. In July 1966 the IBM 7044, which was obtained on a temporary basis, will be returned to the International Business Machines Corporation, and an IBM 1401 will be acquired for limited peripheral support of the IBM 7094. Early in fiscal 1967 a second disk-file unit is to be added to the CDC 6600 system, and a Calcomp Model 835 CRT plotter will be acquired to meet the immediate needs of CDC 6600 users for graphical output.

Computer Scheduling and Usage

During the year the IBM 7094 computer was again utilized to its full capacity. Figure 1 shows its quarterly usage for productive research computing only; time consumed by maintenance, operating system modifications, training, and tape mounting is excluded. The sizable increase in productive computing indicated for the fourth quarter essentially reflects a corresponding decrease in nonproductive use due to the primary scheduling of production jobs only on the IBM 7094 after the CDC 6600 became available. A survey of computer users indicates that this usage of the IBM 7094 will continue at a saturation level throughout fiscal 1967 despite the availability of the CDC 6600.

Although the CDC 6600 computer has been in scheduled operation for less than a full quarter, the demands on it have already increased to the point where it is necessary to schedule two full 8-hr shifts per day.

The total usage of the CDC 924 for processing small problems during fiscal 1966 was ≈50% greater than that for the previous year.

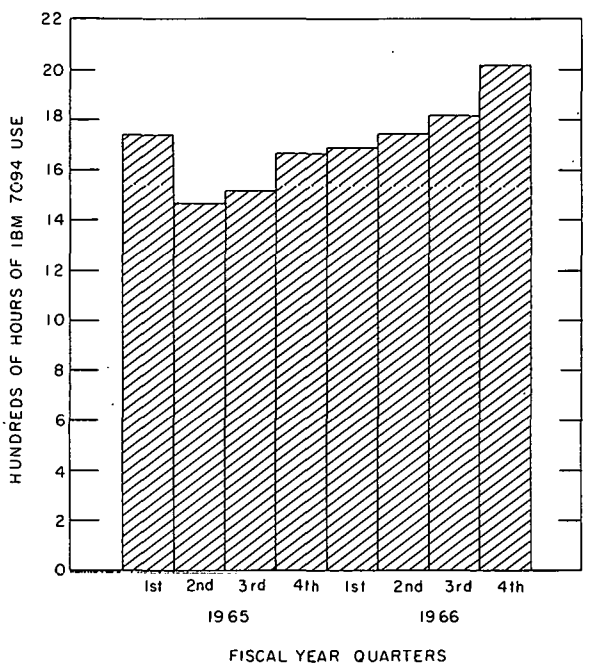


Figure 1. Histogram of IBM 7094 computer usage at Brookhaven National Laboratory.

ENGINEERING ACTIVITIES

Auxiliary On-Line Systems

The engineering activities within the Department during the past year have been primarily concerned with the development of two auxiliary on-line systems intended to extend the capabilities of the CDC 6600 by utilizing relatively small satellite computers to control external devices and to buffer input-output. One of these systems, an input-output supervisory system, will provide facilities for automatic coordination and supervision by the CDC 6600 monitor software of the activities of operating personnel at each input-output station in the computer center. This system will employ a PDP-8 computer. The other system will allow various remote experimental facilities at the Laboratory to utilize directly the CDC 6600 via a long-line digital transmission link. Although this type of system will not be restricted as to the specific satellite computer to be used, the first such system will also include a PDP-8 computer.

The use of a PDP-8 computer in each of the two initial systems under development permits the preparation of common specifications and designs for those components required in both systems. The common components now being developed include synchronizer and controller units to couple one of the CDC 6600 data channels to the data and control interface for a PDP-8, a break-state multiplexer unit to automatically control PDP-8 input-output on a priority basis for the CDC 6600 and six other devices, and a controller for a PDP-8 magnetic tape unit.

Digital Transmission Links

Work is proceeding on the design for the long-line digital transmission links that will allow rapid, bidirectional communication between the CDC 6600 and experimental facilities located up to two miles from the computer center. A link, to be interposed between a synchronizer unit on a CDC 6600 data channel and the controller for a remote satellite computer, will consist of a pair of data terminals transmitting control signals and data to each other via a set of long coaxial cables.

A "phantom balanced line" transmission technique was selected, since the desired performance can be achieved with half the number of cables required for full balanced line transmission. Circuitry was designed to protect the data terminals from lightning surges picked up on the cables. Transmission will be interrupted during a surge and then restored automatically afterwards.

In cooperation with the Architectural Planning Division, preliminary arrangements have been made for the installation of cables in available underground conduits.

Tape Label Reader

A PDP-8 interface unit controlling a number of magnetic tape label-reading devices is being developed for the input-output supervisory system. One such device will be attached to each CDC 6600 tape transport. This feature will allow the system to verify that, when a tape is requested, the correct tape is mounted on the proper transport. The interface unit will control the initiation of tape-loading operations and, via interrupts, will convey information to a PDP-8 concerning the status of loading operations. Each tape reel will have a unique label affixed which can be read by the device and sent to the PDP-8, where it can be determined whether or not the correct tape was loaded. The appropriate modifications to the tape transports are being made, and test circuits for the label-reading and PDP-8 interface are being constructed.

Cathode Ray Tube Recorder

A unit for recording cathode ray tube output on 35-mm film was designed and constructed. This CRT recorder, now connected to the CDC 924 computer, consists of an addressable 5-in. cathode ray tube and an optical system. It incorporates features for program control of intensity, point and vector plotting, and film advance. The installation and testing of this unit have been completed, and its use under program control is now being evaluated.

PROGRAMMING

The Programming Division has been engaged throughout the year in the conversion of IBM 7094 programs and library subroutines for use on the CDC 6600. Considerable programming and conversion assistance has been provided to computer users through the publication of pertinent information in the BNL Computer Newsletter; further assistance has been provided by the establishment of a programming consultation service in a room adjacent to the new computing center. Some selected examples of programming activities are given below.

Operating Systems

Maintenance and improvement of the BOS-FORTRAN II and IBSYS-FORTRAN IV monitor systems for the IBM 7094 computer have been continued. The major effort, however, has been concerned with the CDC 6600 Chippewa Operating System (COS) now in use at BNL. This multiprocessing monitor system has been extensively tested, and its deficiencies are being corrected. It is being modified to improve magnetic tape usage and to provide for more automatic and efficient operation. To minimize the necessary chore of converting existing IBM 7094 programs for use on the CDC 6600, the nonarithmetic features previously incorporated in the IBM 7094 IBSYS and BOS systems for particular Brookhaven requirements are being added, where possible, to the COS.

Hardware Diagnostic Programs

Difficulties in diagnosing the causes of machine failure are inherently associated with the high degree of parallel operation in the CDC 6600 central processor. A failure may occur infrequently and only during certain combinations of operations. If it occurs during a regular program, its diagnosis and correction may be very time-consuming, since the exact failure conditions are often hard to determine.

The problem has been alleviated by a diagnostic program developed at BNL. This program, used during central processor idle periods, repeatedly executes randomly generated sets of instructions and compares the results from successive executions of a set to detect failures. When one is detected, instructions are progressively eliminated to restrict the range of possible failure conditions and thereby reduce considerably the time usually needed to correct the cause of failure.

Initial versions of this program have successfully detected and diagnosed several malfunctions in three different CDC 6600 systems, including the one at BNL.

Satellite Computers

A separate group was established to handle the numerous programming activities associated with the small satellite computers to be used in the auxiliary on-line systems for the CDC 6600 mentioned earlier. Since the first two systems will each utilize a PDP-8 computer, current emphasis is on the development of appropriate input-output and control software for the various peripheral devices

Figure 2. New Applied Mathematics Building.

to be attached to the PDP-8 computers and software for communication with the CDC 6600. Work has also been initiated on CDC 6600 software modifications to permit real-time communication with satellite computers.

A program to simulate a PDP-8 computer was written for the IBM 7094. It contains both a completely compatible PDP-8 assembler and an extensive diagnostic package. In addition, it simulates the use of several input-output devices as well as the PDP-8 interrupt feature. The simulator was used to debug and test programs prior to the delivery of a PDP-8 computer.

Information Storage and Retrieval

A Chemical Titles Data System has been developed for the Chemistry Department to provide its staff members with bibliographies of current literature relevant to their particular professional interests. This system, utilizing data tapes obtained every two weeks from the Chemical Abstracts Service, allows a user to request searches by author or by combinations of significant words and affixes appearing in titles. Every user regularly receives a separate bibliography for each request. The system, written in COBOL for the IBM 7044 and 7094, is now operational as a regular job under control of an IBSYS monitor.

Work has continued on the Medical Records Data System (MEDREC) for the Medical Department. In the design stage during fiscal 1965, MEDREC is now operational and is furnishing, daily, cumulative clinical test reports on individual patients to the appropriate physicians and a report to each clinical laboratory summarizing its daily activity. It also produces, quarterly, an Index of Physicians and a Disease Index, both required to meet state accreditation requirements. The system is now being extended to include data from special tests done by non-BNL clinical laboratories.

Continued activities concerned with the Sigma Center Information Storage and Retrieval System (SCISRS) include the addition of a new retrieval feature and the development of a program to prepare KWIC-type indices of Sigma Center data. A second-generation SCISRS is expected to be written on the basis of specifications established by present users at major nuclear installations.

A second volume of the *Permuted* KWIC *Index to Computing Reviews*, covering the years 1964-1965, was prepared in cooperation with the State University of New York at Stony Brook and has recently been published by the Association for Computing Machinery.

Software for Real-Time Experiment

In cooperation with members of the Physics Department, all the necessary software, including executive control, input-output, and mathematical routines, was completed for the first real-time experiment at the Alternating Gradient Synchrotron (AGS) at high data rates. The experiment utilized a PDP-6 computer connected on-line at the AGS to an array of digitized discharge planes which directly provide accurate coordinate data for particle-trajectory points. The system provides an experimenter with an immediate display of cumulative experimental results in the form of a histogram. It is capable of analyzing and presenting results for sustained rates of >3000 events/min.

Programmed Pattern Recognition

As part of the continuing development of fully automatic techniques for scanning bubble chamber photographs, previously developed programs for beam-track recognition, track editing, and vertex finding were merged into a pattern-recognition operating system under the control of a supervisory program. The system incorporates a routine for control of the Hough-Powell Flying-Spot Digitizer (FSD) which enables the pattern-recognition programs to operate on-line with the FSD. It also allows the on-line adjustment of various FSD and program parameters, during preliminary runs, until satisfactory settings are reached.

The major recent effort in this area has been connected with the use of these pattern-recognition programs to scan film taken at the 80-in. bubble chamber for a study of small-angle (1 to 20 mrad) $\bar{p}$-p scattering. To evaluate their effectiveness, the automatic scanning programs were used to process the same two views of 500 frames each that had also been processed by human scanners at the Nevis Cyclotron Laboratories (Columbia University). When the numbers of beam tracks found by the programs and by the scanners were compared, the program efficiency, which was found to be directly dependent upon the photomultiplier sensitivity setting in the FSD digitizing circuit, ranged from 0.70 to 0.94. As a result, an additional program is being developed to obtain the optimum sensitivity setting essentially without human intervention.

To calibrate the efficiency with which small-angle scatters are detected, a program has been written to produce a data tape containing tracks selected from the digitized FSD input in which artificial kinks of known location and angle have been introduced. This tape can then be processed by the scanning and analysis programs, and the results compared with the known input data. By repeating this process for a range of angles and tracks, the kink detection efficiency can be calibrated.

Figure 3. Part of operating area for CDC 6600 computer.

MATHEMATICAL RESEARCH

Graph Theory

A graph may be represented as a structure obtained by replacing its vertices with mass points and its lines with ideal springs. The eigenspectrum of the graph may then be defined as those eigenfrequencies computed for the normal vibrational modes of the corresponding structure. It had been speculated that two topologically distinct graphs would rarely have the same eigenspectrum. An investigation into the nature of a class of graphs has demonstrated that, contrary to speculation, it is quite common for topologically distinct graphs to be isospectral. The investigation also has shown that low-order spectral moments of large planar graphs depend upon only certain aspects of the structure. One consequence of these results is that "No" is the most likely answer to the famous question, "Can you hear the shape of a drum?"

In a separate investigation, a new and simpler combinatorial proof was developed for the theorem of Tutte that sets forth necessary and sufficient conditions for a graph to be prime.

Differential and Integral Equations

Several new results have been obtained during the continuing study of pairs of either symmetric or unitary operators **U** and **V** which do not commute, but whose commutator **UV-VU** is compact.

It was shown that **V**, if it is self-adjoint, is unitarily equivalent to a singular integral operator, L, defined over the spectral representation space of **U**, which has the form

$$Lx(\lambda)=A(\lambda)x(\lambda)+\frac{1}{\pi i}\int_{\sigma(u)}\frac{k(\lambda)^{*}k(\lambda)}{\mu-\lambda}\,x(\mu)\,d\mu\,,$$

where the operator coefficients $A(\lambda)$ and $k(\lambda)$ are matrix-valued functions. When **U** is a unitary operator, this is an equation on the circle.

A complete spectral analysis of L was obtained for the case in which **U** is a unitary operator with a spectral multiplicity of one. This theory of singular integral equations on the circle complements a previously obtained theory of singular integral

equations on the real line that corresponds to the case in which **U** is bounded and symmetric.

One special case of the results for equations on the circle leads to an explicit diagonalization of symmetric Toeplitz matrices. Another special case, which, through a certain duality between the theories of equations on the circle and on the line, corresponds to the equations on the real line, leads to a new theory that provides complete eigenfunction expansions for the solution of Wiener-Hopf equations.

An analysis of steady supersonic flow about a swept-back wing has resulted in the development of a supersonic lifting-line theory that closely parallels the subsonic lifting-line theory of Prandtl. The theory furnishes explicit formulas for lift and drag as well as the locations of discontinuity surfaces, which are limiting cases of shocks. Although this theory was initially intended only for wings with large aspect ratios, it was found to yield, asymptotically, the correct lift and drag for a delta-shaped wing at high Mach numbers.

The analysis entailed an asymptotic evaluation of equations derived for a linearized case of irrotational, ideal, perfect flow about a swept-back wing of finite span and large aspect ratio at steady supersonic velocities. The original problem was embedded in a one-parameter family of problems in which the parameter determines the largest wing chord. A solution was then obtained by utilizing this parameter in a boundary layer type of singular perturbation expansion that involved the nonuniform stretching of coordinates.

Plasma Model

The dispersion relation, including a detailed analytic continuation for both the long and short wavelength limits, was investigated for a two-component model of a collisionless, nonrelativistic plasma acted upon by a uniform external magnetic field. The investigation was restricted to the case of longitudinal wave propagation parallel to the external magnetic field. Explicit formulas for the roots of the dispersion relation were obtained for initial-value problems in various asymptotic regimes, and qualitative global plots of the roots were based on these formulas. The one-parameter scheme used for classifying the roots, based on the wave number, simplifies the description of the roots and allows a clear view of their over-all structure.

The four decaying Larmor roots (related to the four decaying Larmor modes, but not to be confused with the Larmor resonances for transverse wave propagation) were each found to be of infinite multiplicity, and the details of the way in which each of these roots is split into singlets for higher-order corrections were determined. Plasma oscillation modes were found to be modes with an intermediate range of wave number values. These modes propagate with a speed greater than that of light for much lower wave numbers; they are damped propagating modes for much higher wave numbers.

Diophantine Inequalities

A class of minimum-cost transportation problems was studied as part of the continuing investigation of a previously developed comprehensive method for the solution, by the use of generating functions, of finite systems of simultaneous linear Diophantine inequalities. The form of the generating function for this class of problems was determined from the results obtained in the solution of several specific cases.

The general problem considered is one of determining the cheapest way of distributing stocked items from a number of warehouses to a number of stores when the demand from each store and the costs of shipping the items from each warehouse to each store are known. Analysis of such a problem yields a system of linear Diophantine inequalities which is amenable to solution by the generating-function method.

Numerical Analysis

The behavior of finite-difference approximations to a class of partial differential equations with singular coefficients was investigated by means of a numerical study of the m-dimensional, spherically symmetric diffusion equation

$$u_t = u_{rr} + \frac{m-1}{r} u_r$$

for those cases in which m is even as well as for that in which $m = 3$. It was found that, by utilizing a standard two-level, three-point explicit difference scheme, solutions of the approximating difference equation can be expected to converge uniformly to those of the differential equation when the two following conditions are met: (1) the finite-difference mesh selected is $r = j\Delta r, j = \frac{1}{2}, \frac{3}{2}, \ldots$, and (2) the mesh ratio, $\lambda = \Delta t/(\Delta r)^2$, is $< \frac{1}{2}$.

Mathematical Statistics

As part of a continuing investigation in the general area of predicting values for an unobservable random variable from corresponding values of an observable one, a study was made of such predictions relative to a squared-difference loss. The study was concerned with predicting the unobservable variable, Θ, from the observable one, X, by seeking a measurable function, f, on the range of X such that the risk,

$$E_p(fX-\Theta)^2=R(f,P)\,,$$

is small, regardless of which underlying probability measure, P, obtains in a known family of these measures. A theorem was proved which shows that, corresponding to each predictor, fX, there is a predictor with a uniformly smaller or equal risk which depends upon X only through an adequate statistic. A statistic, $T=tX$, is adequate for X if it is sufficient for the family of distributions of X, and if the corresponding conditional probabilities of Θ given X and Θ given T are almost everywhere equal for each of the underlying probability measures.

The theorem easily generalizes to hold for a risk defined by replacing the square of the error with a convex function of the error.

Monte Carlo Methods

A general, mathematically rigorous definition of the Monte Carlo method was given to cover all the known Monte Carlo procedures. A theorem was established which can be used as a strong law of large numbers for a large class of Monte Carlo processes.

Other work in the Monte Carlo area was concerned with the use of least-squares Monte Carlo methods for computing approximations to solutions of systems of N linear algebraic equations in n unknowns, with $N\geqslant n$, where N and n are "hopelessly large." The basic principle of replacing sums with suitably sampled values of the summand was used to avoid lengthy computations. A workable sequential Monte Carlo process was developed which greatly accelerates the convergence of estimates in many cases.

The concept of weak orthogonality and a Monte-Carlo Gram-Schmidt process were introduced for the case in which such a system of equations arises from a valid discretization of a continuous problem. Also for this case, a technique of progressive refinement of the grid was introduced in connection with the sequential process.

Field Theory

In the Perez-model field theory, every term of the S-matrix perturbation expansion may be readily obtained, since no renormalization is necessary. The perturbation series are known not to converge for any value of the coupling constant, no matter how small. It was shown, however, that, through use of the Padé approximant method, not only may the series be summed to a uniquely determined function of the coupling constant, but also any finite number of terms may be used to provide convergent upper and lower bounds to the correct value.

Previously reported work on the Bethe-Salpeter equations in the Wick-Cutkosky model for the equal-mass case was extended through a study of the normalization properties of Bethe-Salpeter amplitudes and of the existence of multiple poles for the case in which the two particles have unequal masses. The normalization properties of the Bethe-Salpeter amplitudes were analyzed in detail, and the scattering Green's function was found to have multiple poles at an energy equal to the mass difference of the particles. These particles are qualitatively different from those of the equal-mass case which is, in this sense, rather exceptional.

The Lorentz condition was formulated as an operator identity in a newly proposed consistent, covariant quantum theory of the free electromagnetic field in the Landau gauge. The theory corresponds to the fact, determined in previous work on the Bethe-Salpeter equation for equal-mass particles, that a massless vector bound state is accompanied by a dipole ghost. Since no artificial assumptions were introduced into the Bethe-Salpeter formalism, this previous result suggested that it would be natural to use a dipole ghost in the quantization of a massless vector field. The same method of quantization may also be applied to the weak gravitational field by use of a "tripole" ghost.

Elementary Particle Theory

The dynamical existence of the Ω^- particle (1675 MeV) as a $\frac{3}{2}^+$ bound state of the $(\Xi, \bar{K})$ system was investigated. The standard one-channel N/D formalism was used, and the input forces were approximated by the Born amplitudes for

all low-lying one-particle (or resonance) exchange diagrams up to and including the Y_1^* (1385 MeV) exchange. The amplitude for the Y_1^* exchange when computed as though the Y_1^* were a stable particle leads to an obviously incorrect high energy behavior and necessitates the introduction of a damping factor into this amplitude. The Regge pole description of the Y_1^* introduces, in a natural way, such a damping factor. Through the use of this damping factor the Ω^- particle was produced at the correct mass for consistent values of the coupling constants.

LIFE SCIENCES

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Biology

The present report provides brief summaries of projects conducted by members of the scientific staff of the Biology Department. Research is in progress at all levels of biological organization, from ecology to biophysics, and is related to the development of basic information that will lead to improved understanding of the manner in which ionizing radiations affect living things and in which these effects may be used constructively for specific biological purposes. Insofar as the problems examined permit, emphasis is given to the molecular approach, and mechanistic rather than descriptive studies are stressed. Thus, a common theme throughout is the correlation of macromolecular structure with biological organization and function.

A number of the projects derive immediate benefit from the availability of research reactors and particle accelerators at Brookhaven, while more specialized irradiation sources are utilized directly within the Biology complex. A noteworthy feature of the program is the number of projects that relate to studies with plants. In addition to extensive field and greenhouse facilities, specialized growth-chamber space is available for precise manipulation of the environments in which plants are maintained.

The Biology Department maintains a number of collaborative programs with visiting scientists from other institutions, both in this country and abroad, and sponsors the Brookhaven Symposia in Biology, a series of annual conferences at the Laboratory that focus on topics of current interest in biological research. The title of this year's symposium is *Energy Conversion by the Photosynthetic Apparatus*. The proceedings will appear as the 19th volume in the series.

PLANT SCIENCE

Ecology

A central and continuing objective of the ecology program at Brookhaven, paralleling the studies of the ecological effects of radiation, has been study of the structure and function of natural ecosystems. The problems are formidable in that both structure and function vary in response to changes in a large number of factors, and the very size of the systems and the slowness with which they develop makes experiment difficult. Nonetheless, natural ecosystems do have characteristics that are in part analogous to those of single organisms: they have, for instance, characteristic form; requirements for nutrient elements, water, and light; and they have a metabolism. Of these, perhaps the most difficult to measure is metabolism, although in many ways it is one of the most fundamental characteristics of life. During the past year the respiration of a forest was measured in a novel but comparatively simple way.

The technique is based on the fact that during temperature inversions (periods, usually at night,

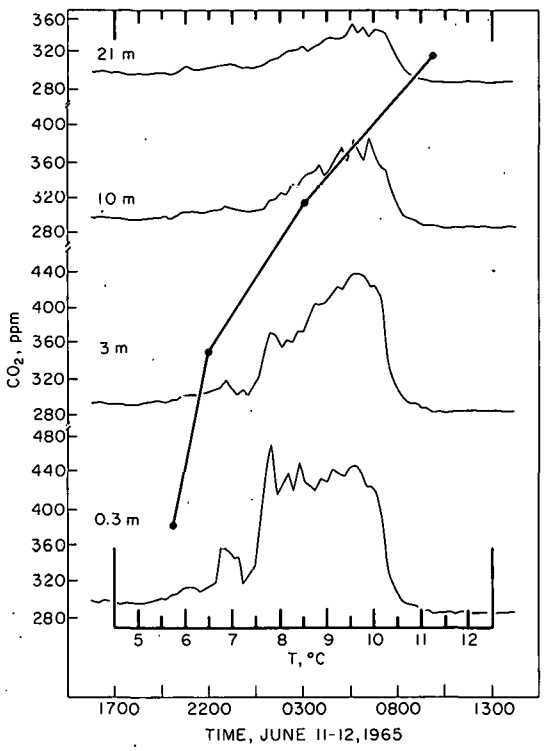


Figure 1. Estimation of CO_2 production by a forest. During temperature inversion there is little vertical movement of the air mass over the forest. Thus, most of the CO_2 produced by respiration is trapped. From the measurements of CO_2 concentration at various heights and by suitable integration, the rate of CO_2 production by the forest is obtained.

when temperature near the ground is lower than at, say, 25 m above the ground) there is very little vertical movement of air masses. This means that carbon dioxide produced by respiration is trapped within the forest and CO_2 levels increase with time. The rate of increase in CO_2 concentration, measured at several heights and integrated over the vertical profile of the forest, is thus a measure of the rate of respiration of the forest. By means of data-recording equipment built by the Instrumentation Division and an elaborate sampling system, the CO_2 concentrations at several heights within the control section of the Brookhaven Irradiated Forest were measured during several temperature inversions. Plotting respiration rates measured in this way during the course of the year has shown that total respiration of the undisturbed forest (based on nocturnal rates and assuming that they apply throughout 24 hr) produces between 3.5 and 18 g CO_2/m^2 per day. The highest rates occurred during summer; the lowest in winter. The annual course followed a bell-shaped curve, as might have been predicted. The annual production of CO_2 on this basis was 2810 g/m^2, a figure that agrees in detail with estimates based on detailed measurements of plant growth. This is estimated to represent the consumption of the equivalent of about 1700 g dry matter per m^2 per year.

Such measurements as these, accumulating over several years, are increasing the value of this small experimental forest both as a case-history study of an ecological system and as a testing ground for techniques and equipment.

Classification of Genetic Systems by "Chromosomal" and Radiobiological Parameters

Data obtained here and elsewhere provide estimates of "chromosome" volume, content of genetic material [e.g., deoxyribonucleic acid (DNA)], and dose of radiation survived by 37% of a population (D_{37} value) for each of some 50 species ranging from viruses to higher plants and animals. A plot of D_{37} values against corresponding volume per chromosome – calculated for presumed monochromosomal forms and measured at interphase for polychromosomal forms – reveals that the organisms fall into seven different groups. A plot of the energy absorption per chromosome for D_{37} against corresponding volumes per chromosome indicates that each group is reperesented by a distinct energy level. A comparison of the energy absorption per chromosome with the amount of genetic material per chromosome also separates the organisms into the same seven groups indicated by the other relationships. No specific relationship obtains between the groups and appropriate content of genetic material. However, for the organisms as a whole the chromosome volume tends to be directly proportional to the content of genetic material and inversely proportional to the D_{37} value. The amount of genetic material per chromosome apparently modifies but does not determine the energy levels for the seven groups of organisms. The relationships indicated may reflect a different basic configuration or organization of genetic material for each group of organism. The organisms within the groups do not reflect taxonomic classification.

Reproductive Integrity of Somatic Cells of *Tradescantia* After Acute Gamma Irradiation

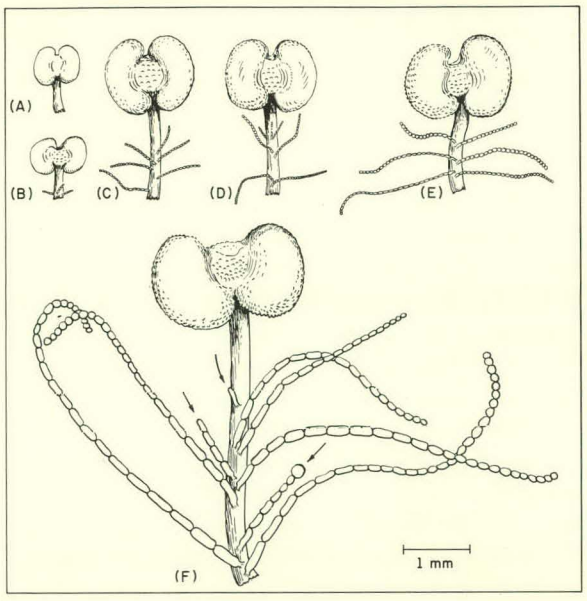
Stamen hairs of several species of Commelinaceae are essentially single-cell meristems and thus excellent material for radiobiological studies. When young hairs are irradiated some lose their reproductive integrity. The survival curves for such loss are comparable to those obtained from cultures of animal or microbial cells. Tests in two different *Tradescantia* species indicate that survival of terminal cells of stamen hairs after gamma irradiation is inversely related to the chromosome volume measured at interphase.

Genetic Variation at the Protein and Enzyme Level in Tobacco and Wheat

Exploration for variation in enzymes and other proteins of different species, hybrids, and mutants was made with use of disc electrophoresis to fractionate soluble proteins. Various species, species hybrids, mutants, and disease-resistant lines of *Nicotiana* and disease-resistant lines of wheat were examined. The variability in protein pattern between species was found to be greater than that between different genotypes of the same species. In some mutants the induced genetic changes were associated with changes in protein and enzyme patterns. Further, in wheat a translocated chromosome segment from *Aegilops umbellulata* that confers leaf rust resistance also increased the number of protein fractions.

Tumors in Interspecific Hybrids of *Nicotiana*

Some interspecific hybrids of *Nicotiana* are known to form spontaneous tumors at late stages



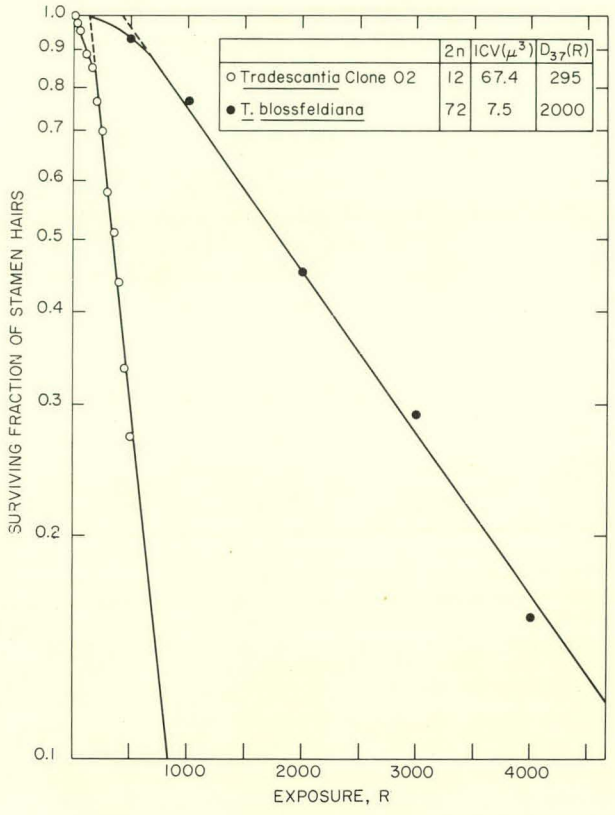


Figure 2. Effect of irradiation on the stamen in *Tradescantia*. At the left the growth pattern of stamen hairs is illustrated [(*A*) to (*E*)]. The mature flower contains six stamens such as shown at (*F*). Each stamen bears 40 to 60 hairs (only a few are pictured) with an average of about 20 cells per hair. The data at the right indicate the effect of radiation dose on survival of stamen hairs in two species of the plant. As obtains for most organisms examined, the species with the smaller chromosome volume (ICV) is the more radioresistant.

of development. In a continuing study of such tumors, acceleration of tumor formation in the tumorous hybrid *Nicotiana glauca-langsdorfii* and induction of morphological aberrations in a nontumorous mutant of the hybrid were found to occur following treatment of seedlings with an extract of tumor tissue and, to a lesser extent, with extracts of leaves of both stocks. Preliminary tests indicate involvement of a high molecular weight compound, possibly related to the nucleic acids. Treatment of seeds with a solution of azauracil induced tumors at the cotyledonary stage under conditions that produced no tumors in control plants. The effect was completely reversed by treatment with uracil. Other base analogues related to both DNA and ribonucleic acid (RNA) caused growth inhibition but proved ineffective in inducing tumors.

Genetic Recombination of *waxy* Mutants Induced in Maize by Ethyl Methanesulfonate

A gene in maize (*Wx,wx*) affects the staining action of pollen and thus provides a technique having the distinct advantage for genetic studies in higher plants that large populations, e.g., 10^5, of genotypes (pollen grains) can be scored with ease. Therefore, the detection of an event as rare as genetic recombination within the *waxy* cistron (gene) becomes feasible. Earlier analysis of a first generation indicated that ethyl methanesulfonate (EMS) induces independent mutations within the *waxy* cistron. In present work EMS-induced *waxy* mutants and spontaneous or standard *waxy* mutants were crossed in all possible combinations to determine recombination rates among the induced and spontaneous mutants. Genetic recombination was obtained in a sufficient number of cases to allow construction of a tentative genetic map of the cistron. The recovery of recombinants produced from the mutants confirms previous indications that EMS produces "point mutations," or at least minor deletions of the genetic material, rather than the deletion of the entire *waxy* locus expected with ionizing radiation. The fact that intracistron recombination occurs in the first generation and in the intercrosses substantiates work of others which shows that EMS produces a low frequency of chromosomal changes but does so at the level of the cistron.

Plant Physiology: Photoperiodism and Photomorphogenesis

Photoperiodism and leaf and stem development can be controlled by low energy red and far-red light that probably act through the chromoprotein photoreceptor phytochrome. However, studies of relationships between physiological responses and spectrophotometrically assayable phytochrome continue to yield complex if not unintelligible results. As a recent example, cucumber hypocotyl elongation requires two brief red light illuminations separated by several hours of darkness in order to show a measurable response, while pea epicotyl elongation gives its maximum response to one such treatment with no increase due to the second. Nevertheless, the phytochrome transformation kinetics observed after red light treatment in the two tissues are almost identical.

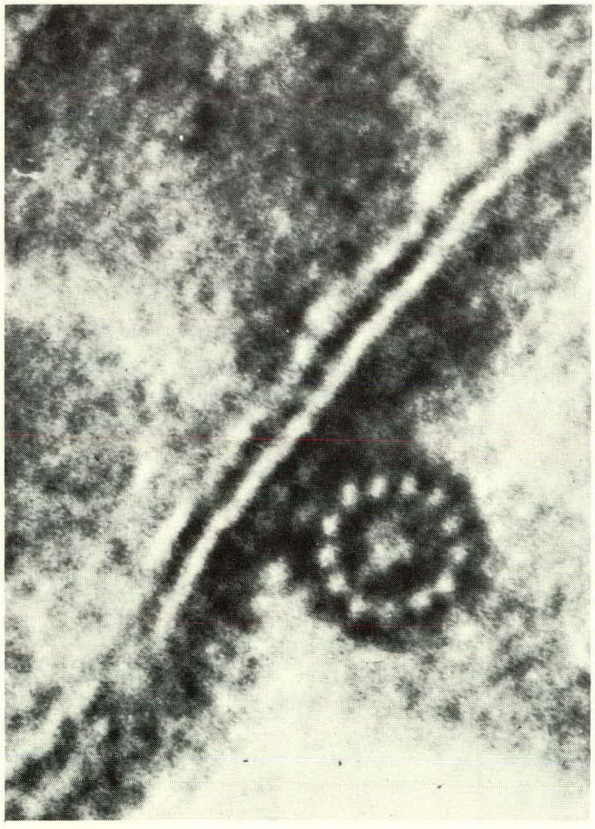


Figure 3. Microtubule from cortex of *Juniperus* cell. Both plant and animal cells contain microtubular systems of uncertain function. The tubules examined are morphologically similar and may be homologous. The characteristic 13 files of elements in the wall of plant cortical tubules is illustrated. 750,000×.

Inhibitor studies on phytochrome transformations in intact tissues lead to the conclusion that the destruction of the far-red-absorbing form is an oxidative metal-dependent process not closely related to respiration. Inhibition of this destruction in corn and oat seedlings also prevents the apparent reversion to the red-absorbing form. Equal inhibition of this destruction in pea tissue, however, is accompanied by constant or increased reversion, which suggests that a true reversion mechanism occurs in this tissue, although not in the cereal seedlings.

Continuing investigation of the photoperiodic flowering response of *Lemna perpusilla* (duckweed) indicates the existence of a red-blue antagonism in addition to the red-blue synergism demonstrated earlier. The antagonism is shown by the fact that the amount of red light required to inhibit flowering under continuous blue light is roughly proportional to the intensity of the blue light. This, together with the observation that most of the effects of blue light can be duplicated by far-red, weakens earlier suggestions that pigments other than phytochrome might be involved.

Structure and Function of Microtubules

A study of the fine structure of the walls of cortical microtubules found in plant cells has shown them to be composed of subunits arrayed in 13 strands spaced at about 45 Å and parallel to the longitudinal axis of the microtubule. Patterns resembling this have been reported for walls of tubules from certain animal cells. The microtubules of the mitotic spindle, the phragmoplast of plants, and tubules variously displayed in animal cells, including astral rays, spindles, the mid-body and flagella, all have a gross morphology similar to that of the cortical tubules of plant cells, which suggests that they are all homologous. A study of the walls of tubules from various origins is being made with the electron microscope to learn more about the fine structure of these elements. This information will be useful in interpretation of the function of the microtubules in the cytoplasm. Also of interest is the relationship of the tubules of the phragmoplast to plasmodesmata and the possible relationship of tubules to cytoplasmic streaming.

Plant Bile Pigments

Bile pigments have important functions as photoreceptors in photosynthesis and the regula-

tion of plant growth and development. Large-scale cultures of blue-green algae have provided abundant amounts of phycocyanin, an algal biliprotein. The chromophore of phycocyanin has been cleaved under mild conditions and found to be a verdin-type pigment. The isolated chromophore has been purified and obtained in crystalline form. Attempts are being made to prepare sufficiently large crystals for structural analysis by x-ray diffraction. Determination of structure is also being attempted by other physical and chemical methods. A comparison of phycocyanin chromophore derived from several species of blue-green algae is under way. The chromophore from all species examined was found to be identical on the basis of ultraviolet, visible, and infrared spectra, chromatographic behavior, and melting point.

Photophosphorylation in Spinach Chloroplasts

In higher green plants chloroplasts are responsible for the conversion of light into chemical energy, this energy transduction being the crucial feature of photosynthesis. Working back from the chemical end reactions (mostly elucidated) toward the initial quantum absorption, the processes become increasingly rapid, more dependent on chloroplast membrane structure, and more difficult to investigate.

The earliest chemical transformations involve conduction of electrons through carriers to an acceptor such as triphosphopyridine nucleotide (TPN) with, at some point, energy being tapped off to synthesize adenosine triphosphate from adenosine diphosphate and phosphate. By using the sensitive technique of double beam spectrophotometry, the steady-state level of the electron carriers cytochromes *b* and *f* can be observed to change during light/dark transitions. Such observations relate one carrier to another and to the two photochemical reactions. Thus, the antibiotic antimycin A was found to block reduction of cytochrome *f* and thereby the flow of electrons to photoact I and TPN. It also inhibited cyclic phosphorylations. In contrast, the herbicide DCMU blocked oxidation of cytochrome *b* and did not affect the cyclic phosphorylations. The findings place the phosphorylation site in the span between reduced cytochrome *b* and oxidized cytochrome *f* and suggest that cyclic electron flow occurs by interaction of a component between these cytochromes with the reduced form of the oxidant of photoact I.

Ion fluxes affecting chloroplast structure also result from electron flow and are closely related to the phosphorylation coupling mechanism. Amines and ammonia uncouple photophosphorylation and cause light-induced swelling of the plastids. The swelling results from water movement following uptake of chloride and cations. Although electron flow is accelerated by the uncoupler, phosphorylation is not inhibited until after a period roughly coincident with the duration of the water uptake. These observations lead to the conclusion that electron flow is more closely related to ion movements than to esterification of phosphate.

Bacteriochlorophyll-Protein Complex of Green Photosynthetic Bacteria

Large ($\approx$0.5-mm-long) rod-shaped crystals of chlorophyll-protein from *Chloropseudomonas ethylicum* were grown from solution in 1 *M* NaCl and 0.01 *M* phosphate buffer (*p*H 7.8) by slow dialysis against 5% $(NH_4)_2SO_4$ in NaCl-buffer. From single-crystal x-ray diffraction the unit cell dimensions were found to be $a = 193 \pm 3$ Å, $b = 99 \pm 1$ Å, $c = 56 \pm 1$ Å, and $\beta = 60° \pm 10'$. A twofold screw axis of symmetry is parallel to *b*. The unit cell belongs to space group $P2_1$ (or higher monoclinic) and contains 2 or 4 macromolecules (42 ± 2 or 84 ± 4 bacteriochlorophyll *a* groups). Studies of the optical properties of the crystals have been initiated to determine the arrangement of the chlorophyll groups.

The acid denaturation of the chlorophyll-protein in solution has been studied. Bchl-P_0, the native form with a far-red absorption band at 809 mμ, is rapidly converted to Bchl-P_1, which has lowered absorptivity at 809 mμ. Addition of five

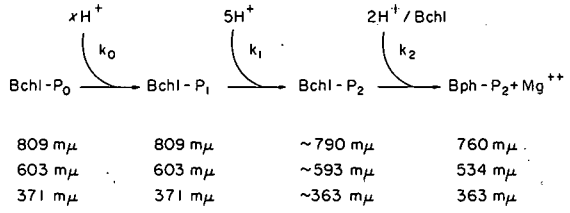


Figure 4. Denaturation of the chlorophyll-protein from *Chloropseudomonas ethylicum*. Modification of the native form of the protein, Bchl-P_0, proceeds stepwise in acid as indicated. The shift in light absorption bands in the conversion of Bchl-P_1 to Bchl-P_2 presumably reflects exposure of chlorophyll to the solvent. The final shift in absorption bands reflects removal of magnesium from chlorophyll.

hydrogen ions converts Bchl-P_1 to Bchl-P_2, which has a far-red band at $\approx$790 mμ. The shift in band is presumably due to the exposure of the chlorophyll groups to the solvent. Finally, removal of magnesium from the chlorophyll leads to the bacteriopheophytin protein (Bph-P_2) with its band further shifted to 760 mμ.

Two *c*-type cytochromes from *Cps. ethylicum* have been purified by ion exchange chromatography. Cytochrome-551.5 appears to lack aromatic amino acid residues, since there is no 280-mμ band in the absorption spectrum. Cytochrome-555, on the other hand, shows a typical protein spectrum. Both cytochromes are involved in photosynthetic electron transfer reactions in the intact cell.

GENERAL PHYSIOLOGY

Radiation-Induced Aging

The decrease in the life expectancy of animals caused by radiation closely resembles the natural aging process. Work in past years has shown a close correlation in the mouse between both natural and radiation-induced aging on the one hand and the development of mutations in the somatic cells on the other. This has led to the somatic mutation theory of aging, and evidence favoring this theory has been accumulating steadily. Recently it was shown that dogs accumulate aberrations in the chromosomes of liver cells at a much slower rate than do mice and have a correspondingly longer life-span. In genetic work with mice, it has been shown that chromosome stability is an inherited character and probably contributes importantly to the genetic component of aging. Work with certain strains of mice has shown that some genetic characters, e.g., leukemia susceptibility, are not correlated with chromosome stability. For these and many other reasons it is evident that mutations play an important, but not exclusive, role in aging. A composite theory of aging has been formulated which correlates a great deal of information on aging, including many findings that have been thought to contradict each other.

Injury and Recovery in the Intestinal Tract Following Irradiation

That the gastrointestinal tract in mammals is radiosensitive is well known. The most sensitive component of the tract is the mucosa lining the small intestine. Although extremely radiosensitive, the mucosa has a remarkable potential for repair. In current work the temporal relation between injury and recovery of the mucosa was examined following fast neutron irradiation in the rat. The irradiated animals and pair-fed controls were injected with tritiated thymidine (1 μCi/g). Autoradiographs of intestinal crypts isolated from the first, middle, and last tenth of the small intestine were made and used to determine grain count, mitotic index, and labeling index. In the same regions, the crypt size and concentration of nitrogen and water were estimated. Severe inhibition of proliferative activity was observed by 6 hr postirradiation at all doses (200, 300, and 400 rads). Recovery began by 12 hr, and the mitotic index, but not the labeling index, returned to the control level by 24 hr. In the 200 and 300-rad groups, the values of mitotic index, crypt cell count, and labeling index exceeded the values found in the control animals by the fourth day. At all doses, the irradiated animals had a higher mucosal water content and lower nitrogen concentration than the controls. For both nitrogen and water, the differences between irradiated animals and controls were maximum at 24 and 48 hr postirradiation. The first tenth of the small intestine appeared to be the slowest to recover from the irradiation and showed the highest correlation between dose and injury.

In a parallel study, the significance of lysosomes in radiation injury was investigated. Lysosome fractions were isolated from the intestinal mucosa of the rat at different times following exposure of the animal to 800 rads of x rays. The protein concentrations paralleled changes in the mucosa mass, reaching minimum values on the third day, with indications of recovery by day four. At the same time, β-glucuronidase activity increased to four times the control value, while that of acid phosphatase increased to 1.5 times. The enzyme activities varied independently following irradiation. Maximum activities corresponded in time to the onset of the repair process.

The Mechanism of Action of Insulin

The best-known result of insulin action is an increase in the rate at which glucose is removed from blood and metabolized by cells. This result was recognized about 40 years ago and can be seen in muscle and fat tissue incubated with glucose and insulin *in vitro*. At first, the interpretation was that insulin changes the activity of hexokinase, an enzyme that converts glucose to glucose 6-phos-

phate; next, that insulin facilitates passage of free glucose across the cell membrane to the site at which hexokinase acts; and still later, that insulin causes some other change in the cell which indirectly affects the processes indicated and results in increased glucose uptake. At present it is thought that insulin interferes with the accumulation of the intracellular messenger called cyclic 3′,5′-adenosine monophosphate. This intracellular messenger accumulates in some cells as a result of the presence of epinephrine (and certain other hormones) in the circulating blood. It has been demonstrated in adipose tissue *in vitro* that lipolysis (the hydrolysis of fat to free fatty acids and glycerol) is stimulated by epinephrine via the accumulation of cyclic 3′,5′-adenosine monophosphate and that insulin opposes this accumulation. Thus the influence of insulin on the activity of hexokinase may be a fifth- or sixth-order effect that proceeds via (a) the messenger, (b) decrease in concentration of intracellular free fatty acid, (c) phosphofructokinase inhibition, (d) accumulation of glucose 6-phosphate, and, finally, (e) relief of hexokinase activity from partial inhibition. Facilitation of glucose transport across the cell membrane in heart muscle *in vitro* is a very fast (in seconds) response to insulin that may not depend on reversal of cyclic 3′,5′-adenosine monophosphate accumulation and, in fact, may be taken as evidence of a change that precedes the reversal. An effect of insulin action in liver is similarly rapid and is the opposite of that caused by epinephrine: insulin, in seconds, causes liver to decrease the rate of release of K^+ to blood; epinephrine, in seconds, causes an increase in the rate. An important question is the location (whether in or close to the cell) of the insulin molecule when these rapid effects appear. Experiments that may answer the question are in progress. In these experiments a modified technique involving fluorescent antibody (against insulin) is being used.

Porphyrin Compartments in the Duck Erythrocyte

The ubiquitous presence of nonheme porphyrin in animal tissues raises the question of the function of this material other than as a precursor of heme. In earlier work bearing on this question, it was possible to isolate two protoporphyrin fractions with notably different specific activities from duck blood incubated *in vitro* with a labeled porphyrin precursor. This finding suggests that duck erythrocytes contain a number of protoporphyrin compartments. In the present work, the labeled precursor is given to the intact animal and the time-course of the specific activity of erythrocyte porphyrin fractions is followed. Initial results suggest the presence of at least two porphyrin compartments in the circulating erythrocyte. The porphyrin in one turns over rapidly – label appears in the porphyrin shortly after administration of the precursor and then disappears rapidly. The porphyrin in the other compartment may not be subject to replacement – label appears in the porphyrin slowly but is retained throughout the lifetime of the cell. Although the presence of porphyrin compartments in the circulating erythrocyte does not establish function for the porphyrin, the compartments do represent a cellular complexity in keeping with such a possibility.

Material Transfer

The problem of molecular traffic through limiting membranes of living cells has concerned biologists for many years. Some features of such transfer processes are now better understood because of the insight afforded by a simple mechanical theory of material transfer through membranes and by concepts provided by the rapidly developing discipline of the thermodynamics of irreversible processes. These theories predict circulation of a chemical current in purely chemical systems – systems composed of two or more membranes or other barriers of different permeabilities separating aqueous homogeneous phases of different chemical compositions arranged in a closed circuit. Tests of such a system indicate that such chemical currents do occur and that the current is proportional to the logarithm of the concentration differences, as is indicated by theory. Unlike the electric current in a closed electric circuit, the chemical current does not vanish on opening the circuit. In the open-circuit condition the system mimics biological systems in which secretion and absorption are presumed to occur. Furthermore, the closed-circuit systems demonstrate that the observable movements within the living cell, called protoplasmic streaming, can be thought of as visual evidence of the chemical and electric currents circulating through regions of the limiting membranes that have different sets of permeability coefficients.

A system designed to increase understanding of the phenomena of bioelectricity has also been examined. It consists of saturated solutions of salt in mixed neutral solvents in contact through a Milli-

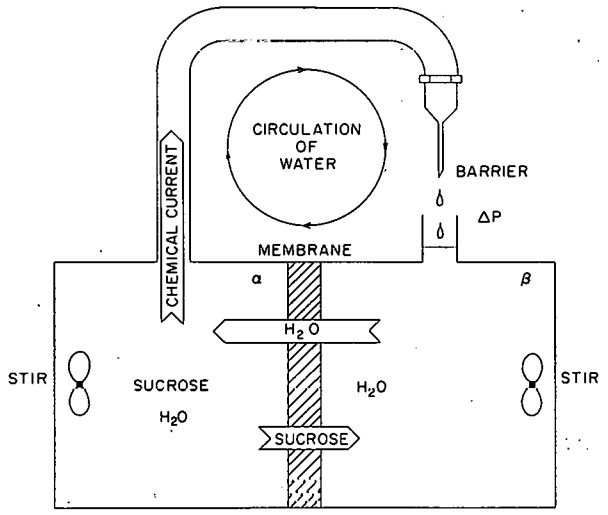


Figure 5. Diagram illustrating a chemical circuit in which circulation of water occurs.

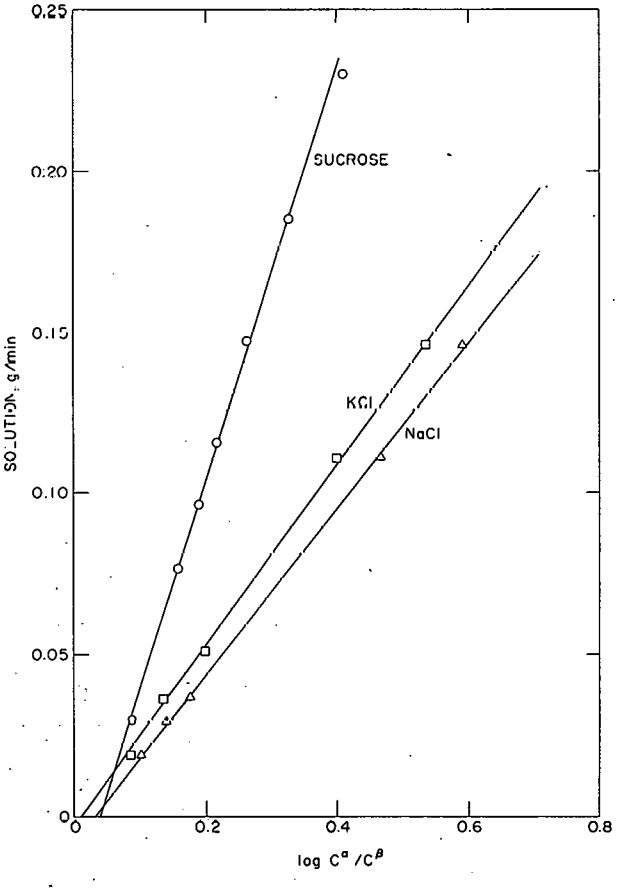


Figure 6. Rate of flow of water across a barrier as a function of the difference between the concentrations of material in phases α and β.

pore filter. When suitable reversible electrodes are placed in the terminal homogeneous phases, electromotive forces, as predicted by theory, of up to 50 mV or so are easily obtained. The electromotive force in these systems can be said to be due solely to the nonequilibrium of neutral molecules across the barrier. These results are of interest to electrophysiologists because little research has been done on the role of neutral molecules in the production of electrical activity by living tissues.

MOLECULAR BIOLOGY

Genetic Transformation of Pneumococcus

Prior work indicated that newly introduced transforming DNA is in the form of single strands and small fragments and suggested the hypothesis that a deoxyribonuclease inside the cell binds and hydrolyzes one strand of the incoming DNA and thereby draws the other strand into the cell. A deoxyribonuclease of the expected specificity has now been isolated from pneumococci. The enzyme is similar to the phosphatase-exonuclease of *Escherichia coli*, which preferentially attacks double-stranded DNA to give rise to single strands and 5′-deoxymononucleotides. The phosphorus of the small fragments produced from donor DNA in transformation, according to earlier work, is in the form of 5′-deoxynucleotides (20% of the total phosphorus), inorganic phosphate (40%), and a phosphate ester tentatively identified as L-α-glycerophosphate. This suggests the action of a 5′-deoxynucleotidase on initial products: enzyme activity corresponding to such a nucleotidase has now been demonstrated in pneumococcal extracts. The glycerophosphate may well originate from inorganic phosphate, since inorganic phosphate taken up by pneumococci was found to equilibrate rapidly with an internal pool of L-α-glycerophosphate comparable in size to the free phosphate pool. The new findings do not prove the hypothesis, but they make the proposed mechanism of entry of transforming DNA more plausible.

New information regarding integration of donor DNA in the recipient cell has been obtained from studies on the kinetics of recovery of introduced marker activity (following its eclipse on entry) at various temperatures and for various markers in the amylomaltase locus. Recovery of single-site markers, which at 30° or 37° appears to follow first-order kinetics, can be shown at lower temperatures to involve multiple reactions. Multisite

markers (identified by genetic analysis) show a lag in recovery even at higher temperatures. At a given temperature the recovery rate for all single-site markers is the same and is distinctly faster than that found for multisite markers. The latter also recover activity at identical rates, regardless of the length of the multisite segment involved. In addition to pointing out a difference between the mechanisms of recovery of single-site and multisite markers (an additional reaction step may be required for the latter), the observed phenomenon provides a useful way of identifying short multisite markers that heretofore could not be so characterized.

Genetic Determination of Protein Primary Structure

A promising approach to understanding the mechanism of gene action is the study of mutationally altered gene products such as proteins. It is now established that the amino acid sequence of proteins is specified in a precise and collinear fashion by the nucleic acid base sequence of corresponding genes, each triplet of bases determining a single amino acid. The composition of base triplets coding for the various amino acids can be deduced, in conjunction with other studies, by inducing known base changes in a gene specifying a protein and determining the resultant amino acid substitutions in the protein product. The histidine *D* gene–histidinol dehydrogenase protein system of *Salmonella typhimurium* is well suited for such a study, since it readily yields mutants susceptible to genetic analysis and produces a protein characterizable at the amino acid level. Histidinol dehydrogenase, from a mutant that overproduces this enzyme constitutively, has been purified to homogeneity both by classical techniques of protein fractionation and by ion exchange chromatography and gel filtration. Work on the physical and chemical characterization of the wild-type enzyme is being initiated. Concomitantly, *hisD* mutations are being produced by mutagens causing specific base changes in DNA. A detailed analysis of amino acid substitutions in the enzyme resulting from induced forward and reverse mutations, together with high-resolution mapping of the *hisD* mutant sites, will help delineate more completely the "vocabulary" of the genetic code.

Source of T7 Bacteriophage DNA

Bacteriophage T7 consists of a single molecule of DNA wrapped in a protein coat. Purified phage is remarkably stable under a variety of conditions, yet only about half the particles are infective. Since it is unlikely that infectivity is lost during purification, the possibility that some of the inactive particles might contain pieces of host DNA wrapped in phage protein was examined. Host cells grown in a medium containing N^{15} and H^2 were transferred to unlabeled medium and, after various periods of growth, were infected with unlabeled T7 phage. The progeny phage were isolated and the extent of labeling of their DNA was analyzed in a CsCl density gradient. The analysis showed that 85 to 95% of the phage DNA is derived from the nucleotides of the host DNA but that very few, if any, intact pieces of host DNA are wrapped in phage coats. Therefore the majority of the inactive phage particles do not represent host DNA. The results raise the question of how infective phage so efficiently degrades and utilizes host DNA for production of its own DNA.

Intracellular Development of Bacteriophage ϕX174

For study of the replication of the tiny bacteriophage ϕX174, an amber mutant (recently isolated and characterized at California Institute of Technology by C.A. Hutchinson, III) offers the advantage, when it is grown in its restrictive host, of yields of intracellular components that are high compared to those obtained with wild-type phage. Initial experiments with this mutant revealed a component with a lighter buoyant density in CsCl and lower specific infectivity than the mature phage particle. Infection with wild-type phage under the same conditions did not yield the lighter component. The particle contains single-stranded DNA which after extraction is infective to protoplasts. The protein component of the particle, however, differs from that of the usual phage coat: more than half the protein associated with the particle is composed of subunits that are smaller than the principal subunit comprising the phage coat. The relationship of the light particle to mature phage is under further examination. The replicative form of the mutant phage has physical properties similar to those of the wild-type material, that is, the double-stranded DNA exists as a ring and upon denaturation gives rise to several forms that differ in equilibrium density in CsCl. The increased yields afforded by the mutant have allowed preparation of labeled replicative material in sufficient quantity for study of the nature of the differences between the physically distinct forms.

Pancreatic Enzymes

In order to learn how the pancreatic acinar cell protects itself from self digestion, the chemistry and intracellular distribution of pancreatic trypsin inhibitors is under study. A trypsin inhibitor isolated from bovine pancreatic juice has been shown to be homogeneous by amino acid analysis, ion exchange chromatography, equilibrium ultracentrifugation, and acrylamide gel electrophoresis. The polypeptide has a molecular weight of 6153 and the following amino acid composition: Asp_7, Thr_4, Ser_2, Glu_7, Pro_4, Gly_5, Ala_1, Cys_6, Val_4, Met_1, Leu_4, Tyr_2, Lys_3, and Arg_3. Although two trypsin inhibitors have been isolated from acid extracts of the gland, only one (Kazal type) is present in the secretion. This suggests that the inhibitors are segregated at the subcellular level in the pancreatic acinar cells. The distribution of trypsin inhibitors within the various compartments of the cell is being studied in order to elucidate their physiological role.

Structure and Function of Enzymes

Previous work has shown that an effective way to determine functioning groups in an enzyme is to use a specific reagent that combines substrate structure with a chemically reactive group in a single molecule. The resultant pseudosubstrate has the potential of combining irreversibly at the enzyme's active center and permitting identification of the altered residue. As applied to the enzyme trypsin, the chloromethyl ketone derived from N^{α}-tosyl-L-lysine (substrate) provided a reagent known as TLCK, which showed that a histidine residue was essential for function. A procedure was developed for chromatographic purification of the alkylated histidine derivative, which proved to be a 3-substituted imidazole. Kinetic study of the reaction of TLCK with trypsin demonstrated saturation behavior, which confirmed the existence of an intermediate enzyme-reagent complex preceding alkylation. The D isomer of TLCK and some related reagents were synthesized for study.

Although L-TLCK reacts uniquely at a histidine residue in trypsin near neutrality, below *p*H 5 histidine is less involved and reaction occurs at at least one other site during inactivation. This finding makes it clear that TLCK is a reagent for trypsin and not for histidine. Similarly, thrombin, an enzyme with a specificity similar to that of trypsin and for which TLCK thus also represents a rational active-center reagent, is inactivated by TLCK, but histidine is not the site of alkylation.

To locate the TLCK alkylated histidine residue in the primary sequence of trypsin, a method of degradation of the enzyme is being developed which will serve also for clarification of other chemical modifications of trypsin under consideration. Progress has been made on a procedure for the isolation of the N-terminal portion of the enzyme (through residue 43) containing the functional histidine residue.

Protein Structure

Interactions between amino acid side-chains largely determine the folding of the polypeptide backbone in enzymes and define patterns of specificity and mechanism of action. An understanding of the manner in which stable conformations of the side chains in particular regions of the structure are developed is of considerable theoretical and practical importance. The problem requires a variety of approaches that include chemical modification of side-chains, physical or chemical perturbation of side-chain interactions at the enzyme surface, and examination of variations in structure among enzymes of the same specificity that derive from different biological sources.

These approaches are being applied in the study of several enzymes of the exocrine pancreas. Modification is exemplified by kinetic studies of the reactivity of certain amino groups in bovine ribonuclease A toward several reactive aryl fluorides and of the manner in which this reactivity may be influenced by changes in conformation of the protein and by structural variations in the reagents. The three reagents 1-fluoro-2,4-dinitrobenzene (I), 4-fluoro-3-nitrobenzene sulfonic acid (II), and 4-fluoro-3-nitrophenyl-trimethyl ammonium chloride (III) differ in the charge of the substituent *para* to the reactive fluorine atom and are neutral, anionic, and cationic, respectively. These reagents display comparable reactivities toward model peptides, and in fact all modify the terminal amino group of ribonuclease in the anticipated manner. Yet contrasting behavior is exhibited in relation to internal amino groups. While reagent I rapidly reacts at both lysine-41 and lysine-7 (the numbers indicate the position of the amino acid in the sequence of 124 residues), II fails to attack at lysine-7, and III reacts extremely slowly, if at all, at either lysine residue. Moreover, the products formed by modification at lysine-41 by reagents I and II are inactive. Extensive reaction of the en-

zyme with reagent III leads to only a slight loss of functionality. These observations are most simply interpreted in terms of electrostatic effects and preferred orientation of interaction of the reagent molecule with the surface of the enzyme. They lend support to the concept that the environment of the side-chains of lysine-7 and lysine-41 is positively charged. Further evidence is provided by the results of kinetic measurements at different *p*H values of the reaction of ribonuclease with reagent I. These show that modification of lysine-41 is controlled by a group with a dissociation constant of 8.8, a value about one order of magnitude smaller than would be expected for a normal lysine side-chain and attributable to the presence of a positively charged group within a radius of 6 to 8 Å.

Determination of Macromolecular Structure by x-Ray Diffraction

Equipment for data collection from single crystals of macromolecules has been developed and installed. Specifically, small, efficient, end-window proportional counters have been developed which are packed in arrays for multiple-reflection recording. Development of small scintillation counters is nearing completion. Preliminary studies have also been made of solid-state detectors under development by the General Electric Company. A unit for holding crystals at constant low temperatures during data collection has been installed. Meanwhile the diffractometer and rotating-anode x-ray generator have been tested by collection of data for $C_3O_2S_3$, a novel sulfur-organic compound; the structure has been determined by a direct phasing method and is being refined. Data for a second small structure are now being collected. A survey of possible isomorphs of modified chymotrypsin has continued. Space groups and unit cells of several other compounds, including a chlorophyll-protein complex and an algal tetrapyrrole, have been obtained.

Medical Research

In developing its research program, the Medical Department has several responsibilities. It has the broad responsibility to advance medical knowledge and the more specific responsibility to advance understanding of the effects of ionizing radiations in man. Some of the investigations are directed toward beneficial applications of these radiations and toward improvement of measures to prevent or counteract their detrimental effects. Other investigations are centered on elucidation of disease states and development of improved methods of diagnosis and therapy. Investigations in these two areas complement each other, since the study of radiation effects contributes to the understanding of diseases, and vice versa, yet the pace of progress in both is controlled by the advances in knowledge of the normal biological processes of man.

A great influence on these advances is the rapid development of new techniques for the examination of structures and mechanisms at the molecular as well as the subcellular and biochemical levels of organization. Information revealed through these techniques and with the aid of such instruments as the electron microscope, dictates re-examination of medical and biological phenomena at even finer levels of organization. Findings from such investigations present the Department with the additional responsibility to exploit them for clinical applications.

The diversified talents and extensive facilities uniquely concentrated at Brookhaven provide the Department with unusual advantages for pursuing its objectives. Its broadly based program incorporates the experience and skill not only of those devoted to research in the field of medicine but of many from the various disciplines in other Departments and from collaborating institutions. The interchange of ideas, information, facilities, and services is essential for the staff to keep abreast of the new developments that have medical implications, and within the framework of the program opportunities are limited only by the scope of the vision and interest of the individual investigator.

Thus, in its role of service to Associated Universities, Inc., to the Atomic Energy Commission, and to the medical community, the Department's primary responsibility is the assemblage of talented scientists capable of elucidating biological phenomena at the finest level of organization and experienced physicians capable of relating these researches to clinical studies.

Specific examples of research under way are given in the following pages. The report is not comprehensive, and the reader may obtain additional information from publications of the Department.

EFFECTS OF RADIATION

Medical Studies of Marshall Islanders Accidentally Exposed to Radioactive Fallout in 1954

During the past three years abnormalities of the thyroid gland have been detected in a number of people of Rongelap Island who were accidentally exposed to fallout in 1954. Other late effects observed with reasonable certainty include increased incidence of miscarriages and stillbirths among the exposed women during the first four years after exposure, lag in complete recovery of the peripheral blood cells, and slight retardation in growth and development of boys <5 yr of age when exposed.

Definite nodules of the thyroid gland have been noted in 16 exposed people. Hypothyroidism has been diagnosed in two additional cases. All but one case occurred in the more heavily exposed population (55 now living of the original group of 64). Children exposed at <10 yr of age accounted for $\approx 80\%$ of these thyroid abnormalities. The nodules in five children were removed and proved to be benign adenomatous nodules closely resembling goiter of iodine deficiency. Two cases of thyroid nodules were seen in adults. One, in an adult woman in the less heavily exposed group (14 now living of the original 18), was nonmalignant. The other was a mixed papillary and follicular carcinoma with localized metastasis.

The radiation etiology of the thyroid lesions in the exposed group appears to be reasonably certain. Iodine deficiency goiter is not likely, since dietary iodine is believed to be adequate in these

islands. In addition, there are no goitrogenic foods in the diet of these people. The thyroid glands had received substantial doses of radiation from radioiodines and external gamma radiation (the exact total dose is uncertain, but it is estimated to have been about 300 rads for adults, and for small children about 700 to 1400 rads). None of the 61 children in the unexposed comparison population in the same age range showed thyroid abnormalities, although two older adults in this unexposed population of 200 had nodules.

A hypothyroid etiology for growth retardation noted in the boys in the exposed group is strongly suggested by the recent findings of hypothyroidism in two of the most retarded boys. Recent growth response to thyroid hormone supports this hypothesis.

The Response of the Skin of Swine to Increasing Single Doses of Ionizing Radiations

The objective of this study has been to determine, by using the skin of swine as an *in vivo* radiobiological test system, the effects of increasing single doses of x rays, thermal neutrons, and fission neutrons and the thermal neutron capture of the B^{10} reaction [$B^{10}(n,\alpha)Li^7$].

During the degenerative phase after exposure, the nuclear volume of the basal cells increased by a factor of about 2.5, while the nuclear volume of the prickle cells increased by a factor of 5.5. In the regenerative phase, the nuclear volumes were 1.5 times as great as those of the controls at 21 days and were the same as the control values at 35 days. At 21 days the mitotic index of the regenerating islands was 5 to 6 times as great as the control value; however, at 28 days it was at the control level. During the degenerative and regenerative phases the capillary diameter increased progressively and was 2.5 times the control diameter at 35 days.

The dose responses to the different radiations may be compared by determining the dose at which 50% of the irradiated fields are not healed at 49 days following single-dose irradiation. This 50% dose was estimated to be 2390 rads for 250-kVp x rays, 950 rads for fission neutrons, 1500 rads for thermal neutrons, and 1000 rads for the $B^{10}(n,\alpha)Li^7$ reaction.

Figure 1. Five patients from Rongelap Atoll in the Marshall Islands, shown with their interpreter and a BNL staff member at the Research Hospital, where they received clinical examination and treatment. Nodules in their thyroid glands appear to be the result of exposure to fallout radiation from a nuclear detonation at Bikini in 1954. The nodules were detected during the regular annual medical survey of the islanders.

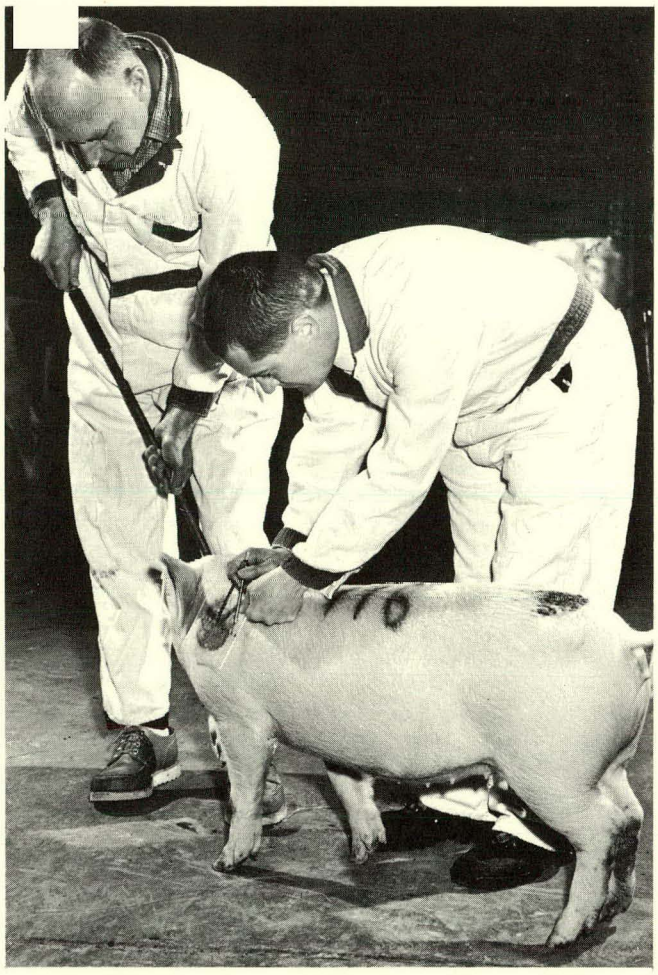


Figure 2. Documentation of the evolution of the skin lesion produced following increasing doses of radiation was obtained at regular intervals by direct measurement and photography.

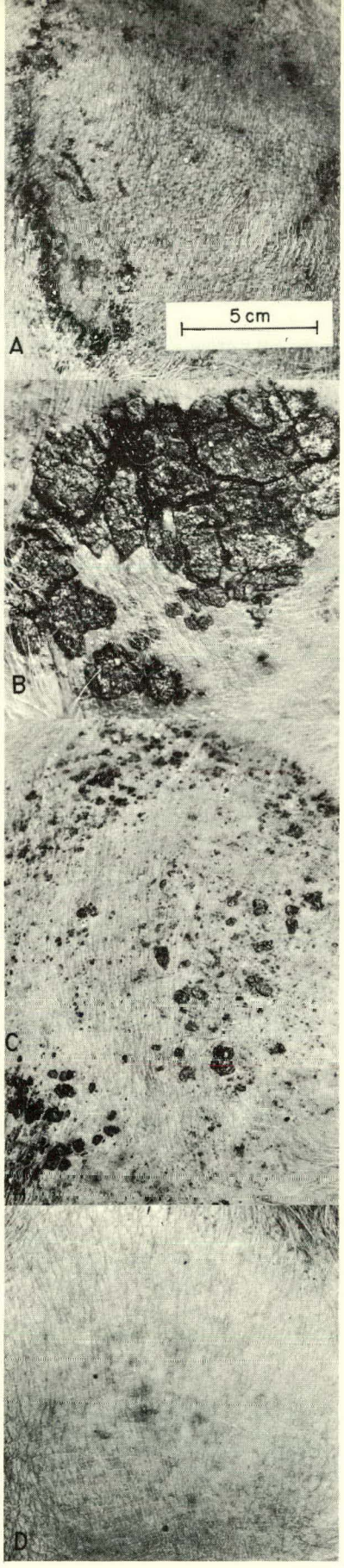


Figure 3. Evolution of a moist reaction that healed following irradiation. The moist reaction seen at 17 days (*A*) involved 50% of the irradiated field at 27 days (*B*). This area of involvement subsequently healed, and at 49 days (*C*) there were only scattered crusts beneath which the skin was intact. At 117 days (*D*) the skin was soft and well healed.

Lens Opacification in the Mouse

In current work on radiation-induced lens opacification in the mouse, posterior subcapsular opacities (visible 7 weeks post irradiation) and anterior polar opacities (not seen before 14 weeks post irradiation) have been followed as separate response systems for 12 to 15 months post irradiation. Results show continuously progressive opacification in either lens location from doses as low as 0.5 rad of 0.43-MeV neutrons, 1.0 rad of 14-MeV neutrons, or 24 rads of 250-kVp x rays. They do not confirm a "stationary phase" or "plateau" in development, suggested by earlier work here and the published findings of other investigators. It appears that such apparent arrest of opacification is probably an artifact of the necessarily arbitrary visual "scoring" scale employed, and difficult to avoid. Radiation-induced anterior and posterior opacities differ markedly in character, but each continues to be indistinguishable from opacities forming in the counterpart area in aging control animals.

The relative biological effectiveness (RBE) of 0.43- or 1.80-MeV neutrons compared with that of 250-kVp x rays appears to be markedly dose dependent, the RBE being about 10 at 100 rads of neutrons and increasing to $\approx$50 for 1 rad of neutrons. The 0.43-MeV neutrons are slightly more effective than those of 1.80 MeV in producing posterior opacities, but about equally effective in the induction of anterior opacification. This fact, considered with the approximate halving of the above figures to obtain the RBE's for anterior opacity induction, points to the existence within one organ of two systems differing markedly in radiation response.

Kinetics of Growth of Spleen Nodules in Irradiated Mice: Anomalous Decrease in Number With Time Post Irradiation

If mice receive uniform x-ray exposures to the whole body of 750 to 1000 R, their spleens show little or no regeneration during the following two weeks. If, however, the exposure is reduced or the mice are protected by injecting donor marrow cells post irradiation or shielding a part of the bone marrow during irradiation by shielding part of a leg or the tail, their spleens show discrete, rapidly growing colonies of nodules, which may be readily seen and counted on or after the eighth day post irradiation. Nodules resulting from injection of bone marrow are known to be clones of hemopoietic cells, i.e., each colony arises from a single injected marrow cell which reaches the spleen. If steady growth of such clonal nodules is assumed, the number of countable nodules above any given threshold size should show a progressive increase on successive days. This expectation is confirmed in the case of protection with injected marrow, but not when whole-body exposure is reduced or the tail is shielded. In the latter cases marked decreases in nodule counts were found. Figure 4 illustrates an experiment in which 600-R whole-body irradiation was given to 14-wk-old female mice of the hybrid strain C3H $\times$ 101. As may be seen, the numbers decrease from day to day with a 10-fold over-all decrease, while the median size increases. In an otherwise similar experiment that included a group on day 11 as well as on day 8, the expected increase in size was found, but no change in number. Thus it appears that most of the nodules seen on the fifth day in this example are destined to disappear by the eighth day, and that the remainder continue to grow. In a similar way, experiments with males of the C3H $\times$ 101 and BNL Hale-Stoner strains receiving 750 R

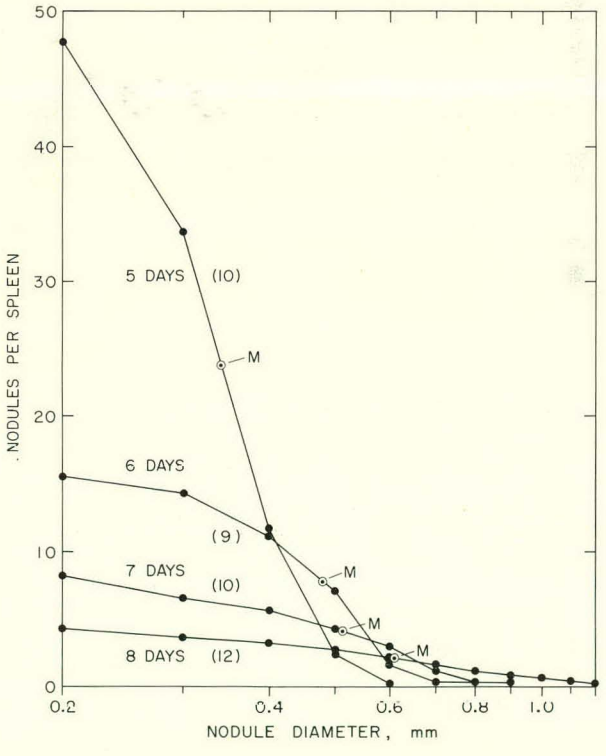


Figure 4. Plots of average number of nodules per spleen vs smallest size counted on successive days following whole-body x-irradiation. Figures in parentheses indicate number of mice per group; M = median size, 50% count.

with tails shielded have shown approximately 3-fold decreases with time.

An attempt is being made to ascertain whether the disappearing colonies in these instances are hemopoietic, and, if so, whether they consist predominantly of cells of the red or white series, and of what degrees of maturity. One possibility is that such colonies never contain any self-renewing cells but that each originates from a single cell which is already committed to differentiation, so that the colony matures and, as the cells are released into the blood, disappears.

Fourteen patients with acute myelocytic leukemia have been treated with ECIB. Leukemic cells in the peripheral blood were reduced in all cases, with a spectrum of clinical response ranging from no apparent effect to prolongation of life for up to 18 months. Several patients were treated after chemotherapy was no longer effective, and life was extended several months. One patient was treated with ECIB during pregnancy in order to avoid chemotherapy, and subsequently delivered a normal child.

Five patients with chronic myelocytic leukemia were treated with ECIB, all except one after ex-

Figure 5. Patients receiving extracorporeal irradiation of the blood.

CLINICAL AND METABOLIC STUDIES

Clinical Studies With Extracorporeal Irradiation of Blood

Extracorporeal irradiation of the blood (ECIB) has been used to treat acute myelocytic leukemia, chronic myelocytic leukemia, and chronic lymphocytic leukemia. The technique involves the placing of a semipermanent arterio-venous shunt in the forearm of a patient, and subsequent intermittent diversion of the blood stream past a 4000-Ci Cs^{137} gamma-ray source. Advantage is taken of the difference in radiosensitivity between leukemic white blood cells and erythrocytes.

tensive chemotherapy. There was a marked decrease in immature granulocytic cells in all patients. The spleens of 3 patients decreased in size but remissions have been relatively short, lasting only 1 to 2 months.

Six patients with chronic lymphocytic leukemia have been treated with ECIB. All showed a decrease in peripheral lymphocyte counts, although there was variability in the rate of response. Spleen and lymph node size decreased in several patients, and an improvement of hemoglobin and platelet levels was noted.

Patients with severe renal disease requiring kidney homotransplantation have been treated with

ECIB, before and after surgery, to reduce the number of circulating immunologically competent lymphocytes. These cells are reduced in number, but evaluation of the clinical response is not yet complete.

Mechanisms of Salt-Induced Hypertension

Several years ago, by selective inbreeding, two strains of rats were evolved that differ markedly in their response to techniques commonly used for the experimental induction of high blood pressure: one strain rapidly develops severe and often fatal hypertension from stimuli that are generally ineffective in the other strain. Studies are continuing in an effort to define the basic differences in the strains that account for these genetically determined dissimilarities in response. The kidney has long been considered to play a central role in the pathogenesis of hypertension; furthermore, it is required for the elimination of salt and water. For these reasons studies of renal function have been initiated. Glomerular filtration rate and renal plasma flow were similar in animals from both strains before and during the early phases of hypertension; however, some evidence suggests that the strain resistant to developing hypertension may maintain its ability to concentrate solutes better than the other strain. The excretion rates of sodium and water after acute oral loading were found to be similar in the two strains. Given a free choice of either saline solution or water to drink, rats from the strain with genetic predisposition to hypertension ingested less saline solution than did those from the other strain; no ready explanation is at hand. However, all the foregoing may indicate differences in hormonal regulation rather than in excretory capacity *per se.*

Genetic characterization of the strains continues. The reciprocal cross has been completed, and a backcross is now in progress and should be completed within the next 12 months. The use of various forms of psychological stress to induce hypertension has not been successful, although there is modest evidence to suggest that "stress" may exaggerate pre-existing hypertension. The technique of parabiosis is now being used to study differences in response between the strains.

In clinical studies, estimation of the biological half-life of Na^{22} in patients has been concluded. This study shows that the previously observed prolonged biological half-life of Na^{22} in patients with

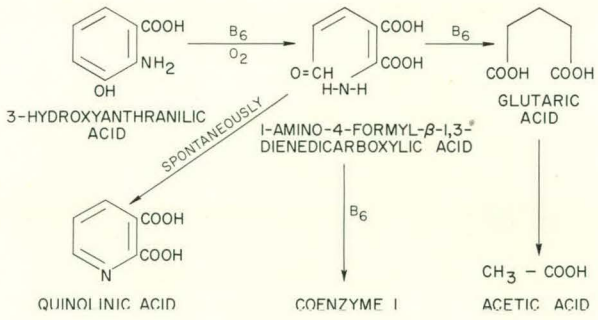


Figure 6. Metabolic pathways hypothetically requiring vitamin B_6.

hypertension is not a consistent phenomenon and cannot be used as another index of the disease. One group of observers reported recently that blood lactic acid was increased in hypertensives; preliminary data suggest that this may be true, although there is no direct correlation with blood pressure levels.

On the basis of clinical and experimental evidence, it is proposed that essential hypertension may be an "inborn error of metabolism," in this instance related to sodium.

Vitamin B_6 as Related to Quinolinic Acid Production in Man

The very high level of quinolinic acid found by urinalysis in a patient with microcytic hypochromic anemia was found to be depressed after administration of vitamin B_6 to the patient. To determine whether a relationship existed between vitamin B_6 and quinolinic acid, a study of the effects of vitamin B_6 deficiency on urinary quinolinic acid levels in the human was initiated. Six male subjects were studied during a 55-day experiment. The urinary levels of quinolinic acid and nicotinic acid were measured during a control period, during depletion of vitamin B_6, and when vitamin B_6 was returned to the diet. The urinary levels of these metabolites were determined before and after the subjects were given a 2-g loading dose of L-tryptophan. The quinolinic acid levels were significantly elevated during vitamin B_6 depletion and returned to control levels when vitamin B_6 was administered. Thus a relationship was established between vitamin B_6 coenzymes and the further metabolism of quinolinic acid or the metabolism of 3-hydroxyanthranilic acid, the precursor of quinolinic acid.

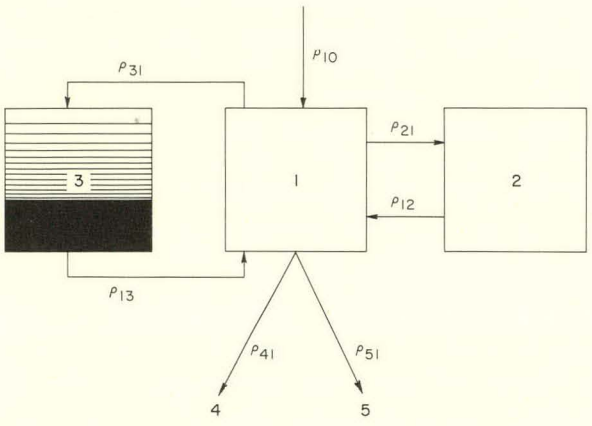


Figure 7. Compartmental model of calcium kinetics. Compartment (1): physiological pool of calcium in isotopic equilibrium within 1 hr (plasma-extracellular-intracellular). Compartment (2): physiological pool of calcium in isotopic equilibrium within 3 days (exchangeable bone). Compartment (3): calcium in "deep bone" or very slowly exchanging bone. The transfer constants, ρ, are designated as follows: ρ_{10}, calcium intake rate; ρ_{12}, calcium flow rate into compartment (1) from exchangeable bone; ρ_{21}, calcium flow rate into exchangeable bone from compartment (1); ρ_{13}, rate of resorption and slow exchange from bone; ρ_{31}, rate of accretion into bone; ρ_{41}, urinary calcium excretion rate; ρ_{51}, fecal calcium excretion rate.

Melanin Metabolism in Parkinsonism

The fact that melanin deposition in the brains of Parkinsonian patients is scanty has led to an effort to improve the clinical state of these patients by correcting this biochemical defect. Small amounts of the melanin precursor dihydroxyphenylalanine (DOPA) had been injected into such patients by others, who reported transitory improvement of the dyskinesia occurring in this disease. These early reports were disputed by later work, and the matter seemed closed. At BNL, administration of large oral doses of DL-DOPA to Parkinsonian patients has led in several instances to a marked amelioration or disappearance of tremor, rigidity, dyskinesia, and other signs of Parkinsonism. The improvement occurred a few hours after reaching optimum doses (4 to 16 g/day), whereas the return of the syndrome following abrupt interruption of the dose occurred 4 to 14 days later. Analyses of blood manganese were performed on these patients because of the aforementioned links between manganese and melanins. In some instances a marked fall in this value could be demonstrated following administration of DOPA. Plateaus were reached only after the life-span of one generation of red cells had elapsed. This was understandable, since most of the blood manganese is red cell manganese and incorporation of the metal in red cell heme had been demonstrated earlier at BNL. Hence, DOPA was intercepting the metal during its transport from the plasma to the blood-forming organs. Consequently the possibility that DOPA is a ligand that competes with plasma proteins for manganese was investigated. A method was adopted that permits sedimentation of plasma proteins with minimal contamination by exogenous manganese. These studies have confirmed that plasma manganese is almost entirely bound to proteins. The primary protein fraction binding this metal is a β_1 globulin. It was shown that, in contrast to some nonaromatic amino acids, phenylalanine and dihydroxyphenylalinine compete for this metal with the plasma proteins. The mechanism by which this competition takes place seems to be sequestration by the amino acid, but this has not yet been proved.

Kinetics of Calcium and Strontium Metabolism

A multicompartmental type of analysis was used to describe strontium metabolic data in both men and rats. The compartmental sizes and transfer constants and their standard deviations were obtained with a computer program. The values of the various parameters obtained with Sr^{85} were very similar to those previously obtained with Ca^{47} in man over a 10-day period of study. Differences in the rate of bone turnover as measured by calcium and strontium tracers were noted in longer-term data obtained by the whole-body counting technique. Quantitative examination of the variability of the observed data from the calculated values indicates that the model approximates strontium metabolism in both men and rats and is consistent mathematically and compatible with known physiological constants. Quantitative differences in the values of the calculated parameters per unit body weight were observed between men and rats. In particular, the transfer constants derived from the rat kinetic data were considerably larger than those obtained from the human kinetic data.

Both the compartment sizes and transfer constants were shown to vary markedly as a function of age. Studies of the effect of age on strontium and calcium kinetics were extended to include infants and children. Enriched Sr^{84} and Ca^{46} have

been administered to them, and the calcium and strontium in their plasma and excreta determined by neutron activation analysis with use of the Medical Research Reactor and the Brookhaven Graphite Research Reactor. The various parameters of skeletal metabolism were computed with use of the above program.

Determination was made of the radiation dose to the body from a quantity of injected Thorotrast because of the potential carcinogenic action of this x-ray contrast medium. The integral dose to the critical organs (liver and spleen) over 15 to 25 yr was calculated on the basis of an *in vivo* gamma spectrometric measurement. Whole-body counter measurements were made in Lisbon on 18 patients with Thorotrast burdens, and their gamma spectral data were analyzed by computer. A computer program was used to calculate the theoretical *in vivo* relationships between Th^{232} and its descendants as a function of time. Thus the initial amount of Th^{232} was deduced from the spectrometric measurements of the Ac^{228} and Tl^{208} daughters at any given time. After determination it was possible, by referring to the calculated time pattern of the Th^{232} decay scheme, to determine the activities of each of the daughters over the time period following administration and to sum these to obtain an average dose to the liver and spleen. The complex decay scheme of Th^{232} and the resultant dynamic relationship involving equilibrium, altered by the different metabolic patterns of distribution and excretion of the daughters, introduce a high degree of variability into the analysis. Despite this, the method appears most promising, and efforts will be made to further refine it.

Studies With Radioisotopic Carbon and Hydrogen of Disorders of Intermediary Metabolism of Carbohydrates and Fats

Further studies of the capacity of diabetic and obese patients to convert glucose-1-C^{14} to $C^{14}O_2$, when the labeled carbohydrate is added to an oral load, have suggested that measurement of this $C^{14}O_2$ in the exhaled carbon dioxide 1 to 2 hr after ingestion can provide an effective index of early or minimal impairment of glucose tolerance. More recently such patients have been compared with matched normal control subjects for extent of conversion of glycerol-1,3-C^{14} to $C^{14}O_2$ of the breath. Diabetic and/or obese patients oxidized this carbohydrate only ½ to ⅓ as rapidly as the normal group, which gives further information on the extent and nature of the disturbance in carbohydrate metabolism. The C^{14} of the glycerol was converted more extensively to blood glucose in the diabetic patients. Administration of glucose and insulin has been shown to correct the abnormal metabolism of the labeled glycerol.

The transfer of tritium from glycerol-2-H^3 to fatty acids of the liver of obese and lean mice *in vivo* has been found to occur to the same extent as that from DL-lactate-2-H^3 and succinate-2, 2′-H^3. All these precursors appear to be much better donors of tritium (and presumably hydrogen) for reduction of fatty acid intermediates than certain other labeled carbohydrates (glucose-1-H^3 and DL-malate-2-H^3) which were theoretically predicted to be better sources of such metabolic hydrogen. All the C^{14}- or H^3-labeled precursors show a similar extent of higher incorporation (5- to 8-fold) into the liver fatty acids of obese, hyperglycemic mice compared with that of lean siblings. Fasting and then refeeding markedly stimulates incorporation of all labeled precursors into fatty acids in lean mice but not in obese mice.

Additional studies of the action of cortisone to increase incorporation of some of these H^3- and C^{14}-labeled carbohydrates into the blood glucose and liver glycogen of rats *in vivo* show that such an effect can be noted (with labeled lactate and malate, for instance) within 2 to 4 hr after intraperitoneal administration of cortisone, but it is less marked than after 4 days of such treatment daily. As with earlier long-term dosage, the incorpora-

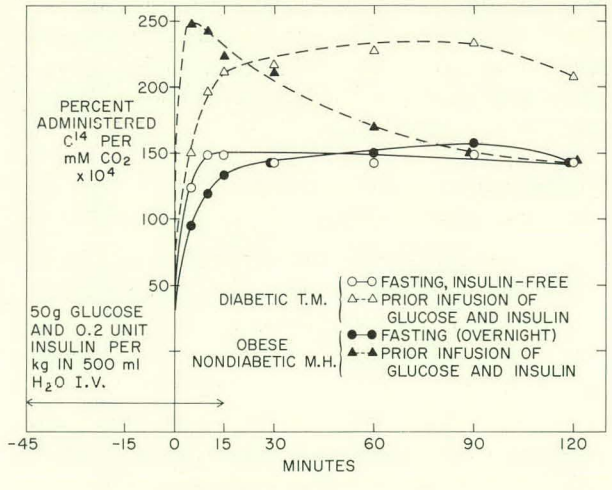


Figure 8. Specific activity of breath $C^{14}O_2$ after intravenous injection of a trace amount of glycerol-1,3-C^{14}.

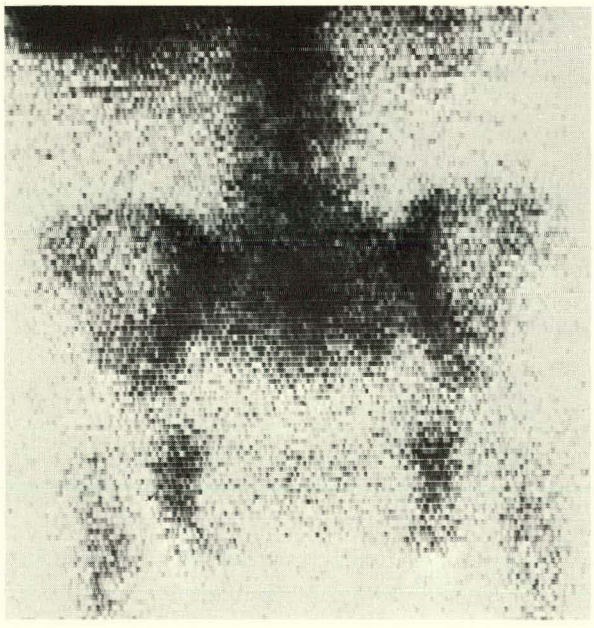


Figure 9. Normal marrow distribution as shown by scanning of technetium-99*m* colloid.

tion of H^3- or C^{14}-labeled glycerol or succinate is not stimulated within short time periods after cortisone administration.

The effect of ethanol on gluconeogenesis has been further investigated by determining the amount of tritium in rat liver glycogen and the relative intensity of labeling of different positions of glucosyl residues after administration *in vivo* of trace amounts of ethanol-1-H^3. The amount of tritium found suggests relatively close coupling between oxidation of ethanol and reduction of glucose intermediates. The position labeling suggests that oxidation of ethanol proceeds through coenzyme systems also utilized for oxidation of lactate and possibly glycerol.

Clinical Use of Technetium-99*m* as a Scanning Agent

Technetium-99*m* as pertechnetate can be used to evaluate thyroid function, and the state of the "trapping" mechanism in the thyroid measured with this isotope appears to correlate well with other tests of thyroid function. A simple measurement, the "trapping index," is determined from continuous recording over the neck for 15 to 20 min following an intravenous injection of the pertechnetate. Actual thyroid uptake of technetium is determined from the scan by comparison with a phantom standard. The advantages of using Tc^{99m} rather than I^{131} are that the results are obtained with one visit by the patient and the radiation dose is considerably lower, $\simeq$0.5 rad for 2 mCi of Tc^{99m} compared with 5 rads for 10 μCi of I^{131}. Newer data-blending techniques have been developed which make it possible to obtain good scans in a reasonable time even with very low uptake in the gland, such as occurs after suppressive medication.

Evaluation of bone-marrow scanning with a technetium-sulfur colloid is under way. Newer methods of colloid formation and stabilization are being studied in order to simplify the procedure, make sterilization of the product more certain, and possibly improve localization in the marrow.

The blood clearance and urinary excretion of a technetium–iron ascorbate compound have been studied. Between 10 and 20% appears to localize in the kidneys, primarily in the cortex. Excellent renal scans have been obtained following administration of this compound. An attempt will be made to evaluate renal function with this material.

Computer Applications

The CDC 6600 digital computer recently acquired by the Laboratory is being used in the development of several computer programs used in conjunction with medical research projects and for medical records. Among the new programs are several connected with the problem of determining the amounts of two radioactive labels present together in tissue or blood samples in double tracer experiments. Another program is concerned with calculating the radiation dose to the spleen and liver in patients who received injections of thorium 20 years or so ago, the input data being derived by whole-body counting. Still another is used in determining proton and meson ionization spectra in connection with biological experiments performed with the use of beams at the Cosmotron. As part of a collaborative project with the Submarine Medical Center at Groton, Connecticut, theoretical studies directed toward developing improvements in the Navy diving decompression programs are being conducted. Previously initiated programs in current use include that for calculation of the radiation dose distribution pattern in extracorporeal irradiation of blood. Recent modifications of the program take into account the effects of prolonged interrupted treatments, with the rate of renewal of red cells being affected by the radiation.

NUCLEIC ACID STRUCTURE AND FUNCTION

Factors Affecting the Stability of the Double Helix of DNA

The x-ray diffraction patterns of fibers of many specimens of deoxyribonucleic acid (DNA) change reversibly with change of water content of the fibers. For crystallization of the *A* form, 75% relative humidity (r.h.) was optimum, whereas at 92% r.h. and above, the semicrystalline *B* form was observed. Some specimens, however, remained in the *B* form at all humidities – an anomalous behavior attributed to impurities in the DNA. The *A–B* reversible conformational change in the 75 to 92% r.h. range was thought to be a property of pure sodium DNA, but recently many samples of sodium DNA have been found that retained the *A* form at 92% r.h. or even at 98%. Studies on DNA samples taken from preparations made over a period of many years have now shown that the change in structure from the *A* to the *B* form in sodium DNA depends on the presence of salts as well as on increase of relative humidity, and that a salt-free sodium DNA does not change its structure with increasing relative humidity.

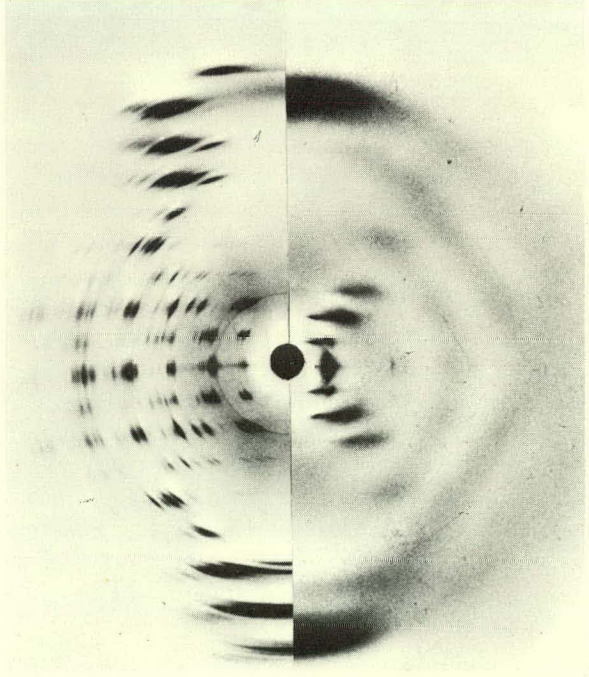


Figure 10. X-ray diffraction photograph of calf thymus DNA (sodium salt). Left: *A* conformation at 75% relative humidity; right: *B* conformation at 92% relative humidity.

X-ray diffraction patterns from fibers of the complex of Daunomycin (an antibiotic) and DNA are less well defined than those from DNA but allow an approximate value for the pitch of the helix to be determined. When the content of the drug in the fiber was 1 molecule per 8 base pairs, the pitch of the DNA helix was 41 rather than its normal 34 Å; for 1 molecule of Daunomycin per 4 or 5 base pairs, the pitch became 48 Å. These observations can be explained if it is assumed that the planar tetracyclic ring of the Daunomycin intercalates between adjacent base pairs, stretching the DNA molecule by 3.3 Å per insertion of 1 molecule of drug, and uncoiling the helix at the point of insertion by about 24°. The radius of the molecule complexed with Daunomycin was slightly less than that of native DNA. Preliminary model-building studies indicate that the tetracyclic ring of Daunomycin can be accommodated in the extended DNA molecule. The point of attachment of the amino-sugar to the tetracyclic group has not yet been established. However, it could probably be accommodated in either the large or small groove of DNA.

Preparation and Structural Analysis of Mammalian Ribonucleic Acids

Soluble ribonucleic acids (sRNA's) play a crucial part in protein synthesis. To study nucleotide sequences, some effort has first been concentrated on the preparation and analysis of RNA. For structural studies it is essential to have a technique whereby sRNA can be prepared in large quantities, free of contamination with other RNA's.

Standard methods for large-scale preparation of yeast sRNA, involving purification by DEAE-cellulose chromatography, were found unsuitable when applied to mammalian tissue. Approximately ¼ of the nucleic acid could be accounted for by ribosomal RNA and DNA contamination. A new method for large-scale preparation of sRNA from animal sources has been devised in which contamination with other RNA's and DNA is minimized. Final purification is achieved with Sephadex G-200 chromatography by using a 7-liter column and eluting with potassium acetate. The preparation has twice the amino-acid acceptor activity of yeast sRNA and appears homogeneous when analyzed with the ultracentrifuge, by gel electrophoresis, and chromatographically. Liver sRNA purified by this method is at least as pure as yeast sRNA prepared by standard meth-

ods, it has no measurable DNA, and ribosomal RNA contamination is $<0.2\%$.

Preliminary work on nucleotide sequences indicates that purified, unfractionated liver sRNA and yeast sRNA show some minor differences in primary structure; they also differ in content of some unusual nucleotides such as pseudouridylic acid and methylcytidylic acid.

Radionucleoside Incorporation by Thymidine-Synchronized Cells

The incorporation of specific DNA precursors, radioactive nucleosides, by HeLa S3 cells at various times after release from excess thymidine treatment has been studied to provide information about the competence of thymidine-synchronized mammalian cells. Tritiated deoxycytidine (H^3-CDR) is incorporated without delay, which provides unequivocal evidence that 90 to 95% of the cells are in S phase (DNA synthesis) at the time of release from thymidine blocking. Tritiated thymidine (H^3TDR) and 5-iodo-2′-deoxyuridine (I^{125}-DU) incorporation are markedly inhibited for ≈ 2 hr after release from thymidine treatment. A pool of thymidine derivatives is established during treatment with high concentrations of thymidine which effectively competes with H^3TDR or I^{125}DU. Since the pool size has a significant effect on labeling of DNA, certain restrictions must be imposed on the use of radioactive thymidine or deoxyuridine in pulse-chase experiments with thymidine-synchronized cell populations. A period of growth (2 to 3 hr) in medium without thymidine is essential before maximum incorporation of H^3TDR or I^{125}DU can be demonstrated. Cells grown in medium containing 2 mM thymidine are blocked in S phase, but DNA synthesis continues at a limited rate for several hours. After release of the cells from blocking, DNA synthesis is completed within 3 to 4 hr. The onset of a mitotic burst is, invariably, apparent at about 6 hr post release, and peak mitosis (35 to 40% mitoses) occurs at 8 hr. A study of the distribution of labeled mitoses shows that a small percentage of cells is in late S phase at the time of release from thymidine blocking.

The Effect of Ionizing Radiation on Cell Survival

The thymidine analogue iododeoxyuridine (IDU), labeled with gamma-emitting iodine isotopes, provides a convenient means of determining the viability of cells, since it is incorporated only into newly formed cells and disappears only when they die. A significant fraction of IDU given to mice is incorporated into liver, kidney, muscle, and other cells having a life-span >600 days. The effect of ionizing radiation on such cells depends on the interval between labeling and exposure, i.e., on the age of the irradiated cell. Exposure to 300 R of x rays 2, 5, 8, 16, and 24 hr after labeling killed 45, 45, 40, 12, and 10%, respectively, of the cells (5-day old mice). The life-span of cells surviving 1 month was unaltered. X rays given 1 month after labeling had no effect on cell survival. X rays given 6 months after labeling had no immediate effect on cell survival, but the average life-span was reduced by 15% after a single exposure to 400 rads of Co^{60}, and by 25% after three such exposures (6-month old mice).

Compensatory Enlargement of the Kidney

The mechanisms that regulate the sizes of organs of the body are not understood. The mouse kidney provides a useful system for the investigation of this problem because removal of a single kidney can be accomplished with minimal injury to the animal and provides a growth stimulus to the remaining kidney which is quite uniform from one animal to the next.

For many years it was thought that the compensatory growth of the kidney was the result of an increase in the mean cytoplasmic mass of the functional cells, or hypertrophy, as occurs in the heart muscle, for example, when its work load is increased. More recently the regulatory mechanism, whatever it may be, has been thought to operate through control of synthesis of the genetic material, deoxyribonucleic acid (DNA).

In order to compare these two hypotheses, the increase in kidney mass has been measured by determining the increase in dry weight and the rates of incorporation of amino acids into protein and of cytidine into ribonucleic acid (RNA). The cell proliferative activity has been calculated from the fraction of functional cells synthesizing DNA at a given time, the index of synthesis. The absolute increase in the size of the cell population is determined by integrating the index of synthesis over the elapsed time. Cellular hypertrophy is gauged by the increase in organ mass in excess of that required by cell proliferation.

These indices show that hypertrophy begins within the first 2 hr following nephrectomy, whereas acceleration of DNA synthesis is delayed for

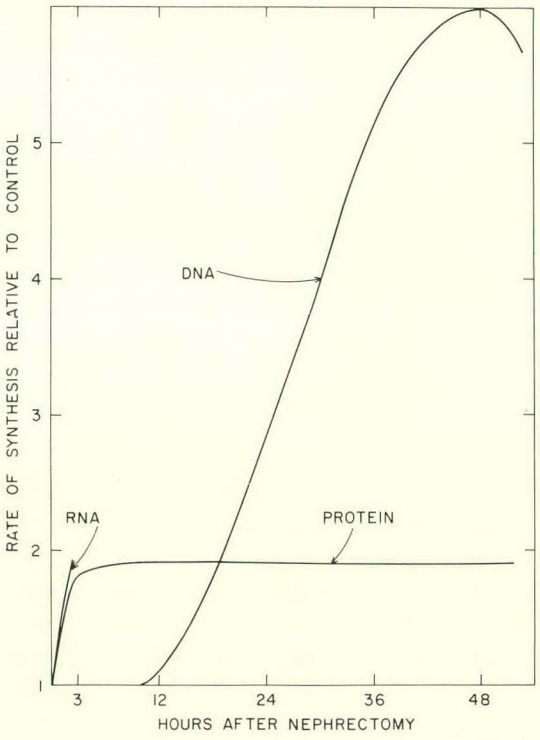


Figure 11. Early sequence of events in the remaining kidney after contralateral nephrectomy. Rates of synthesis of RNA, protein, and DNA are based upon rates of incorporation of H^3-cytidine, C^{14}-leucine, and H^3-thymidine, respectively.

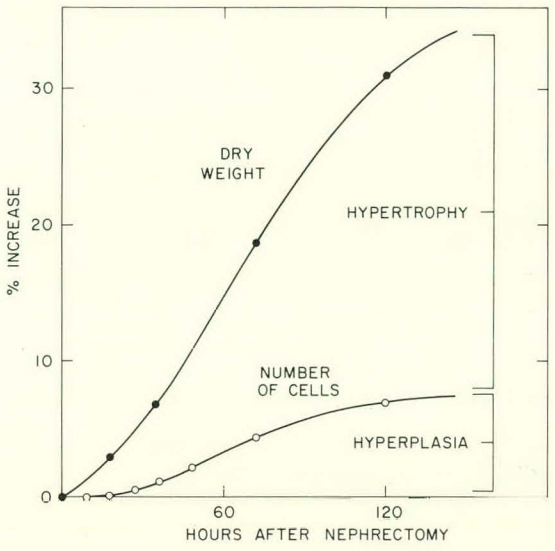


Figure 12. Relative contributions of hypertrophy and hyperplasia to the increase in kidney mass. The increase in cell population size is calculated from

$$N_t/N_0 = \exp\left[(1/t_s)\int_0^t \Delta I_s dt\right],$$

where N_t is the number of cells at time t, t_s is the duration of DNA synthesis, and I_s is the fraction of cells labeled autoradiographically by H^3-thymidine.

>18 hr. At 72 hr after operation, hypertrophy accounts for >75% of the increase in organ mass. It appears that the initial response to the growth stimulus is an increase in mean cell mass, and that DNA synthesis and cell division are secondary phenomena which do not directly mediate the control of compensatory growth of the kidney.

ANTIGENS AND ANTIBODIES

Lymphocyte Transformation

Phytohemagglutinin transforms small lymphocytes into large pyrinophilic blast cells; the transformation is accompanied metabolically by synthesis of RNA and protein and eventually by DNA synthesis. Approximately 90% of guinea pig lymphocytes from lymph nodes are susceptible to transformation by phytohemagglutinin. In 5- and 6-day cultures in which only the minimal essential medium and horse serum were used, spontaneous transformation of guinea pig lymphocytes into large blast pyrinophilic cells was not seen. Fetal calf serum caused transformation, although to a much lesser extent than phytohemagglutinin. Thus, the spontaneous transformation described in published results may be due to stimulation of lymphocytes by foreign protein.

Clumping is an important factor in ensuring transformation when using phytohemagglutinin with guinea pig lymph node cell cultures. If the lymph node cells are prevented from clumping after exposure to phytohemagglutinin, they do not transform; i.e., clumping is a necessary part of the transformation process. On the other hand, neuraminidase (sialidase) clumped guinea pig lymphocytes but did not transform them as did phytohemagglutinin. Sensitized guinea pig lymphocytes are also transformed by specific antigens, e.g., *Trichinella*; clumping is a necessary part of this transformation response also. Nonsensitized lymphocytes that did not transform also failed to clump in response to the specific antigen *Trichinella*. Therefore, clumping of lymphocytes by itself does not appear to be sufficient to initiate blast transformation but does appear to be a necessary part of the transforming process.

In lymphocyte transformation resulting from use of phytohemagglutinin the effect is independent of previous exposure of cells to phytohemagglutinin. In contrast, after exposure to a specific antigen only 5 to 15% of lymphocytes are transformed *in vitro*, and this only in a population of cells previously specifically sensitized to the antigen tested. In the absence of previous specific sensitizations, there is no transformation by antigen. Preliminary evidence suggests that these transformed cells are responsible for the ability to transfer delayed hypersensitivity to the same antigen from sensitized donors to normal recipients.

Cytokinetics of Lymphoreticular Tissue During the Secondary Antibody Response

Radiation-induced repression of antibody formation is intimately associated with lymphoid cellular elements involved in the synthesis of antibody. Proliferation of lymphoid cells becomes evident in regional lymph nodes of mice during the secondary antibody response to tetanus toxoid in *de novo* formation and rapid growth of germinal centers.

Tritium-labeled thymidine, cytidine, and DL-leucine were used in an autoradiographic study of lymphoid cells during the latent phase of the secondary response, i.e., before the sharp rise in titer of serum antibody. When H^3-cytidine was given intravenously, an increased initial labeling intensity of a limited number of small lymphocytes ($<1\%$ of all lymphoid cells) was seen in regional lymph nodes a few hours after booster injection of tetanus toxoid.

This labeling increased before the appearance of large lymphoid cells heavily labeled with tritiated cytidine. Both changes largely reflect RNA synthesis, since a significant rise of initial labeling after injection of H^3-thymidine was not evident at this time. These findings indicate an early increase in RNA synthesis in a fraction of lymphoid cells after booster injection of antigen. This event is paralleled but not clearly preceded in time by an intensified incorporation of H^3-DL-leucine.

There was a significant increase in the initial labeling index of large lymphoid cells after H^3-thymidine labeling during the second day after injection of antigen. The observed increase coincided with the appearance of small germinal centers prior to the rise of serum antibody titers. An increased proliferation of plasmoblasts and immature plasma cells occurred $\approx$1 day after detectable new formation of small germinal centers and paralleled the rise in serum antibody titers. Large plasmocytoid cells appeared in greater numbers from day 3 on, along with a gradual rise in serum antibody. The relative numbers of mature plasma cells increased on day 5; maximum proliferation of germinal centers and plasmocytoid cells subsided on day 6 as the serum antibody elevated to peak titer. These experiments are being extended to study radiation-induced repression of antibody responses in mice.

The Immune Response of Lymphocyte-Depleted Animals

Attempts were made to abolish the primary response of calves and rats to fluid tetanus toxoid by depleting the animals of lymphocytes prior to immunization. Calves were depleted by extracorporeal irradiation of the blood or lymph, rats by drainage from the thoracic duct.

The calves had primary responses in the range of, or somewhat lower than, those of controls. One rat had a diminished primary response; three had no primary response.

The results with rats are consistent with those in the literature implicating lymphocytes in the primary immune response. The results with calves appear contradictory. The following explanations are offered for the differences observed. Depletion procedures for calves differed from those used for rats; thus quantitative and qualitative differences in the depleted states are likely to appear. Rats were subjected to more stress than the calves, as the result of abdominal surgery, cage confinement, and the loss of protein as well as lymphocytes from the thoracic duct. Naturally acquired tetanus antitoxin is common in calves, rare in rats, which may have complicated these experiments. There may be species differences in the role of circulating lymphocytes in the primary response.

Immunological Mechanisms Studied With Extracorporeal Irradiation of Lymph

With continuous extracorporeal irradiation of thoracic duct lymph (ECIL) in cows, it has been possible to maintain allogenic skin grafts as long as irradiation was continued, when the grafts were placed in the drainage bed of the thoracic duct. Evidence has been obtained to show that this effect is caused by cell-bound, immunologically activated, small lymphocytes and not by non-cell-bound material. Lymphocytotoxic antibodies are

produced during the course of these experiments, but results indicate that they are not capable of initiating the allograft rejection process. These studies are being extended to include the renal allograft mechanism, with particular reference to the pathway of antigen stimulation of immunologically competent small lymphocytes, and preclinical studies of the effectiveness of this treatment for human renal homografts.

PROTEIN STRUCTURE AND FUNCTION

Synthesis of Insulin and Its Analogues

Insulin, a protein produced in the pancreas, is the principal hormone controlling carbohydrate metabolism in animals and humans. Lack of this hormone is the cause of diabetes. The synthesis of sheep insulin, accomplished some three years ago, was the first instance of chemical synthesis of a protein. Since the demand for insulin is steadily increasing and the supply from natural sources is not unlimited, the possibility exists that synthetic insulin may soon be needed to supplement insulin from natural sources. Immunological reactions are frequently encountered in the treatment of diabetic humans with insulin isolated from other animals. Thus, the need of synthesizing human insulin becomes apparent. This synthesis has now been accomplished at BNL. Both chains of human insulin have been made synthetically and subsequently combined to form human insulin. This represents the first synthesis of a human protein. One of the problems encountered in the chemical synthesis of insulin is the low yield obtained when the two insulin chains are combined. However, a method has now been developed by which insulin chains can be joined to form the complete protein in 60 to 80% yield. As a result of these accomplishments, work is under way to synthesize hybrid insulins (i.e., insulins consisting of chains belonging to different species) and insulin analogues. The possibility exists that synthetic analogues may be obtained which possess more desirable biological and immunological properties than the native hormone.

Hydroxylysine Formation and Collagen Synthesis in Scurvy

Hydroxylysine, $H_2N \cdot CH_2 \cdot CH(OH) \cdot CH_2 \cdot CH(NH_2) \cdot COOH$, is an amino acid found in the animal body only in collagen. Experiments in this laboratory have shown that all the hydroxylysine in collagen is formed by hydroxylation of lysine during synthesis of the collagen. Studies of the mechanism of the hydroxylation have yielded results that are consistent with the hypothesis that the hydroxylation occurs by incorporation of atmospheric oxygen into the lysine. Other theoretically possible mechanisms have been experimentally excluded, and it has been found that anaerobic conditions prevent the hydroxylation.

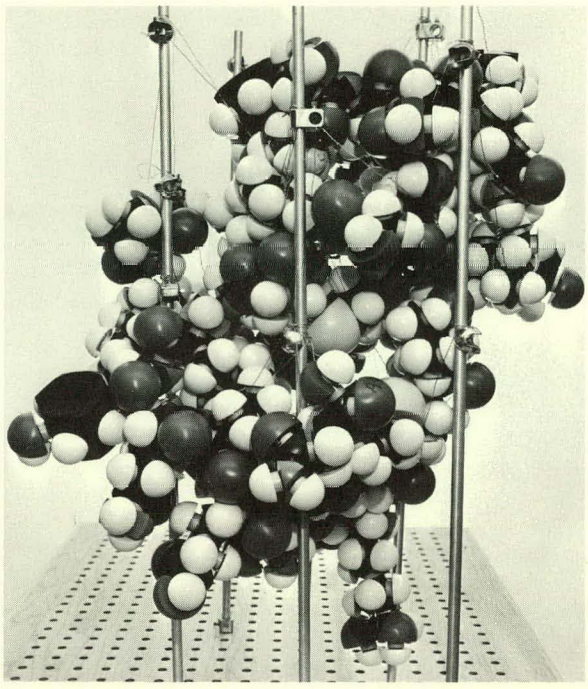


Figure 13. Molecular model of human insulin.

In other laboratories the mechanism of direct oxygen uptake from O_2 has been found to hydroxylate proline to form hydroxyproline, another amino acid that is unique to collagen. It has been shown that in the synthesis of collagen a precursor protein or peptide is first formed that contains proline, which in a later stage is hydroxylated to hydroxyproline.

In the tissues of guinea pigs made scorbutic by lack of vitamin C, collagen formation, either *in vivo* or *in vitro*, has been found to be retarded. The question of whether the retardation is accompanied by failure to hydroxylate proline has been studied by administering C^{14}-labeled proline and observing the ratio of C^{14} specific activity of hydroxyproline to the specific activity of proline in collagenous connective tissue, where the ratio

normally approaches unity. A failure to hydroxylate proline would be expected to decrease the ratio. Results from different laboratories have been conflicting.

Experiments in this laboratory on the incorporation and hydroxylation of both proline and lysine uniformly labeled with C^{14} into the purified salt-soluble skin collagen of control and scorbutic guinea pigs, have shown that, although the specific activity ratio of hydroxyproline to proline was slightly below 1.0 in both scorbutic and control animals, the ratio of hydroxylysine to lysine activity in the scorbutic animals was only half that of the controls. The results indicate that in the synthesis of salt-soluble skin collagen vitamin C deprivation has an effect on the hydroxylation of lysine that it does not have on the hydroxylation of proline.

Mechanisms Controlling Membrane Permeability and Transport Processes at the Cellular and Molecular Levels

The broad objective in these studies is the elucidation of hormonal and other mechanisms controlling membrane permeability and transport processes at the cellular and molecular levels. One aspect of the present program is concerned with the physiologic evaluation of changes in the chemical structure of selected neurohypophyseal hormones in order to identify groupings that serve as the sites triggering hormonal activity and other groupings that serve to bind and orient the hormone to its receptor. Another aspect of this work is concerned with study of the intermediate events in hormone action and their differentiation from the primary hormone-receptor interaction and/or the final effector process.

Studies by Kimbrough et al. on 1-deamino-8-lysine-vasopressin, by Cash and Smith on 1-*N*-acetyl-8-lysine-vasopressin, and by Zaoral on 4-asparagine-8-lysine-vasopressin have been confirmed and extended. 1-*N*-acetyl-8-lysine-vasopressin, an analogue of lysine-vasopressin (LVP) in which the terminal amino group is acetylated, was found to have $<1\%$ of the mammalian antidiuretic and uterotonic activities of LVP, to inhibit competitively the pressor activity of synthetic LVP and highly purified natural arginine-vasopressin (AVP), and to have reduced affinity for neurophysin, the presumptive physiologic carrier protein of vasopressin and oxytocin within the hypothalamo-neurohypophyseal system.

In sharp contrast, 1-deamino-8-lysine-vasopressin (1-β-mercaptopropionic acid-lysine-vasopressin), an analogue of LVP in which the terminal amino group is deleted, has higher mammalian antidiuretic activity than its parent hormone, although its mammalian pressor potency and its effect on amphibian membrane permeability are less than those of LVP.

Another striking deletion effect is observed in the case of 4-asparagine-lysine-vasopressin, an analogue in which the glutamine residue of the natural hormone is replaced by an asparagine residue, which shortens the amino acid side-chain in position 4 by one methylene group. This analogue at low dosage levels has a higher antidiuretic/pressor activity ratio than LVP or AVP; moreover, under the above conditions it has greater absolute antidiuretic potency than AVP, the most potent known natural mammalian antidiuretic hormone.

To evaluate the relative significance of structural changes in oxytocin at position 4 in relation to identical changes at position 5, the synthesis of a series of analogues has been initiated. Thus far 5-valine-oxytocin and 1-deamino-5-valine-oxytocin have been synthesized and purified. On study with several biological assay systems, both analogues have been found to have strikingly lower activity than their counterparts with the same structural alteration in position 4.

In addition, work is proceeding on identification of the precise arrangement in three dimensions of a neurohypophyseal hormone through the synthesis, crystallization, and x-ray crystallographic study of selenium and tellurium analogues of oxytocin.

In efforts to improve upon the Wilzbach method for random tritiation, synthetic work has been initiated to develop specifically labeled oxytocin and vasopressin analogues for high-resolution radioautography of target cells and for biochemical studies on cell fractions.

Bioenergetic Mechanisms Involving Free Radicals

Studies have been continued on the properties of free radicals that may be involved in many of the pathways of oxidative metabolism and in the chemical reactions giving rise to some of the effects of ionizing radiations on living systems. The stable forms of most organic compounds contain even numbers of electrons. Free radicals are half-oxidized or half-reduced forms possessing odd numbers of electrons. The magnetic moments associated with the spins of their unpaired electrons

make free radicals paramagnetic. This allows detection and analysis by the sensitive and nondestructive method of electron paramagnetic resonance (EPR).

Some of the results obtained with both rapid-flow and quick-freeze equipment during the year have provided much more extensive analysis of the labile free radical forms of a number of hormones, drugs, amino acids, and proteins. In several instances quite complete assignments of the distribution of unpaired electrons on the free radical molecules were achieved. From this, in turn, evidence was obtained that (1) in certain cases multiple forms of radicals can exist [e.g., the equilibrium between protonated and dissociated free radicals of dihydroxyphenylalanine (DOPA) or thyronine], (2) molecular conformations can be reflected in the interactions of labile free radical moieties with solvent (e.g., the restricted interaction seen with native insulin as opposed either to denatured insulin or to the more open and random conformation of casein), and (3) amino acid side-chains may be restricted in their rotation about the single bonds joining them to the α-carbon atoms (e.g., tyrosine radical anions or tyrosine residues of proteins).

In experiments with substituted thyronines, EPR results from continuous-flow and quick-freeze methods were combined with electrochemical analysis and with reaction-product analysis by thin-layer chromatography. From this it could be concluded that thyroid hormones are readily oxidized, that free radical paths may be followed, and that in the free radical forms the substituted iodines become labilized so that deiodination ensues. This may be the mechanism underlying thyroid hormone oxidation by "deiodinase" enzymes that have been reported recently; and the activation of halogens in the free radical state may also explain flavin-sensitized photodeiodination of iodothyronines, which has been a subject of some general interest.

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SUPPORTING ACTIVITIES

Technical Operations and Services

The technical services and facilities essential to the Laboratory's research programs are provided by a number of organizational units whose operations are described below under appropriate headings.

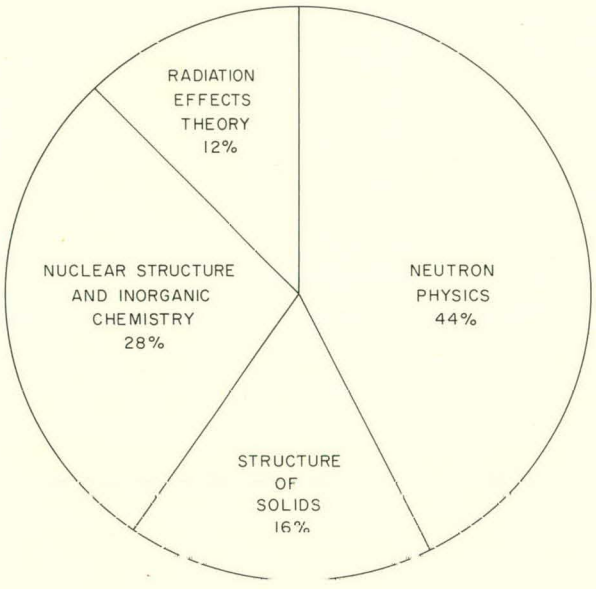
REACTOR OPERATIONS

High Flux Beam Research Reactor

The High Flux Beam Research Reactor (HFBR) achieved criticality for the first time at 20:34, October 31, 1965, after the 20th element had been loaded. The following day marked completion of the loading of the first core into this reactor.

During the latter part of 1965 a number of low-power tests were made to measure nuclear properties of the reactor that are independent of the power level. The reactor power was then increased in steps until a power level high enough to allow investigation of the reactivity transients produced by Xe^{135} could be made. As higher power levels were reached, the use of previously installed thermocouples and strain gauges made it possible to investigate some of the temperature and stress conditions on the vessel, particularly around beam-tube nozzles. The full design operating power level of 40 MW was attained on February 9, 1966, and further tests were conducted.

Figure 1. Experimental level of the HFBR.



Research Budget		Use Charges
Physics Department		
Neutron physics	$502,992	
Structure of solids	180,000	
Radiation effects theory	140,004	
		$ 822,996
Chemistry Department		
Nuclear structure and inorganic chemistry		320,004
Total		$1,143,000

Figure 2. Distribution of use charges for the HFBR, fiscal 1966.

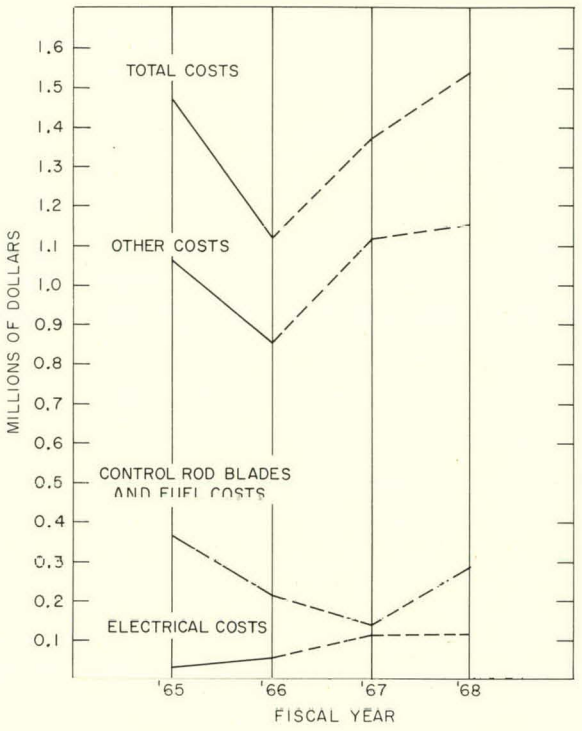


Figure 3. Costs associated with operating the HFBR.

April 8, 1966, marked the completion of the first fuel burnup cycle, and the 14 outer elements were discharged without difficulty. The reactor remained in a shutdown condition with only half of the core loaded throughout the rest of the month while plant modifications were completed and preparations made for the reactor dedication ceremonies during the week of April 19.

Prior to start-up, the reactor and its auxiliary equipment were subjected to various engineering tests designed to prove the operability of each system and the validity of the operating procedures. These tests also afforded the operating crews ample time to achieve mechanical competence in operating the equipment. The primary and experimental facilities systems were tested when filled with light water and then, after being drained and dried, when filled with heavy water.

Some major problems have developed during operation of the reactor. Most of them have been corrected or their solutions are known and corrective action will soon be taken. One exception is a slight rattle emanating from the reactor vessel or associated piping. To aid in determining the source of this noise, a periscope designed to allow observation of the vessel under full pressure and flow conditions is being procured.

Experimental Use. As soon as the reactor had reached a significant power level, several experimenters were able to commence useful beam experiments. Equipment continues to be added to the experimental level of the reactor (see Figure 1). The expected use of the reactor is reflected in Figure 2, which indicates the relative and specific costs to the research budgets for the operation of this reactor. The various categories of operating cost are shown in Figure 3.

The assignment of the experimental facilities and a brief description of the status of experimental apparatus follows.

Horizontal Holes

H-1: Polarized Neutron Experiment, Nuclear Cryogenics Group.
Several measurements of neutron beam quality have been made with use of collimators fabricated for this purpose. The fabrication of the collimator to be used regularly for this experiment is near completion. It is specially designed to bring two divergent neutron beams out of the reactor to two independent spectrometers. Installation of out-of-pile equipment and shielding is in progress.

H-2: Fast Neutron Chopper, Neutron Choppers Group.
Installation of the collimator, out-of-pile equipment, and shielding has been completed. The "chopped" neutron beam is enclosed in an aluminum pipe and is so well collimated that no shielding is required around the beam pipe. The detectors are located at the containment wall of the building. Experiments are in progress.

H-3: Capture Gamma Experiment, Nuclear Structure Group.
Fabrication of the collimator and out-of-pile shielding is almost complete. The standard reactor beam hole shutter has been replaced with one of special design which, together with the special collimator, will allow three neutron beams to be brought out for experiments.

H-4:* Dual Beam Experiment, Solid State Group.**
The collimator and out-of-pile shielding have been designed so that two divergent beams can be brought out of the reactor for the independent operation of two spectrometers. Fabrication of the equipment has been completed, and final installation will be made in the near future.

H-5: Powder Spectrometer, Solid State Group.
Installation of the collimator and out-of-pile equipment has been completed. Data are being taken on a routine basis.

H-6: Dual Beam Experiment, Solid State Group.
The collimator and out-of-pile equipment have been installed and the experiment is in progress. The second, or "satellite," spectrometer has also been installed and is in routine operation.

H-7: Triple-Axis Spectrometer, Solid State Group.
The collimator, shielding, and out-of-pile equipment have been installed. Routine operation of the spectrometer is now in progress.

H-8: Polarized Beam Experiment, Solid State Group.
Installation of the collimator shielding and out-of-pile equipment has been completed. Experiments are now in progress.

H-9: Slow Neutron Chopper, Neutron Choppers Group.
The installation of the collimator and shielding has been completed. Installation of out-of-pile equipment is almost complete. Operation of the experiment is expected soon.

Vertical Irradiation Thimbles

V-10: Foil Irradiation Facility.
Many foil irradiations were made in this facility in conjunction with the measurements of neutron beam quality made in some of the horizontal beam holes. Several sample irradiations have been made for the Chemistry Department.

V-13: HFBR Materials Surveillance Experiment.
This facility is used for the HFBR materials surveillance program. Irradiation of instrumented capsules containing samples of reactor construction materials is in progress.

*The experiments in holes H-4 to H-8 are programmed into a single computer which controls and collects data for all five spectrometers at the same time.

**This group is composed of experimenters from the Chemistry and Physics Departments.

Brookhaven Graphite Research Reactor

The Brookhaven Graphite Research Reactor (BGRR) duty cycle for the year was 73.2%. This constitutes 99.2% of scheduled operating time. There were 11 scheduled shutdowns for service and maintenance of the reactor and experimental equipment. Two additional scheduled shutdowns were made in conjunction with the annual Visitors' Days. Five unscheduled shutdowns of the reactor occurred during the year. Three were due to interruptions of incoming electrical power, one to a shift in the in-core position of an irradiation sample, and one to an error by the console operator.

In the graphite annealing program, a standard annealing operation was conducted during each of the scheduled shutdowns of the reactor. Periodic measurements of the width of the central air gap and of the net vertical displacement of the structure show the continued effectiveness of the an-

nealing program in reducing the radiation-induced growth of the graphite.

The exit-air bypass filter facility, consisting of absolute-type filters and activated charcoal beds for the removal of radioactive air contaminants, was made operational during the year and operating crews were instructed in the requisite procedures in the unlikely event that its use becomes necessary.

Routine inspections and audits by various Laboratory and outside groups again demanded a substantial portion of staff members' time. In general, the results of these inspections were favorable.

Utilization. The operating expense of the BGRR rose slightly during fiscal 1966 (see Figure 4) as a result of the purchase of new fuel and the shipment of spent fuel. The over-all budget limitations placed on the users have dictated drastic steps in cost-cutting, but the resulting inefficient mode of operation of the reactor and the drop in utilization of the facility have denied users the benefits of lower total costs. This spiral effect has resulted in plans for further reduction in the duty cycle, to be instituted at the start of fiscal 1968.

The use of the BGRR and associated charges for the last three years are summarized in Table 1. Approximately 30 experimental holes continue to be assigned to research departments of the Laboratory and to outside users. The work of the various BNL Departments is described in the appro-

Table 1

Summary of Reactor Use Charges

	Use charges (in thousands of dollars) 0 100 200 300 400 500 600 700	Percent of total usage	Dollar amounts
Fiscal 1966			
Outside Organizations		3.7	$ 31,835
Irradiation Service Group		3.9	33,000
BNL Research Departments:			
Physics		56.1	478,450
Chemistry		7.1	60,988
Nuclear Engineering		25.5	217,968
Biology		3.7	31,967
		100.0	$ 854,208
Fiscal 1965			
Outside Organizations		6.3	$ 69,967
Irradiation Service Group		3.6	40,226
BNL Research Departments:			
Physics		59.6	663,057
Chemistry		7.1	78,720
Nuclear Engineering		19.7	219,747
Biology		3.7	40,860
		100.0	$1,112,577
Fiscal 1964			
Outside Organizations		9.0	$ 108,952
Irradiation Service Group		4.0	40,992
BNL Research Departments:			
Physics		60.0	647,930
Chemistry		8.0	94,620
Nuclear Engineering		15.0	169,100
Biology		4.0	40,860
		100.0	$1,102,454

priate sections of this report. Research conducted by outside users is described briefly below.

1. Columbia University. In a cooperative program with the BNL Physics Department, the following investigations were made with use of the Columbia single-crystal spectrometer, which has an effective neutron energy range from 0.0006 to 10 eV: scattering of neutrons resulting from the motions of water molecules in various hydrates; neutron scattering study of the rotational motion of hexamethyl benzine and of polar molecules of *d*-camphor and ethylene dibromide; scattering of neutrons resulting from the motion of methyl groups and from segmental motion in a series of polymers; and the use of Thermica as a neutron monochromator.

2. Naval Ordnance Laboratory. In cooperation with the BNL Physics Department (Solid State Division), diffraction studies were made by using single crystals and a polarized beam of neutrons.

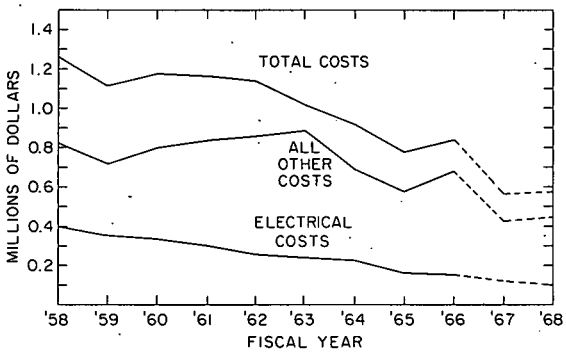


Figure 4. Costs associated with operating the BGRR.

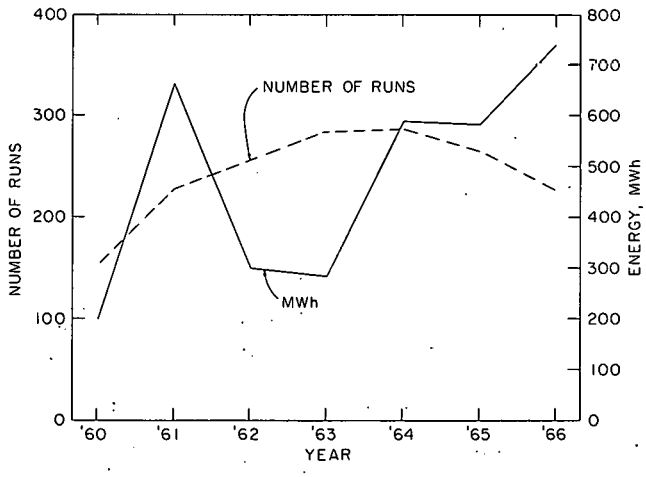


Figure 5. Use of the MRR.

In addition, powdered magnetic materials were studied with the use of a powder diffractometer.

3. General Electric Company. Most of the materials studied during the past year by the Neutron Diffraction Group on its neutron spectrometer have been intermetallic compounds containing transition and/or rare-earth atoms. The main interest has been in elucidating the magnetic structure, i.e., the spatial arrangement of the spins associated with transition or rare-earth atoms. The following have been investigated: the magnetic structure of Mn_3Rh, Y_2Co_{17}, $HoCo_{17}$, Au_4Mn, CrO_2, and calcia-stabilized zirconia (CSZ), the crystal structure of UY_6O_{12}, and the crystal and magnetic structure of $PbCrO_3$.

Medical Research Reactor

The Medical Research Reactor (MRR) was operated on 240 occasions during the year and 738,163 kWh of operation were accumulated (see Figure 5). This increase in accumulated kWh of operation, along with a slight decrease in the number of start-ups, reflects the trend in reactor usage to longer running times at higher power levels. The total integrated energy to date is 3,330,754 kWh.

Experimental programs conducted during the year included

1. Determination of trace elements in tissue by activation analysis.
2. Effect of fission fragment irradiations on the conductivity of noble gases.
3. Application of neutron radiography to biological materials.
4. Investigation of the $B^{10}(n,\alpha)Li^7$ reaction on Hela cells and bacteria.
5. Evaluation of various ionizing radiations on production of a moist reaction of pig skin.
6. Determination of mean survival time of dogs receiving whole-body irradiation following various surgical procedures to alter intestinal physiology.
7. Investigation of cellular distribution of B^{10} in tissue by neutron autoradiographic techniques.
8. Investigation of linear energy transfer distribution in a mixed radiation field.
9. Activation of foils for calibration purposes.

In addition, the MRR was operated in connection with the training of $\simeq$20 Health Physics Fellows participating in the 1965 summer program.

Installation of boron-containing stainless steel control rods in place of the canned B_4C control

rods originally provided, started in fiscal 1965, was completed with the installation of such a rod in position No. 2 on September 20, 1965.

During December 1965 the silver-plated copper-mesh iodine filters were removed from the exhaust air system, and activated charcoal filters were installed in their place. Roughing filters of standard air-conditioning roll-type media were installed in an attempt to prolong the life of the absolute filters.

A program of visual inspection of fuel elements has been completed. Some discoloration was found on nearly all fuel elements, but in no case was the condition severe enough to warrant removal. Graphite core pieces were also visually inspected and no serious abnormalities were noted.

One unscheduled shutdown of the MRR, on July 22, 1965, was caused by a malfunctioning pyrometer. The reactor was restarted when the cause of the shutdown had been confirmed, and the scheduled run was completed.

A new fuel element was installed on June 7, 1966, to meet a need for greater excess reactivity to overcome xenon buildup and to compensate for fuel burnup.

A fuel discharge pig has been fabricated and auxiliary components are in the final stages of completion. Fuel burnup and the physical condition of fuel elements may require some replacements to be made during the coming year.

IRRADIATION SERVICES AND ISOTOPE PRODUCTION

In Table 2 a summary is given of the volume and income involved in providing services to outside organizations during the past three years. The AEC's policy of noncompetition and the increasing availability of similar services commercially are behind the continuing decrease in the dollar volume of reactor irradiations despite an increase in the number of irradiations performed. The volume of processed radioisotopes remained essentially the same as last year, since these particular materials are still not supplied in similar form commercially. The work involving Co^{60} sources and cyclotron irradiations continued to be sporadic and relatively minor in scope.

PROCUREMENT OF SPECIAL MATERIALS AND SERVICES

The procurement for the scientific departments of all radioactive and stable isotopes, as well as special materials controlled by the AEC, is a responsibility of the Isotopes and Special Materials Group. In this connection, 256 purchase orders were placed for radioisotopes, 46 for stable isotopes, and 61 for special materials. While the numbers in the last two categories are essentially the same as in the previous fiscal year, there was about a 20% drop in the orders for radioisotopes. Against these orders ≈446 shipments were received and processed, a decrease of 11% from fiscal 1965. Of the orders placed, ≈41% were for the Medical Department, 16% for Biology, 15% for Chemistry, 12% for Nuclear Engineering, 13% for Physics, 2% for Instrumentation and Health Physics, and 1% for the Reactor Division. These percentages are essentially the same as last year's.

The Isotope and Special Materials Group is also responsible for annual inventories of radium

Table 2

Summary of Services to Outside Users
(Handling and Other Charges Included)

	Fiscal 1966		Fiscal 1965		Fiscal 1964	
	Number	Volume, $	Number	Volume, $	Number	Volume, $
Reactor irradiations	350	26,139	291	39,200	453	52,209
Processed radioisotopes	868	135,485	854	124,472	441	72,032
Co^{60} sources	6	*	1	4,317	3	4,158
Cyclotron irradiations	10	2,889	18	4,515	3	580
Total	1,234	164,513	1,164	172,504	900	128,799

*AEC transfers - Co^{60} not produced by Brookhaven.

sources and purchased stable isotopes and for negotiations for the loan of valuable isotopes. The number of radium sources at Brookhaven was unchanged at 38 with a total activity of 5.86 curies and a value of ≈$39,495. The inventory of purchased stable isotopes, $42,426, showed a slight decrease over last year's $44,485, since during the year consumption valued at $12,429 exceeded the cost of new purchases ($10,370). The stable isotopes on loan increased from 38 to 46 in number and from $393,000 to $487,000 in value, exclusive of 5 special samples valued at $666,000.

Only one Brookhaven irradiation program, BNL-29, was active in the Materials Testing Reactor and the Engineering Test Reactor at Idaho Falls. This program was approved last year for the irradiation of several instrumented capsules containing 10% enriched U^{235}-bearing fuel samples in liquid metals. The capsules were to be irradiated this year and next; however, the irradiation requirements were reduced and the program was completed during fiscal 1966.

Three programs requiring large doses of neutron irradiation were performed in one of the AEC's Savannah River reactors during a special high-flux operating period. The first program involved irradiation of five capsules containing silica and pumice, and the second, irradiation of three capsules containing diamond chips. Both irradiations were part of continuing studies of neutron-induced lattice imperfections. The third program consisted of irradiating one capsule containing 1 μg ytterbium dispersed in nickel and titanium foils for activation studies.

Source and Special Nuclear Materials Accountability

Table 3 presents a 3-year summary of the amounts of source and special nuclear (SS) materials on hand at Brookhaven at the end of each fiscal year. Based on dollar values published by the AEC, the current inventory of SS materials represents a value in the range of $14 million. The net increase of $3.3 million in value over last year represents the large amount of enriched uranium received. Although a large amount of depleted uranium was added (≈30 tons in the form of shielding blocks), the value of this material is relatively low.

Sylvania Electric Products, Inc., completed delivery of the 1400 BGRR fuel elements under last year's contract and was awarded a new contract for 925 BGRR fuel elements to be delivered during fiscal 1967. The United Nuclear Corporation completed delivery of 280 HFBR fuel elements under an option to their previous contract. Solicitations were sent out late this year for the fabrication of 84 HFBR fuel elements during fiscal 1967 and 112 during fiscal 1968. For purposes of quality control during the fabrication of both the HFBR and BGRR fuel elements, Brookhaven personnel made 30 inspection trips to contractors' plants this year.

A major portion of the heavy water inventory, about 90,000 lb, was charged into the HFBR system early this year with a loss of about 200 lb. The 17,000 lb of heavy water used in the HFBR critical facility over the previous six years showed an over-all loss due to evaporation of about 950 lb after removal from the facility. Since this particular heavy water was degraded in deuterium content, it was returned to the AEC's Savannah River Plant and replaced by an equivalent value of high purity heavy water.

Two visits were made by inspectors from the International Atomic Energy Agency (IAEA) under the extended Four Reactors Agreement with the U.S. Government. The first visit, on October 15, 1965, constituted the ninth inspection and was

Table 3

Source and Special Nuclear Materials on Hand at End of Year (in kilograms)

	Fiscal year		
	1966	1965	1964
Station BZA			
(Entire Laboratory exclusive of the MRR and BGRR)			
Natural U	526	558	1,701
Depleted U	23,219	756	763
$U^{235}>75\%$	575	288	212
$U^{235}<75\%$	3,878	3,896	6,342
U^{233}	23	23	23
Pu^{239}	57	52	2
Th	825	854	942
Heavy water	53,190	54,577	54,430
Station BZB (Graphite Reactor Fuel)			
$U^{235}>75\%$	79	83	82
Station BZC (Medical Reactor Fuel)			
$U^{235}>75\%$	3	3	3

made by Mr. Carlos Buchler and Mr. Yuzuru Motoda. The second visit, on March 21-22, 1966, constituted the tenth inspection and was made by Mr. Yuzuru Motoda. These inspections involved auditing of the SS materials inventories for the BGRR, inspection of accounting and operating records for evidence of diversion, and a general review of facility usage in terms of peaceful purposes. Except for two minor discrepancies, the results of these inspections were satisfactory.

The results of the IAEA's destructive analyses performed last year on the burnup of a spent BGRR fuel plate agreed within 1% with the Brookhaven calculated value. While this close agreement was gratifying to both parties, the main purpose served was to give the IAEA insight into the peripheral problems involved in arranging the transfer and shipment of such irradiated samples.

The annual audit of SS materials at Brookhaven and the accounting records was performed by representatives of the AEC's Division of Nuclear Materials Management during the period July 19 to 30, 1965. In line with recommendations of this audit and last year's, the SS Accountability Manual for the Laboratory was revised to incorporate a new section on measurements and was updated to reflect current practices and policies. No SS materials were removed from inventory as surplus items this year, but 19.4 kg of natural uranium, 7.5 kg of depleted uranium, 25.9 kg of thorium, 4.7 kg of $<75\%$ enriched uranium, and 24 g of $>75\%$ enriched uranium were removed through waste disposal.

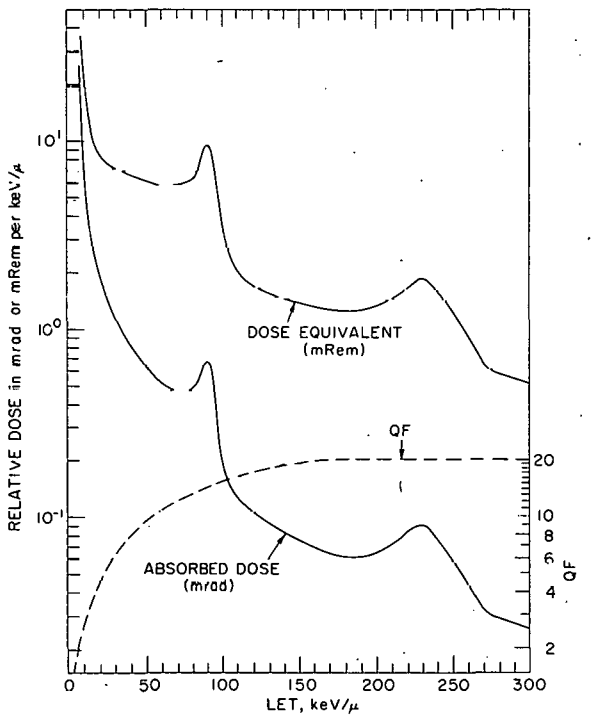


Figure 6. Relative absorbed dose and dose equivalent as a function of linear energy transfer (LET) above the AGS shielding near the G-10 target. Effective $QF=5.0$.

HEALTH PHYSICS

Health physics activities during the past year have been enlivened by extensive surveys and analyses of special problems connected with start-up of the High Flux Beam Research Reactor. A large amount of extra decontamination work was required as a result of receipt of contaminated tools and equipment from an off-site facility. Disposal of a wide variety of hazardous nonradioactive chemicals has been added to the duties of the Division's Waste Disposal and Reclamation Group. Because of increased beam intensity, exposure control at the Alternating Gradient Synchrotron (AGS) has become increasingly difficult, especially during shutdown periods. Applied research and development work and routine services have continued and are discussed below.

At an AEC-sponsored symposium on accelerator radiation dosimetry and experience, held at Brookhaven in November 1965, 39 papers covering all aspects of the subject, including 6 by members of this Division, were presented.

Synchrotron Monitoring and Dosimetry

The integrating pulse-discharge ionization chamber, described last year, has been utilized in the design of an extensive system of in-ring and experimental floor monitors for the AGS. The in-ring units will function as spill monitors during operation and as personnel monitors when access to the ring is permitted. The units for the experimental floor will provide local display of the dose rate, an adjustable alarm, and radio signals to transmit data to remotely located monitoring receivers.

Extensive measurements of linear energy transfer (LET) spectra and quality factor have been made at the AGS and the MRR with use of a Rossi-type spherical proportional counter. Quality factors (QF) at the AGS varied from 1.5 to about 6.0, depending on location. Figure 6 shows the distribution of both absorbed dose and dose equiva-

lent with LET at one AGS location. Plans have been made for a study of quality factor vs depth in a tissue-equivalent phantom at typical AGS locations.

A second method of determining quality factor has been adapted for use with two identical ionization chambers filled with high-pressure tissue-equivalent gas. With collecting potentials of 300 and 1200 V, respectively, on the two chambers, a difference in currents is found as a result of columnar recombination within the tracks left by ionizing particles. This difference is a function of LET and, hence, of quality factor.

Work has started on development of a radiation monitor that will give the dose equivalent for any type of mixed radiation. A Rossi-type LET counter is utilized as a detector. Pulses from the counter are amplified by an operational amplifier which converts the detector output into a pulse spectrum suitably weighted for quality factor, and thus an indication of dose equivalent is possible.

Personnel Monitoring

A detailed study of the costs of personnel monitoring services was made in cooperation with representatives of the U.S. General Accounting Office in Washington. Average unit costs, including full allowance for overhead, were 50¢ per badge for beta-gamma monitoring and 71¢ per badge for neutron monitoring.

The validity of personnel monitoring procedures at the Cosmotron and the AGS was studied by comparing the results of routine interpretation of film badges with absorbed doses measured simultaneously with tissue-equivalent ionization chambers and values of quality factor determined with the Rossi-type LET counter. The routine method of interpretation, which uses a Pu-Be calibration for reduction of the NTA film track count, was found to yield a value of dose equivalent in scattering areas that is not smaller than the correct value. In some areas the routine interpretation leads to considerable overestimation of the dose equivalent, and therefore more sophisticated evaluation of dosages is utilized for investigation of sizable exposures.

Personnel monitoring service was provided for 3088 individuals during calendar year 1965, a 3% increase over 1964. Film dosimeters were provided for ≃6900 visitors. The distribution of exposures for the 3088 persons regularly monitored is shown in Table 4. The maximum single acute exposure was 1.62 Rem. All exposures were <3 Rem per 13-wk period, and in no case was the prescribed limit on integrated exposures exceeded.

Radioactive Waste Disposal and Reclamation

The annual shipment of waste disposal vaults to the New York State burial area at West Valley, N.Y., consisted of 38 units weighing 343 tons and containing 15.2 Ci of activity.

Data relating to the liquid waste system are presented in Table 5. The amount of activity leaving the site in the stream to which the effluent is discharged totaled 39.8 mCi during the fiscal year, and the average concentration was 3.7×10^{-8} μCi/cc, which is 3.7% of the applicable off-site drinking-water limit. Fifteen water and soil samples were taken adjacent to the sand filter beds of the central sewage system and analyzed for radioactivity. There was no detectable difference between these and four comparison samples taken elsewhere on the site. A tenfold variation in natural K^{40} content was noted among the samples.

The activity in the cooling-air effluent from the BGRR was relatively constant, with an average discharge rate of 13,300 Ci of Ar^{41} and 0.0085 Ci of I^{131} per day.

Reclamation of contaminated equipment and materials has been a major activity this year. In addition to a variety of decontamination jobs re-

Table 4

Distribution of Exposures of Individuals Receiving Regular Personnel Monitoring Service

Exposure index range*	Calendar 1965	Calendar 1964
0.00–0.49	2795	2711
0.50–0.99	161	170
1.00–1.49	73	63
1.50–1.99	32	28
2.00–2.49	14	18
2.50–2.99	5	4
3.00–3.49	6	3
3.50–3.99	0	1
4.00–4.49	1	2
4.50–4.99	1	0
5.00–5.99	0	0
6.00–6.99	0	1
Total	3088	3001

*Exposure index = ½ of β exposure in rads + γ exposure in R + neutron exposure in Rem.

Table 5

Summary of Liquid Waste Data

	Fiscal 1966	Fiscal 1965
Input to filter beds, gal/day	950,600	814,250
Output from filter beds, gal/day	720,100	652,250
Net loss in filter beds, %	24.3	19.9
Stream above discharge point, gal/day	8,450	98,900
Stream at site boundary, gal/day	783,300	767,600
Rainfall, in./mo	2.8	3.3
Activity concentration at input to filter beds, Ci/cc	0.74×10^{-13}	0.58×10^{-13}
Activity concentration at output from filter beds, Ci/cc	0.40×10^{-13}	0.63×10^{-13}
Activity concentration at site boundary, Ci/cc	0.37×10^{-13}	0.53×10^{-13}
Activity at input to filter beds, mCi/mo	8.1	5.4
Activity at output from filter beds, mCi/mo	3.3	4.7
Activity at site boundary, mCi/mo	3.3	4.7

Figures are averages for each fiscal year.

lated to normal BNL operations, 50,000 tools and many large surplus items were decontaminated. A total of 2816 lb of contaminated mercury were triple-distilled and returned to stock.

Environmental Monitoring

The sampling of bottom silt and vegetation of the Peconic River downstream from the Laboratory outfall was extended to the full length of the river. A limited quantity of other types of samples including fish, frogs, and turtles was also obtained. Co^{60} and Cs^{137} were the major gamma-emitting isotopes. The maximum concentrations of these isotopes, about 10 pCi/g in each case, were found between 1 and 3 miles below the outfall.

In addition to the four perimeter monitoring stations, seasonal sampling for airborne I^{131} was conducted at "in-line" on-site stations. This program was carried on in cooperation with the Meteorology Group by using the I^{131} released from the BGRR stack to study atmospheric diffusion. The meteorological implications of the data are described in the Meteorology section of this report. The average I^{131} concentration at the perimeter due to the BGRR effluent was 0.003 pCi/m^3, a negligible value compared with the maximum permissible.

The highest external radiation level at the site boundary occurred at a point north of the gamma forest source and averaged 4.61 mR/wk. This may be broken down into three components of 2.16, 0.86, and 1.59 mR/wk due to background, Ar^{41} from the BGRR, and the forest source, respectively. The permissible level is 500 mR/yr, or an average of 10 mR/wk.

Ba^{140}-La^{140} from the second Chinese weapons test (May 15, 1965) declined to below detectable amounts during July. Fresh fission products from the third test (May 9, 1966) were apparent at Brookhaven 9 days later, with a maximum 1-day gross beta air concentration of 3.6 pCi/m^3.

Samples of air particulates, including both longer-lived natural and fallout isotopes, averaged 0.181 pCi/m^3 of gross beta activity. The average concentration in precipitation was 7.1 nCi/m^2/mo as compared with 13.0 nCi/m^2/mo last year. The rate varied considerably, with a maximum value of 19.9 during May due to the combined effects of the spring maximum and the Chinese weapons test. The principal isotopes detected in both air and precipitation were cosmic-ray-produced Be^7 and fission product Cs^{137}.

Laboratory Safety

The injury frequency rate at BNL remained below 3.00 injuries per million man-hours worked for the second consecutive year. The 1965 rate of 2.71 and the 1964 rate of 2.45 are the lowest in BNL history. The cost for New York State workmen's compensation benefits (borne by the Laboratory) rose above that for the previous year, but the payment of 27¢ for each $100 of payroll is still extremely low for operations of this nature.

A major hydrogen explosion at another accelerator laboratory focused attention on the BNL cryogenic safety program. This program has been active since 1957, with one engineer devoting almost full time to it and a Laboratory-wide committee supplementing Safety Services Office activities in reviewing policies, standards, and major facilities or experiments.

A comprehensive review and replacement program for portable fire extinguishers has been substantially completed. The objective was to modernize this equipment where necessary and to eliminate those types whose maintenance made excessive demands upon the available manpower. A series of BNL fire and safety standards has been given to designers and consultant engineers to

serve as the basis for new facility specifications. In addition, a Fire Protection Systems Test Manual has been issued.

During 1965 there were no losses due to fire. Other types of reportable property damage amount to only $6100 and were due to three incidents: a fault in a beam magnet cooling-water hose, a violent chemical reaction, and the failure of a centrifuge rotor.

Aside from routine accident investigating and inspection activities, personnel of the Safety Services Office devote the major portion of their time to consultant activities. These include participation in departmental safety committees, review of specific pieces of apparatus, review of proposed facility designs and specifications, and response to daily requests from experimenters for information on specific hazards.

MECHANICAL ENGINEERING

In the past year the Mechanical Engineering Division has increased from 171 to 189 members with assignments as indicated in Table 6.

In the Accelerator Department work continues on improvements for the linac injector to the AGS. A duoplasmatron ion source has been operating at the linac and has increased the beam intensity by 50%. Development work continued on a prototype 15-section high-gradient accelerating column to better utilize this source. The column is under test with a special high-voltage dome, and an operational column is under development and construction. A fast emittance device has been designed, fabricated, and installed on the linac; it will display an emittance pattern of the 50-MeV linac beam in the control room.

A double-pulsing deflector has been installed in the 5-ft straight section of the AGS ring; it consists of an 8-turn water-cooled coil and a special series-parallel multiple position switch. This device will allow the normally used 10-ft straight section to be made available for other purposes.

A fast external beam apparatus for 1-turn extraction from the AGS ring has been installed to provide an rf separated beam to the 80-in. bubble chamber. The apparatus includes a hydraulically rammed ejector magnet and various special chambers and air locks for internal targeting. This separated beam is the first operating vacuum system at the AGS to incorporate sputter-ion pumps for all high-vacuum areas.

Table 6

Assignment of Mechanical Engineering Division Personnel as of June 30, 1966

	Engineers	Designers and draftsmen	Secretarial and clerical
Accelerators			
Advanced accelerator development	2		
AGS	9	20	1
AGS conversion	16	15	–
Cosmotron	5	5	–
Experimental planning and support	11	6	–
Administration	1	–	1
Central Design	1	8	1
Chemistry	1	–	–
Nuclear Engineering	6	20	–
Physics			
Bubble chambers	14	16	–
General	11	18	–
Safety Services	1	–	–
Total	78	108	3

Total personnel – 189

There are now three hydraulically rammed magnetic devices in the AGS ring. To ensure the reliability and efficiency of the external beam system, a program involving the procurement of complete spares and revision of some of the mechanical components has been undertaken. Selection of materials suitable for high vacuum and radiation environments will be emphasized. The installation of new hydraulic units on the three rammed systems has reduced the shock load by a factor of three, and a test laboratory for the rammed septum and ejector magnets is currently being set up to allow spare units to be life-tested. Since ring components are highly radioactive after use, emphasis will be on the replacement of complete units, rather than repair of these units in place.

Apparatus for a slow extracted beam to provide an external beam over many AGS turns is in process of design and manufacture. Work is progressing on the design of remote-moving mechanisms for the septum and ejector magnets, vacuum boxes, and special vacuum chambers. A freon-cooled, 480-transistor power supply for use with the ejector magnet is being constructed. The ejector magnet assembly, which consists of one 2-turn

and two 3-turn magnet segments, with space for coil ends and water-cooling between each segment, is under fabrication. This magnet has a septum thickness of ¼ in. compared with the 1-in. thickness used for the fast beams and it will be energized at a current of 6350 amp/pulse. It can provide an angular kick of 20 mrad to the 30-BeV proton beam.

A new 0.030-in. septum magnet for the slow beam has been fabricated and successfully tested. The septum is cooled by a high electrical resistance stainless-steel tubing helix soldered to its edge. Thermal testing proved very satisfactory, and this edge-cooled septum will be capable of providing 1100 G for the same pulse length as the ejector magnet assembly.

An automatic program transfer mechanism has been developed and installed in the G-10 target section to facilitate target-blade handling and reduce radiation exposure. This, in conjunction with the automatic cycling air lock at this location, makes it possible to remove a target blade from the main AGS vacuum chamber and replace it with another held in a magazine without either shutting down the AGS or having personnel enter the machine enclosure. Eight different blades can be accommodated by the magazine of the device.

With proton intensities in the AGS ring $>10^{12}$ protons/sec, organic materials, especially "O" rings adjacent to the target section, have failed after only a few months of operation. These Viton "O" rings will be replaced with Inconel-X "O" rings coated with a few thousandths of an inch of indium and having the same dimensions as the rubber rings. Five sputter-ion pumps of the type expected to be used in the future have been in service on the ring since April 1965 with excellent maintenance experience.

Members of the Mechanical Engineering Division assigned to the Experimental Planning and Support Division of the Accelerator Department have been involved in the operation of the experimental floors at both the Cosmotron and the AGS. Their work is connected with the planning and setting-up of experimental beams and experiments on the floors of both accelerators as well as the design of new equipment for general use on these floors.

A major and continuing effort within this group is the design and procurement of new bending and focusing magnets for the accelerators. Deflecting magnets include four with apertures 6 in. high, 18 in. wide, and 36 in. long; two of the "C" type with apertures 6 in. high, 15 in. wide, and 30 in. long; and two 90-ton magnets, with apertures 12 in. high, 48 in. wide, and 48 in. long, to operate at a peak field of 15 kG. The last-named are to have hydraulically operated stands which will allow them to be moved horizontally as well as to rotate. Among the quadrupole magnets procured were four slim quadrupoles with 12-in.-diam by 24-in.-long apertures and six improved regular-type quadrupoles with 18-in.-diam by 32-in.-long apertures. Five quadrupoles with 18-in.-diam by 36-in.-long apertures were designed and built to replace the rectangular quadrupole magnets in the separated beam for the 80-in. bubble chamber. These new magnets have better field characteristics and require considerably less power. In addition, six quadrupoles with 3-in.-diam by 36-in.-long apertures were designed for the slow external beam originating at the F-10 straight section.

Improved shielding materials containing depleted uranium, lead matte concrete, and cast iron are being investigated. The lead matte concrete weighs 280 lb/ft^3 as compared with 245 lb/ft^3 for ilmenite concrete.

The Optical Survey Group has performed alignment service in the setup of experimental beams at the AGS and the Cosmotron and has also been of assistance at the HFBR, 60-in. cyclotron, vertical accelerator, and the Chemistry Building. At the HFBR internal measurements were taken on the nine beam port tubes to establish the beam center lines on the experimental floor.

In the AGS Conversion Division work is proceeding on modifications of the AGS ring for higher intensity. An octupole air-core magnetic structure for the 2-ft straight section has been modeled and magnetic measurements are being made. A new vacuum chamber to make possible the installation of a vacuum pump at each magnet module has been designed with quick-disconnect vacuum flanges. A model of one of these flanges was built and tested, and an improved model has been released for fabrication.

The spare AGS magnet girder and two spare magnet assemblies have been set up. The first model of an improved radial adjustment device was installed and tested, and the design has been modified in scale and is being rebuilt. A prototype quick-disconnect bus-bar connector has been built, and contact resistance measurements are

being completed. The necessary water manifolding has been designed for the magnet module, the first unit has been installed on one of the two spare magnets, and tests are under way. As designs are proved, production models will be installed on the girder for tests under simulated AGS magnet ring conditions.

The new linac injector for the AGS conversion is still under study. The designs of several components were investigated in an attempt to optimize costs and reliability. These include the copper-clad accelerator structure, drift tubes, quadrupoles, and support systems. In addition, analysis of the design of water- and air-cooling systems proceeded.

Models and prototypes of various components have been designed and fabricated. A model to investigate standing-wave, iris-loaded waveguides was built to operate at 800 Mc/sec. A 4-ft-long rf power model with full-size cross section has been fabricated and is being assembled. This section will be run to its full power of 300-kW peak. Components to be tested are drift tubes, tuners, and vacuum and cooling systems. Vacuum components, rf joint design, vacuum seals, mechanical tuners, temperature control, and temperature monitoring for tuning purposes will also be evaluated.

In the rf development program, resonant cavities were designed and fabricated for three power amplifiers. A low-conductivity water system has been built with all necessary interlocks and monitors for the testing of these amplifiers. Design work is proceeding on coaxial waveguide components, including mating flanges, phased-measurement bridges, and power dividers. A dc drift tube quadrupole magnet and a pulsed quadrupole magnet have been designed and fabricated and are being tested.

At the Cosmotron a standardized design using low-friction bearings and track was developed for moving heavy loads with minimum effort and high positioning accuracy. This system was used on a 5000-lb collimator that can be moved into and out of a magnet beam array, on a pair of quadrupoles or bending magnets in the incident external proton beam, and on a 10-ton quadrupole triplet that can be moved on a track of 20-ft radius through an arc of 14½°.

A self-propelled magnet-positioning truck was designed to support and move a 26-ton bending magnet into position. The magnet is aligned on a 4-wheeled truck that moves at the rate of about 16 in./min on standard 50-lb/yd crane rail. Two magnets are now on straight rails, and one is on a curved rail with a 20-ft radius and operating through a 40° arc. In carrying out these motions an accuracy of alignment of 1/32 in. is maintained.

Since Mylar is used on many vacuum beam port windows, a study of radiation damage was made. The threshold for decrease of the strength of Mylar is close to 10^{15} protons/cm^2 and falls to $\approx$½ the unexposed value at 3.0×10^{15} protons/cm^2. Based on these values, a decision was made to change the Mylar windows on vacuum beam pipes after each 7-day exposure to the main beam.

The major efforts of the Cryogenic and Target Group of the Experimental Planning and Support Division have been directed toward the design, fabrication, and operation of liquid hydrogen, liquid deuterium, and liquid helium targets and the procurement and distribution of the cryogenic fluids for use with these targets. Twelve hydrogen targets have been designed and constructed for the AGS experimental program, and seven targets have been prepared and operated at the Cosmotron. Four of the AGS targets require additional assembly and testing.

Three of the target systems depart sufficiently from normal design to warrant more complete description. One target system has two 6-in.-diam by 36-in.-long inner vessels surrounded by a concentric cylinder wrapped with superinsulation and a vacuum in the outer casing. The outer cylinder is connected to a large (200-liter) reservoir to reduce thermal disturbances due to refilling to a minimum. Other features of this system include a vacuum pumping station with freon-refrigerated baffle, a pressure regulator for liquid density control, a deuterium purifier system, and a temperature control bath for the pressure-regulating control gas. The second system has two 6-in.-diam by 120-in.-long targets. The third is a Mylar hydrogen target with an inner system that has a 7×4-in. rectangular cross section 45 in. long. This target is contained in a cylindrical Mylar vessel with hemispherical domed ends, the liquid hydrogen being contained in the inner vessel and the gaseous hydrogen in the annulus. The liquid and gaseous hydrogen are at the same pressure because the inner membrane is only 3 mils thick and a rectangular cross section must be maintained.

Liquid-hydrogen and liquid-helium transfer lines were constructed and maintained for various experimental setups. Additional associated equip-

ment for hydrogen targets, i.e., hydrogen reservoirs, liquid level indicators, gaseous vent lines, vacuum electronics, and electrical power control chassis, have been maintained by the Cryogenics Group. Transfer lines and associated equipment were constructed and installed at the hydrogen storage facility.

A liquid-hydrogen helium-cooled target was designed, fabricated, and operated with a cold helium gas shield around the target to lower the boil-off rate. A deuterium purification panel was designed and constructed, as was a deuterium recovery system. Work was completed on the mobile installation for the 2-W, 4.2°K helium refrigeration unit. Engineering studies are continuing on the solid hydrogen target to be utilized with this system. The cryostat for the superconducting magnet is now being assembled.

Members of the Division have been responsible for the distribution of the deuterium gas for use in the experimental program and of 240,000 liters of liquid hydrogen within the Laboratory, as well as for the record-keeping involved.

General cryogenic support was provided to other areas of the Laboratory. For the Chemistry Department a regenerative liquid-nitrogen, cold-charcoal absorption system for the neutrino experiment was designed. A survey of liquid helium requirements was conducted for the Supply and Materiel Division, and assistance was provided in planning the distribution system for liquid helium purchased from outside vendors. For the Nuclear Engineering Department, consultation service was provided on the design of a liquid-nitrogen-cooled irradiation facility for a vertical hole in the graphite reactor, and a liquid-nitrogen dry-gas system was installed in the Hot Laboratory. In addition, engineering studies were made of the liquid-nitrogen storage and distribution system at the HFBR. Preliminary discussions were held with members of the Physics Department on the design of a cold neutron moderator for the HFBR.

The Central Design Section of the Mechanical Engineering Division provided engineering and design services for the Chemistry, Biology, and Medical Departments and augmented the efforts of design groups in nuclear engineering, general physics, and high energy physics.

Design work for the Chemistry Department included a device used in detecting a beam in the spark source mass spectrometer. Design and development work was also done on apparatus to be used in conjunction with the Brookhaven solar neutrino experiment being installed at a depth of 4900 ft in the Homestake Gold Mine in Lead, S.D. The equipment associated with the piping of the 100,000 gal of trichloroethylene, the mixing of the helium purge gas, and the condensation and charcoal traps for the argon was designed together with the related piping and controls.

For the Biology Department, members of the Division designed a disc electrophoresis apparatus consisting of Lucite trays and electrodes for use in a specialized analytical technique for making electrophoretic analyses of biochemical substances by detecting the rate of migration of proton molecules. Also designed were a controlled environment enclosure, several containment vessels, and a device for the adjustment and elevation of a large mixer.

Work for the Nuclear Engineering Department included several gas filters, a shielded carrier used for transferring radioactive materials from the Hot Laboratory's experimental cells, and a low-temperature vertical irradiation facility for the neutron irradiation of samples at or near the temperature of liquid nitrogen.

In the Physics Department, members assigned to the Bubble Chamber Group have been at work on modifications of the optical system and camera film-drive mechanism of the 80-in. bubble chamber to convert it to bright-field illumination and provide a faster film drive to accommodate multipulsing. This chamber has been successfully multipulsed and the equipment needed for the expansion system is available. The 30-in. chamber has been used for some experimental work involving Scotchlite illumination and neon-hydrogen operation and has been available for experimental use almost constantly. The 20-in. chamber was dismantled and its reconstruction as a 31-in. chamber has been proceeding throughout the year. All necessary components have been received, and assembly and preliminary testing should be completed late in the summer or early in the fall.

The major engineering effort of this section was connected with the preparation of the 14-ft Cryogenic Bubble Chamber Project Final Pre-Title I Report (Informal Report BNL 9695) and the design and procurement of the equipment needed for the research and development of large chambers and high-field magnets. This covered the acquisition of a helium refrigerator with a 175-W capacity at 4.2°K, procurement of large liquid hydrogen

storage to provide necessary hydrogen refrigeration, and design and construction of superconducting magnets and containment vessels. Also involved was the design and procurement of parts for a half-scale model of the 14-ft chamber and the development of an area in which the above-mentioned equipment could be assembled, tested, and operated.

Much of the general engineering work in the Physics Department has been connected with installation of equipment at the HFBR. Four neutron spectrometers were installed on the HFBR experimental floor and are operating under central computer control. As auxiliary equipment a 2-circle goniometer was completed to orient a crystal and cryostat in 4° of freedom. Design was completed on the primary shield and collimator assembly for the H-1 polarization spectrometer, and contracts were awarded for the fabrication. A spectrometer for use with a 30-ft-long internal reflecting neutron beam pipe was designed. The length of the beam pipe allows the spectrometer to be set up at a greater distance from the reactor face in a low background area.

The slow and fast neutron chopper assemblies were tested at the spin test facility to rated speed. The slow neutron rotors were tested to a speed of 13,000 rpm, and the fast neutron rotor to 15,000 rpm. In all cases, operation was completely successful. The fast neutron chopper and shielding have been installed at the HFBR and tested at low speeds. Preliminary results indicate that the physics performance is excellent. The slow neutron chopper assemblies are being installed, and the second horizontal rotor system has been designed and is in process of fabrication.

A capture gamma-ray spectrometer is being designed and fabricated. This device allows the neutron beam from the HFBR to impinge at a variable angle on a crystal. Neutrons of varying energy from the reflected beam strike a target which emits gamma rays by the neutron absorption process. An interesting feature of this device is the main biological shield, which is concrete and uses a water-filled tank as a window. The inner and outer radii of this annular tank are of thin material. The ends of a 7-ft-long tube moving with the arm of the spectrometer are sealed at the inner and outer radii to keep water out of the tube. Thus shielding blocks need not be moved when the detector angle is changed. The detector array is shielded by lead and Masonite and moves on air pads around the periphery of the main shield, tracking the submerged collimator by a magnetic servo system. This equipment should be completely installed by the end of fiscal 1967.

A mechanical velocity selector has been designed which consists of a rotor arranged to spin on an axis parallel to the beam access. The rotor has a 6-in.-diam hub supported in bearings and driven by a 15,000-rpm hysteresis motor. On the periphery of the cylindrical hub are cemented, cadmium-plated, shim-steel blades arranged on a long pitch helix. The whole unit, rotor, motor, and bearings, runs in a vacuum. Fabrication should be completed by the fall of 1966.

A magnetic lens system consisting of shaped inner and outer coaxial conductors has been designed and is being fabricated. Current is passed through one conductor and returned through the other, and the space between these conductors then contains a shaped magnetic field, which is used to focus high energy charged particles. The system consists of two separate assemblies located 30 ft apart. Each assembly consists of an inner and outer conductor through which pulse current is passed. The conductors are fabricated by joining different conical sections together to form the proper shape.

A neon recirculation system for wire plane hodoscopes has been designed to remove impurities from the circulated gas and maintain the proper alcohol-to-neon proportion. Piping, valving, and instrumentation for operating the system automatically and with minimum maintenance have been designed.

A light chopper consisting of a disc with 180 slots and capable of rotating at variable speeds up to 36,000 rpm has been designed and fabricated. The system will give up to 108,000 cycles/sec of light pulses with an accuracy of 2%.

The conversion of the 60-in. cyclotron to sector focusing is proceeding satisfactorily. The main magnet coils and cooling system have been installed and tested, and magnetic measurements have been made. Uniformity of the field exceeds specification, and the fabrication of the profile coils is proceeding. Other components such as the rf system and vacuum system are in process of fabrication and assembly, and the various power supplies to power the magnet are being installed. Completion is expected by the end of 1966.

Members of the Division assigned to the Nuclear Engineering Department have continued to

supply engineering, design, procurement, and construction assistance for the HFBR during the preoperational and postcritical periods. With respect to the reactor vessel this included installation of all internal equipment, design of handling tools, repair of the anticritical grid, modification of flow reversal valves, clamping of irradiation thimbles, and beam-tube temperature probes. For the primary system items covered were installation of an off-gas demister, a D_2O acidification system, modifications to coolers and circulation pumps, removal and reinstallation of a flowmeter, and a vacuum drying system for the D_2O piping. An in-pile irradiation facility was designed and built for the HFBR material surveillance program. This facility, which will allow controlled exposure of metal specimens to reactor radiation, has been installed in core edge location V-13. A flux-monitoring facility was designed and built to allow foil irradiation in conjunction with HFBR beam-tube calibration experiments.

In connection with the Radiation Division's source development program, the first 300 BNL Mark II bonded sources have been received and have undergone extensive destructive and nondestructive tests at BNL and also at the Savannah River Plant. A simple source holder for reactor activation was approved by SRP, and the first batch of 100 strips has been shipped to SRP for activation.

Two portable irradiators fabricated by an outside vendor were operationally tested and checked for shielding integrity. The units were returned to BNL after extensive modifications by the fabricator and, after further tests, were shipped to their final destinations in Israel and Gloucester, Mass.

A 4-pass horizontal conveyor was purchased and tested for installation in the high-intensity radiation cell later this year, and a recessed hot cell facility was designed for the Radiation Division.

The effort on the chemonuclear loop has shifted from design and testing to construction. The two major out-of-pile process piping sections of the loop are essentially complete, and the auxiliary loop equipment is being assembled in the support structure. All the out-of-pile equipment will be contained in 5 leak-tight vessels, 3 of which are complete. The vessels and loop equipment will be delivered to BNL this summer. The section of the BGRR in which the loop is to be installed has been cleared, and the shielding directly over the main loop containment vessel has been installed. This construction effort is expected to continue through most of the coming year.

Power cycle analysis has been continued for magnetoplasmadynamics generating systems utilizing fission fragment-induced ionization, and the study of the 1000-MW ordered bed reactor is nearing completion.

The pumped boiling cesium corrosion loop for the Metallurgy Division was put in operation during fiscal 1966. The loop is constructed of a columbium-zirconium alloy and utilizes a canned helical induction pump. It is operated in a vacuum chamber at 10^{-8} torr, and the process conditions at the inlet to the turbine simulator test sections are 1600°F and 130 psi at a cesium vapor flow rate of 90 lb/hr.

The design and construction of two pumped sodium corrosion loops for fast reactor application at temperatures up to 1500°F are under way.

A Co^{60} blood irradiator has been completed for the Medical Department which will allow simultaneous treatment of two patients. It is expected to be put into service this summer. Engineering assistance is being provided to the Chemistry Department for the solar neutrino experiment. This involves erection and leak-testing of the 100,000-gal vessel and the perchloroethylene circulating system. A study is being made of advanced reactor research concepts to provide a significant increase in pulse neutron flux. A pulsed fast reactor concept is being investigated which will use rotating wheels containing sections of either fissionable material or a reflector. Preliminary calculations have been completed for liquid-metal-cooled cores of various sizes and shapes.

MACHINE SHOPS

Three general categories of service are provided by the Central Shops Division: on-site fabrication, fabrication by vendors, and inspection and quality control. In addition, management of the Laboratory-wide machine-tool acquisition and replacement program, the machine-tool standards program, and the small-tool standards program are the responsibility of the Division.

The Division provided 151,197 productive manhours of work in fiscal 1966, compared with 146,290 hours in fiscal 1965. The contributions of the several Departments to the Division's work load are indicated in Table 7. Work performed for

the Accelerator, Physics, and Nuclear Engineering Departments accounted for 78.2% of the total work load. The short-order work remained at about the same level as in fiscal 1965. The average backlog for fiscal 1966 increased for the second year, partly because of time lost in clean-up of contamination and a decrease in the level of work contracted to vendors.

The Division contracts fabrication work to vendors as necessary to operate in the best and most economical way and to accomplish work for which no on-site facilities exist. Frequently jobs are divided, part being done on site and part contracted to vendors. At times fabrication of component parts is contracted to vendors and the final assembly and testing is done on site in the Division's facilities.

It was increasingly difficult during the year to contract work to vendors, especially in the case of large machined parts and weldments. Problems encountered in getting vendors to maintain specified quality levels entailed many man-hours spent in vendor survey work, contract placement, expediting, and quality control. The dollar volume and the number of jobs placed during the year were substantially lower than in fiscal 1965. A total of 240 jobs were fabricated by 66 vendors. The Accelerator, Physics, and Nuclear Engineering Departments accounted for about 90% of the total dollar volume involved in these jobs.

The Inspection and Quality Control Section continued to assist the scientific departments in making measurements relative to the establishment of experimental design criteria and the setting up of research equipment. Of the nearly 61,000 pieces inspected during the year, the Division contributed almost 47,000 pieces to the work load, an increase of 15% over fiscal 1965, and vendors accounted for about 9,000 pieces, $<\frac{1}{2}$ the corresponding work load in fiscal 1965.

About $300,000 was available under the Laboratory-wide program for machine tool acquisitions. About 76% of the total was allocated to the Central Shops and the balance divided among eight staff shops. The emphasis in the over-all program remained on the replacement of old and worn-out equipment. In the staff shops 85% of the funds expended was for replacements, whereas in the Central Shops about 60% was for replacements and 40% for tools needed to extend the fabrication capability of the Division. The most significant areas of new and increased capability include numerically controlled milling and jig boring operations, chemical cleaning, and tracer-controlled lathe-turning operations. The addition of a print-out device to the coordinate measuring machine has greatly decreased the time required for making and recording measurements.

Building modifications and additions provided three new facilities: one for chemical cleaning of aluminum, stainless steel, copper, and brass; one for conducting welding under environmentally clean conditions; and one for abrasive cleaning work.

Jobs of many different types were performed by the Division during the year. Some were short-order jobs requiring from a few minutes to a few hours, while others required up to 3841 man-hours for completion. A number of interesting and involved jobs required special tooling, the application of unique fabrication techniques, and even the development of special techniques. A total of 1307 jobs, each requiring more than 15 hours to complete, were worked on during the year. Some of these jobs are of special interest, either because of the nature of the job itself or because the jobs illustrate particular types of work being done by the Division.

The electric discharge machining (EDM) equipment installed last year has resulted in significant changes in fabrication procedures for certain type of jobs. With this equipment some jobs can be done faster, others more precisely, and the Division has been able to accomplish some work

Table 7

Contributions to Machine Shops Work Load

	% Man-hours		
	Fiscal 1966	Fiscal 1965	Fiscal 1964
Accelerators			
AGS	16.1	14.1	12.7
Cosmotron	4.1	5.2	9.1
Biology	4.0	4.2	2.1
Chemistry	4.7	3.5	2.1
Instrumentation and Health Physics	0.9	1.0	1.7
Medical	3.1	2.5	1.7
Nuclear Engineering	22.1	26.2	32.8
Physics	35.9	31.3	28.8
Reactors	7.2	9.1	4.8
Miscellaneous	1.4	1.9	2.0
Outside contracts	0.5	1.0	2.2

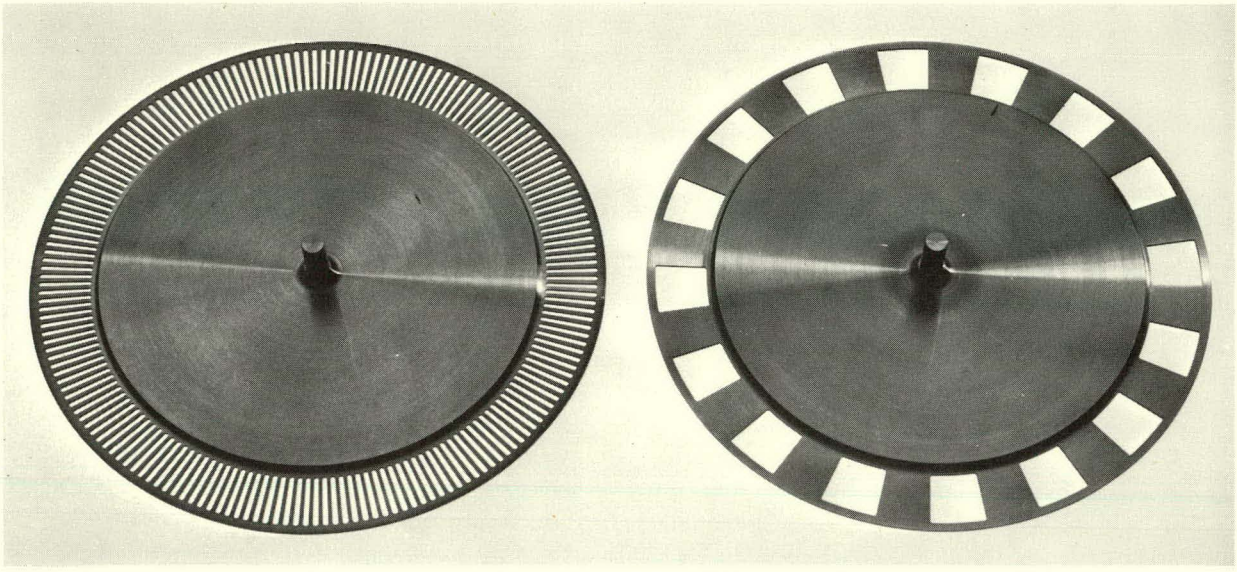
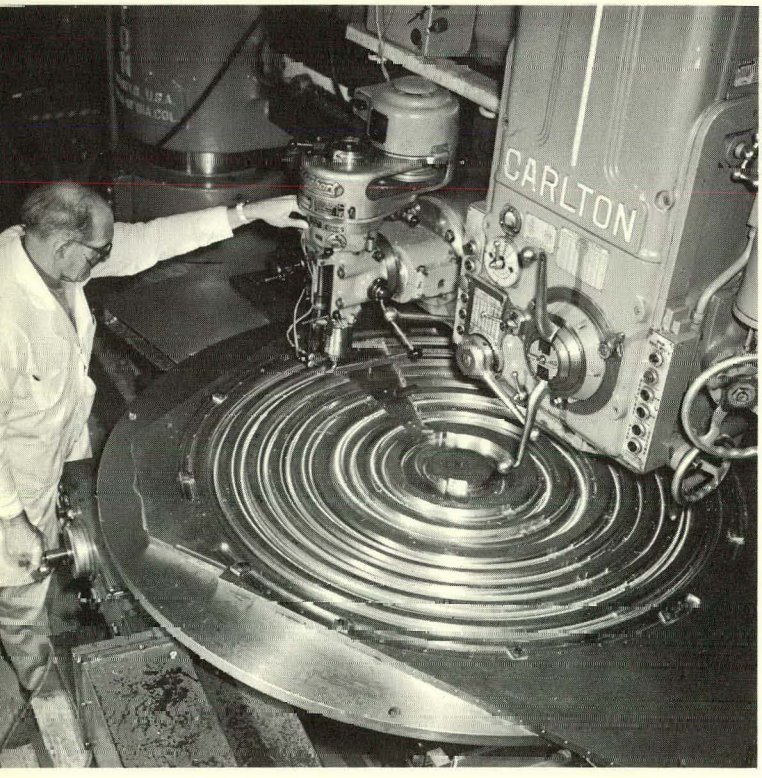


Figure 7. Light-scanner rotors 6.250 in. in diameter with 180 slots (left) and 16 slots (right) machined in 0.031-in.-thick aluminum by EDM equipment.

Figure 8. Copper liner for the 60-in. cyclotron acceleration chamber being machined for magnetic-field shimming coils.



that could be done in no other way. In the almost 10 months that the machine has been in operation 50 jobs have been completed. Figure 7 shows two light-scanner rotors, one with 16 slots and one with 180 slots. The variation in size and shape of the slots could not exceed 0.001 in., and the concentricity had to be maintained within 0.005 in. The rotors were made of 75 ST aluminum, 6.250 in. in diameter; the heavy section was 0.125 in. thick, and the slotted area was only 0.031 in. thick. To machine these pieces conventionally without distortion would have been virtually impossible. Cutting time was 4 min for each of the 16 large slots and 1½ min for each of the 180 small slots. Other jobs performed on the EDM equipment include slotting of thin-wall stainless steel drums, cutting and planing of three types of meteorite into 0.187-in. squares 0.002 in. thick, and cutting of copper and cobalt crystals. Square and rectangular holes and cavities have also been cut in brass, aluminum, copper, steel, Alnico, and stainless steel. Use of the EDM has permitted 1-piece construction of source holders previously made of several welded parts. Holes 0.001 in. in diameter and slots 0.004 in. wide have been located 0.080 in. apart in 0.001-in.-thick foil. A grating requiring 22 slots 0.004 ± 0.0005 in. in width and 2.514 in. long was fabricated from 0.040-in.-thick brass.

New liners for the 60-in. cyclotron were machined from 1 in. thick copper plate measuring 60×72 in. Because of the size of the plates a spe-

cial setup had to be devised utilizing a large 8-ft radial drill, a milling head, and a 60-in., power-driven rotary table (see Figure 8). Machining involved ≈200 holes per plate, cavities, and angular and stepped edges, as well as radial stepped grooves originating from two different centers.

A particularly troublesome problem encountered in making joints in hollow conductors for magnet coils was solved in a rather simple way. Approximately 110 vacuum and pressure-tight joints had to be made in the hollow copper conductor used in the fabrication of the profile coils for the 60-in. cyclotron. Design restrictions required the fabrication by machining of intricate shapes and transitions which later had to be assembled into the coil structure. The past practice of brazing joints in the copper conductor involved the use of intricate jigs and fixtures or of brazing alloys with different melting points when joints were adjacent. In this particular case it was decided to use the Heliarc process to weld at least one of any two adjacent joints. Several techniques were tried, with an internal ferrule used at the joint to keep filler material from leaking into the hollow core of the conductor. The technique finally adopted, however, consisted of making a simple butt joint with the ends of the conductor chamfered at about 45° and maintaining a flow of argon gas through the conductor as the joints were being welded. Sample joints made in this manner were radiographed, sectioned, and subjected to tension tests, and this procedure was found to give the best over-all results. This technique produced an extremely strong joint which can be bent more readily than a brazed joint without fear of fracture. Adjacent joints can be made without fear of destroying or damaging the one made first. The technique has also resulted in a considerable cost saving in fabrication and a greater flexibility in the coil design. This is believed to be the first application of the technique to this type of fabrication.

A new clean welding room was put into service in the latter part of the year. Two P&H 500-A ac and dc Heliarc welding machines are located in the room together with an Airline Model 36S welding chamber. The latter, shown in Figure 9, is a positive purge-type chamber suitable for use with a number of different gases. Materials welded with use of this facility have included both refractory and pyrophoric materials. Jobs completed included welding of (1) cobalt fuel element test pieces, (2) 0.020-in. columbium units to 0.035-in. cobalt strips, (3) zirconium and alloys for fuel elements, (4) 0.030-in. tantalum wire to 0.015-in.-diam tantalum tube, (5) 0.025-in.-diam tantalum tube to 3/32-in. plate, and (6) molybdenum to stainless steel tubing.

A number of repair and modification jobs were performed at the HFBR during the year. Typical of these jobs was the replacement of a flexible line with rigid pipe in the D_2O system. Liquid nitrogen was used to freeze a plug in the pipe and thus permit the D_2O pipeline to be welded without draining the pipe and associated equipment. The frozen plug of D_2O held against a pressure of 5 psi. This technique has been tested satisfactorily at pressures up to 400 psi.

One of the anticritical grid segments for the HFBR required extensive repair welding of the highest quality which had to be accomplished in cramped quarters within the reactor vessel itself.

The Inspection and Quality Control Section provided special assistance in addition to its regular work in a number of cases. Typical of these unusual jobs are the following: Samples of the Mark II bonded type of BNL standard cobalt source were submitted and examined to determine cladding thickness, weld quality, pits, and voids. A special test procedure was devised for measuring cladding thickness, and calibration curves were developed for use with an Aminco-Brenner Magne-Gage. Inspection for pits and cracks in the stainless steel cladding was made by the fluorescent dye penetrant test method. A unique method of measuring depth was developed for this job; it involved the use of fluorescent dye penetrant, time-controlled conditions, and comparison of the resulting data with a calibration curve derived from a test block standard prepared with holes of known diameters and depths.

In Figure 10 an inspector is shown using the Sheffield Cordax 200 coordinate measuring machine for the measurement of hole location on a bed-plate for use in ordered packed-bed fuel element experiments. Bed-plates with as many as 11,881 holes had to be measured to a tolerance of ±0.001 in. Use of the machine has reduced measuring time by about 90%. The machine was also used to fabricate a special grid through an opaque film on glass for the Technical Photography and Graphic Arts Division. The required grid specification was 50 lines/in. over a distance of 8 in., each line to be 0.010 in. wide by ¾ in. long with an opaque space of 0.010 in. between the lines.

Figure 9. Welder utilizing the inert gas chamber installed in the clean welding facility.

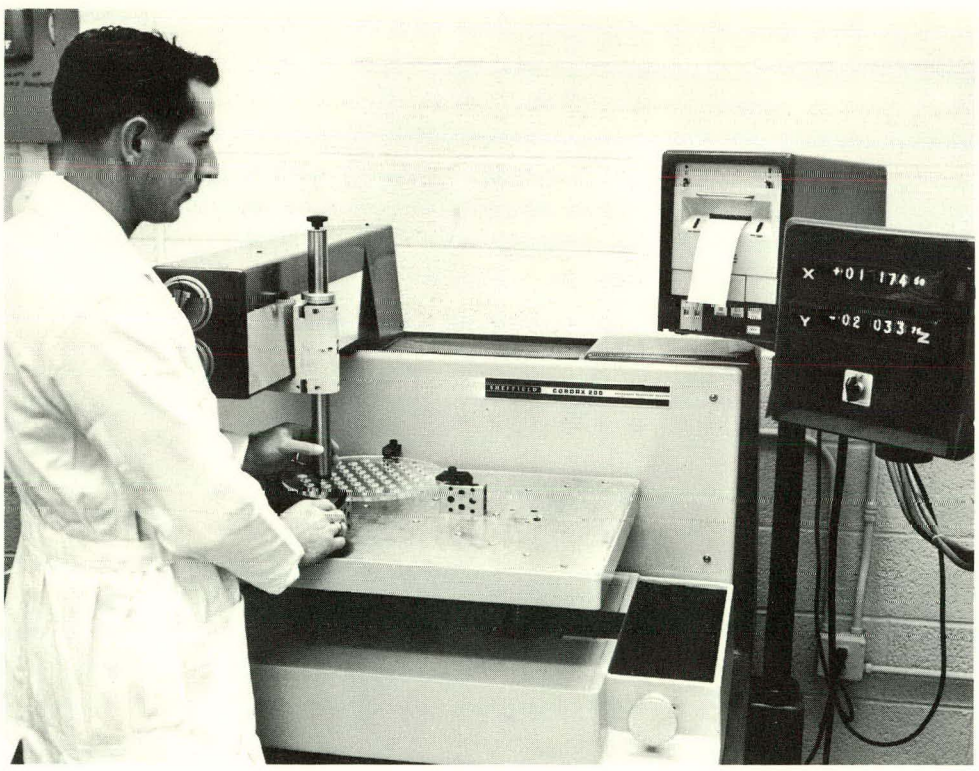


Figure 10. Inspector using the coordinate measuring machine to determine the precise location of holes in a bed-plate for a fuel element experiment.

The Cordax was used with a spring-loaded scribe adapted to the probe arm.

In addition to the work for Brookhaven, the Central Shops Division also did work for the Massachusetts Institute of Technology, the State University of New York at Stony Brook, the Universities of Wisconsin and Rochester, U.S. Naval Ordnance Laboratory, Union Carbide Corporation, AEC of Canada, Western Reserve University, the U.S. Department of Health, Education, and Welfare, and Picatinny Arsenal.

TECHNICAL INFORMATION

While the Laboratory's responsibilities with respect to public information and education are one aspect of the Information Division's work, the major effort in terms of number of staff members lies in the area of technical information. Thus, the Research Library, the Classified Library, technical editing, the processing of reports and their distribution, and patent review are all functions of the Division. These activities are discussed below.

The resources of the Research Library were used more extensively this year than in any previous year. Book and journal circulation showed the highest gains. The loan of translations tripled, with 80% of the loans resulting from the announcement of their availability in the *Weekly Selected Reading List.*

With the growth of industrial and academic research on Long Island, requests for the loan of library material have risen sharply. To meet this demand without having to lend material needed on site, approximately half of these requests are being filled by providing Xerox copies of the desired articles.

Requests for translations continue to increase. Eighty-seven articles were translated from the Russian, French, German, Italian, Hungarian, Polish, and Japanese languages. For the first time, a significant number of abstracts and articles were translated into Russian at the request of Brookhaven scientists presenting papers at meetings in the Soviet Union.

The Reference Section of the Library has become the center for coordinating two programs for the selective dissemination of information. Scientists representing the Laboratory's scientific departments receive weekly reports of the existence of journal literature of interest to them and their colleagues, by means of the service known as Automatic Subject Citation Alert. A second program carried out with the participation of the Chemistry and Applied Mathematics Departments is of particular interest to chemists. With the receipt of *Chemical Titles* on tape, the Chemical Titles Data System has been inaugurated, with Library staff members assuming the responsibility for operational continuity.

Work has continued with the Photography and Graphic Arts Division in a study of mechanized retrieval systems applicable to the rapid location of photographs. With a system selected, a subject analysis of photographic negatives has begun and a thesaurus is being compiled.

Demands for the Reference Section's routine services continue to increase. Requests for bibliographies and literature searches nearly tripled over last year's total, and a continuing search in five subject areas is being conducted.

In the Classified Library, the work load remains at approximately the same level as in the past few years. More than 1100 documents were received from other installations. The annual inventory revealed total holdings of some 17,000 documents, of which 7600 are secret. Although the Laboratory issued no classified formal reports, 725 requests from staff members for technical information were serviced during the year.

There was a decrease in the number of scientific manuscripts originating from Brookhaven-supported research and published as journal articles. However, this decrease was balanced by the growing number of informal, preliminary reports issued by scientific and technical staff members. The number of formal reports processed by the Editorial Section of the Information Division remained at about the same level as in recent years.

During the fiscal year the BNL Patent Office, which is responsible for review and clearance for patent matters of all scientific manuscripts, adopted an improved method of reporting inventions, combining the previously used preliminary invention report with the record of invention to simplify and reduce paper work. Although a direct comparison of the number of inventions reported under this new system and the prior system cannot be made, the total appears to be within the range of the past few years. However, the number of patent applications increased by almost 60% and reached a new high.

Table 8 summarizes the activities of the BNL Patent Office during fiscal 1966 and the two previous years.

Table 8

	Fiscal year		
	1966	1965	1964
Patent clearances	1155	1208	1085
Preliminary invention reports	3*	37	43
Records of invention	39	26	27
Patent applications	22	14	14

*Discontinued during fiscal 1966.

Two international activities in the field of technical information involved members of the Division's staff. The Head of the Research Library served as leader of a delegation of technical information specialists on a tour of Soviet information centers and libraries from February 20 to March 17. The visit was one included in the Agreement Between the U.S. and the U.S.S.R. on Exchanges in the Scientific, Technical, Educational, Cultural and Other Fields. The exchange visit by a Soviet delegation had been made in January; the Head of BNL's Research Library accompanied the delegation on its tour of 17 U.S. information facilities.

During March, the Head of the Information Division served as Director of the Technical Information Center at the Werken Met Atomen Exhibit at Utrecht, Netherlands. This exhibit was one of the AEC's "Atoms in Action" presentations in foreign countries.

TECHNICAL PHOTOGRAPHY AND GRAPHIC ARTS

The general level of activity in the Technical Photography Group has continued high. During fiscal 1966 a total of about 6200 jobs were worked on at the request of members of the BNL staff. The work load as expressed in jobs varied from 350 to 650 a month during the year. The production figures associated with the majority of the jobs are given in Table 9. A number of the services performed by the Technical Photography Group are not reflected in these figures.

The microdensitometer has been used to advantage in several areas of research in addition to the work associated with evaluation of bubble chamber film. Of particular interest was its use in studies of the absorption and sedimentation values of RNA molecules in solutions. A film was exposed by passing ultraviolet light through the solutions while in an ultracentrifuge. The microdensitometer was then used to measure the density distribution on the exposed film.

The Group has assisted in work on the spectral characteristics of arc plasma in air through the use of film with an extended range (1,000,000 to 1) of exposure latitude. High-speed motion picture photography was also used in these experiments, as well as in design test studies for hydrogen targets, in a multipulse camera for bubble chamber pictures, and in an experiment on photochemical reactions in which a dye was introduced in order to observe mixing patterns.

Requests for evaluation of lenses have increased. Some optical bench work has been involved, but most of the work has consisted of photographing resolution-targets and scales using the geometry of the required use of the lens system.

A number of short motion picture films have been produced by the Group. A film on extracorporeal irradiation of blood and lymph was given worldwide distribution by the AEC. Other short films were concerned with genetic plant tumors, the orderly packing of spheres, and the reactor physics of U^{233}, and a film dealing with the control of radiation exposure was made for use by the Health Physics Division. Several 3 to 5-min films were put together for use in a self-service viewer in the Exhibit Hall. Work is in progress on a film to document various applications of gamma irradiators. Under a contract with Owen Murphy Productions, Inc., a 30-min film about the Laboratory, to be called "The Brookhaven Spectrum," is near completion.

Experience with some new pieces of equipment installed last year has fully justified their acquisition. A continuous paper processor has been in operation for 10 months and has handled 52% of the total black-and-white print output. Use of this

Table 9

	Fiscal year		
	1966	1965	1964
Photographs	12,979	14,188	12,100
Photomicrographs	6,201	2,729	1,799
Lantern slides	13,840	14,551	13,883
Prints	51,258	51,851	50,990
Film processed, ft	3,815,853	3,781,043	4,525,997
Charts & graphs drawn	4,348	4,217	5,038
Motion picture footage	32,011	37,435	14,794

processor results in a significant time saving when three or more prints of a negative are required.

A small processor that uses sensitized paper on which the emulsion incorporates some of the developing agents has proved very useful when a stabilized print is wanted quickly. With this system such a print can be processed in about 15 sec. It has proved valuable in connection with the Bulletin Board and for press work in general.

Use of another small processor for short lengths (1 to 100 ft) of 16 or 35-mm film has resulted in considerable time saving. The processed film, completely dry, comes out of the processor <2 min after insertion into the machine. This machine is very useful in processing the short length of film used in connection with some types of computer output and also for test exposures of many types. The machine is easy to operate and is on standby 24 hr/day.

The silver recovery system has proved very worth while. During fiscal 1966, $\approx$\$11,000 worth of silver was collected and sold. The system is useful not only because of the dollar value of silver recovered but also because the used hypo can be reconditioned, after extraction of the silver, at a modest cost in time and chemicals and used again. During the year the savings resulting from this procedure amounted to about \$4600.

Several items of equipment installed during fiscal 1966 have improved the services provided by the Graphic Arts Group of the Division. A Photo-Direct Camera Processor was purchased after nine months of use on a trial basis. The experience with this equipment has proved that it can produce inexpensive printing plates of high quality for facsimile reproduction by the offset process. The Ektalith Processor, in use for several years, has been replaced by the Photo-Direct equipment. A 41-in. Robertson Process Camera was obtained as surplus equipment as a result of the shutdown of the AEC CANEL project. The larger film and copy board sizes of this camera will make it possible to expose a greater number of drawings or photographs simultaneously and thus result in labor saving. In addition, material that was difficult to process with the old camera, because of size limitation, can be processed with ease on the new equipment.

A Quick Copy Service Center was set up to provide short-run facsimile reproduction for customers with minimum delay and cost. As part of this service, a Xerox Model 2400 machine, which is $\approx$6 times faster than other copy machines, was installed to handle many jobs previously done on the slower machines. The Xerox service provided by another part of the Division has therefore been discontinued.

Production statistics for fiscal 1966 are shown in Table 10; they indicate a general increase in activity over any previous year. Some jobs were also subcontracted to the Government Printing Office in New York, and the Laboratory telephone book and some form work were purchased from commercial printers.

Some of the larger reports produced within the BNL printing plant during the year are listed below.

	Pages	Total impressions
Neutron Cross Sections, Second Edition, Supplement No. 2, Volume IIA, BNL 325	396	2,098,800
Annual Report, July 1, 1965, BNL 929 (AS-19)	258	567,600
Brookhaven Symposia in Biology No. 18, Genetic Control of Differentiation, BNL 931 (C-44)	282	1,269,000
Symposium on Inelastic Scattering of Neutrons by Condensed Systems, BNL 940 (C-45)	202	242,400
Some More Two-Body Kinematics Tables, BNL 945 (T-391)	706	847,200
Proceedings of the Summer Study Group on the Physics of the Emperor Tandem Van de Graaff Region, BNL 948 (C-46):		
Volume I	478	573,600
Volume II	394	472,800
Volume III	436	523,200
Annual Report, Nuclear Engineering Department, December 31, 1965, BNL 954 (S-68)	186	134,850

Table 10

	Fiscal year		
	1966	1965	1964
Photo-offset impressions	14,390,880	12,891,113	13,304,220
Quick Copy impressions	5,335,952	4,803,934	5,146,058
Reports and booklets, copies produced	80,625	75,805	92,625

INTERNATIONAL COOPERATION

The spirit of international cooperation in science is greatly fostered by the many arrangements whereby foreign scientists come to work at Brookhaven and Laboratory scientists attend overseas meetings and conferences. In addition to these individual visits, the Laboratory is involved in formal programs for cooperation with research centers in Turkey, Greece, and Puerto Rico. The first two of these programs are described below.

The BNL-Çekmece Cooperative Agreement

During the past year the sister laboratory arrangement between BNL and the Çekmece Nuclear Research Center has remained in effect. Only two man-trips were made to Çekmece as compared with ten in the previous year. The exchange of correspondence between research groups, the interlibrary loans, and miscellaneous other services by BNL have continued. The reduction in activity may be ascribed in part to the fact that many of the initial goals have been achieved, and a waiting period is appropriate to allow the joint projects to mature.

It should be noted, however, that BNL participation in the cooperative agreement has been limited by the small size of the Çekmece research staff. The recruitment and retention of scientific staff remains the most critical problem of the Turkish Center and has been of continuous concern to BNL. Undoubtedly most new research centers in the developing countries of the world face a similar situation. Obviously these new laboratories cannot flourish until the staff problem is solved. Experienced scientists are needed for senior staff positions to form a strong cadre to guide the research, but not many candidates are available. Although there are many able, experienced Turkish research scientists, most have emigrated to Europe or the United States and cannot be persuaded to return to Turkey under present conditions governing appointments. It is even difficult to recruit young, inexperienced research workers. The young scientists already on the staff seek more training and broader experience abroad. On the average, after two or three years at the laboratory, they obtain a fellowship or appointment in Europe or the United States. It is hoped that many of them will return to Çekmece after a few years and be capable of assuming greater responsibility.

Despite slow growth of staff, Çekmece has continued to develop both scientifically and in physical plant. First-class research has gone forward in chemistry, plasma theory, and biology completely under the direction of highly qualified Turkish scientists. The projects in which BNL personnel have participated – reactor physics, neutron cross sections, and neutron diffraction – have continued, and a few manuscripts have been prepared for publication.

The practical activities of the Center have increased steadily. The number of radioisotope shipments increased to 188 in fiscal 1966 from 50 in the previous year. A greater increase will occur next year because new hot laboratory facilities will permit the production of radioiodine, which is much in demand for routine medical use in Turkish hospitals. Some work on industrial radiography has gone forward. Last fall an IAEA Study Group Meeting on Irradiation Techniques at Research Reactors was held in Istanbul with Çekmece serving as host. A BNL staff member from the Reactor Division was one of the principal speakers. In all the above matters, BNL has given assistance and advice.

During the past year, a new chemistry building with hot laboratories, a combination administration and library building, and eight apartments have been completed and are ready for occupancy. Other buildings are under construction. It is clear that the Turkish Government continues to give strong support to the development of this research center. Without doubt the BNL-Çekmece sister laboratory arrangement can expedite the development. The Çekmece management and the Turkish Atomic Energy Commission have expressed a strong desire to keep the cooperative agreement in effect for several more years.

Cooperative Program With the Greek Nuclear Research Center (Demokritos)

Throughout 1965, informal discussions and formal correspondence between Brookhaven National Laboratory, the Director of the Greek Nuclear Research Center (Demokritos), and the Chairman of the Greek Atomic Energy Commission, Professor Zervas, took place to explore the feasibility of a possible cooperative sister laboratory arrangement. These discussions came to fruition late in 1965 when a formal, intergovernmental arrangement for initiation of the BNL-Demokritos sister laboratory program was completed.

In January 1966 a group of BNL scientists, representing the Nuclear Engineering, Physics, and Medical Departments, visited Demokritos to establish more detailed areas of possible cooperation. The group was joined at Demokritos by a scientist from the BNL Chemistry Department and a representative of General Atomic Division, General Dynamics Corp., who held visiting scientist appointments at Demokritos under IAEA auspices. The group spent one week at the Greek Nuclear Research Center, and its conclusions were summarized in a report submitted to the US AEC Division of International Affairs in May 1966. A similar report was submitted to Admiral Theofanides, the President of the Greek Atomic Energy Commission.

A brief summary of the report is given below.

1. Strong and active research programs already exist at Demokritos, and many of these have counterparts in similar research efforts at BNL. The areas in which cooperation might be successful include physics (solid state and neutron physics), reactor technology, chemistry, and the life sciences (medicine and biology). The interest in carrying out such cooperative ventures is high at both institutions.

2. BNL will assist Demokritos in certain peripheral but important problems in the carrying out of research, namely, those in the field of computers and data processing methods and the administrative problems encountered in the operation of a large laboratory.

3. A loan agreement should be negotiated whereby certain surplus equipment not needed at BNL might be temporarily transferred to Demokritos to assist specific research programs.

4. A continuous and frequent exchange of personnel between the sister laboratories is essential and should be continued for several years.

After the initial formal visits to Demokritos, steps were taken to implement these recommendations. In May of 1966 another visit by BNL personnel took place. A member of the Reactor Division reviewed problems of isotope production at the Demokritos Reactor, a Physics Department representative discussed the crystal-growth and sample-preparation laboratories for the solid state group, particularly for neutron x-ray diffraction experiments. A Biology Department scientist visited the Divisions of Biology and Biochemistry and Experimental Medicine. Collaboration with the reactor physics group was continued by a BNL specialist in this field. In addition to these contacts, a visit was made late in June by a member of BNL's Chemistry Department to further a program of crystal structure determinations by neutron diffraction techniques.

A loan agreement has been approved by the US AEC and forwarded to the Greek AEC for approval. Under this proposed agreement, a cryostat, oven, neutron detector, and a paper-tape perforator would be transferred to Demokritos for use in an experiment to determine the effects of crystalline binding of atoms on the shape of neutron absorption resonances.

Further visits to Demokritos are contemplated for the summer and fall to assist in the above experiment and to establish additional programs, especially in the life sciences. One of the problems under review at present is that limiting the scope of the cooperative program so that a reasonable number of successful projects can be maintained.

Administration and Operations

The management operations reviewed in this section have been designed to facilitate and encourage the research activities of the Laboratory's scientific staff.

PERSONNEL

Scientific Staff and Students

During the 12 months ending May 31, 1966, the number of regular staff members increased by ≈4%, as shown in Table 1. This compares with an average increase of 8% per year for the previous three years. Turnover continued to be significant: 56 scientists and engineers were appointed to the staff, and 38 terminated their appointments.

Since 1961, the number of salaried visitors as of May 31 has ranged from a low of 103 to a high of 122. During this period, postdoctoral Research Associates have accounted for 70% of the appointments in effect at year end. Turnover in this category is particularly high because of the limited term of these appointments. During the past year, 52 recent graduates began salaried appointments as Research Associates, and 49 completed their terms. Of those completing postdoctoral investigations, 14 were promoted to the regular staff.

The number of scientists and students holding nonsalaried appointments continued to increase. As of May 31, fewer than 10% of these appointees were participating at the Laboratory on a full-time basis.

May 31, instead of June 30, was used in Table 1 to exclude from the statistics more than 300 visitors who were at Brookhaven only during the summer months. Similarly, the year ending May 31 was used in Table 2 to include participants in only one summer program.

Table 1

Scientific Staff and Students on May 31, 1966 and 1965

	Regular staff		Visitors			
			Salaried		Nonsalaried	
	1966	1965	1966	1965	1966	1965
By appointment category						
Staff						
Senior Scientist	78	74	1	0	56	54
Scientist	153	143	10	5	139	130
Associate Scientist	154	142	10	10	152	147
Assistant Scientist	57	65	9	12	98	92
Research Associate	—	—	79	76	72	57
Students						
Junior Research Associate	—	—	6	5	112	87
Research Assistant	—	—	0	0	101	103
Total	442	424	115	108	730*	670**
By academic degree						
Ph.D. or M.D.	312	300	103	100	493	448
Master	54	50	6	6	96	99
Bachelor	72	69	6	2	124	107
No degree	4	5	0	0	17	16

*62 of these appointees were at BNL on a full-time basis as of May 31, 1966.
**50 of these appointees were at BNL on a full-time basis as of May 31, 1965.

Table 2

Classification of Visiting Scientists and Students Participating in BNL Program for One Month or More, June 1, 1965 – May 31, 1966

	Guests and salaried visitors							
	More than 3 months		Less than 3 months		1965 Summer program		Total	
	Salaried	Guest	Salaried	Guest	Salaried	Guest	Individuals	Institutions
University staff	21	53	8	55	74	41	252	107
Thesis students	9	21	1	22	2	3	58	25
Student Research Assistants	1	9	0	18	114	36	178	69
Subtotal	31	83	9	95	190	80	488	138 different
Industry	2	2	1	2	2	4	13	10
Other institutions	16	38	8	16	7	12	97	51
Total	49	123	18	113	199	96	598	199 different

Table 3

Consultants' Services

	Fiscal year		
	1966	1965	1964
Total contracts in effect June 30	98	91	92
Number of consultants used	59	61	63
Number of man-days of service	472	495	626

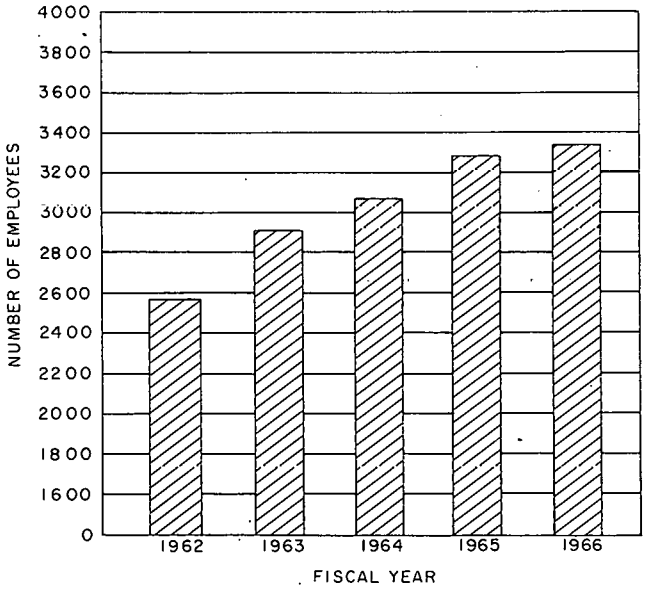


Figure 1. Laboratory growth.

Table 2 lists the numbers of visiting scientists (not including salaried Research Associates) and students who worked at the Laboratory for cumulative periods of one month or more. The total of 598 individuals compares with last year's total of 596 and the all-time high of 603 reported in 1964. In addition to those included in Table 2, 275 scientists and students worked at Brookhaven for less than one month.

Table 3 shows the extent to which consultants' services have been employed during each of the past three years.

Summer Program for 1966

Arrangements have been made for 330 visiting scientists and students to work at the Laboratory during the summer of 1966. Of this number, 145 are staff members from colleges, universities, industrial organizations, and other institutions, and 185 are students.

Special groups include 112 students in the Laboratory's fifteenth annual summer student program and 19 Health Physics Fellows.

Employment

Throughout fiscal 1966 the Laboratory experienced steady growth (see Figure 1) and employed a total of 471 personnel. As of June 30 the population, exclusive of guests, research collaborators, and temporary appointees, was 3343, a net increase of 98 over 1965. Table 4 summarizes the employment experience for the year.

The need for technically specialized personnel remained constant and difficult to satisfy, particularly in the fields of data processing and engineering functions.

Training and Education

The supervisory training program extended from November to March and was again directed toward smaller, discussion-type seminars, with a total of 229 service and scientific division supervisors in attendance.

Table 4

Employment Statistics*

	June 30, 1966	June 30, 1965
Scientific staff**	547	527
Scientific professional staff	390	357
Nonscientific staff	2406	2361
Total	3343	3245

Turnover data	Number	1966 Annual rate (%)	Number	1965 Annual rate (%)
Accessions				
Scientific staff**	113	21	107	21
Scientific professional staff	82	22	64	19
Nonscientific staff	276	12	298	13
Total	471	14	469	15
Separations				
Scientific staff**	93	17	96	18
Scientific professional staff	49	13	30	9
Nonscientific staff	231	10	163	7
Total	373	11	289	9
Net Accessions				
Scientific staff**	20	4	11	3
Scientific professional staff	33	9	34	10
Nonscientific staff	45	2	135	6
Total	98	3	180	6

*Figures do not include 97 temporary summer nonstudent employees. Guests and temporary student employees are included in Table 2.

**Including Research Associates and visitors.

Secretarial seminars conducted in April included presentations by the managers of seven Laboratory service divisions who outlined administrative functions in their respective areas of responsibility in order to facilitate secretarial procedures in these areas.

Under the Laboratory's tuition refund policy, 227 employees attending 14 academic institutions were reimbursed in part for tuition costs.

Labor Relations

Contract negotiations between the Laboratory and Directly Affiliated Local Union No. 24426, AFL–CIO, began in October 1965 and reached committee agreement on December 14, 1965. On December 16 the membership, consisting of employees throughout Central Shops, Plant Maintenance, Supply and Materiel, and the Fire Fighters, failed to ratify the agreement and a strike vote followed. Negotiations resumed with the assistance of the Federal Mediation and Conciliation Service and final agreement was reached on January 10, after the withdrawal of the 3-platoon, 56-hr work week for the Fire Fighters. The 3-year contract provides an hourly rate increase of 10¢ effective January 1, 1966, 10½¢ in 1967, and 15¢ in 1968. The vacation policy of ¼ day additional vacation for each 5 years of service was extended so that 20-year employees will now receive 24 vacation days per year; this benefit has also been extended to all nonbargaining-unit wage employees. No other benefit changes were effected under the contract.

Negotiations with the Long Island Guards Union, representing 28 patrolmen, resulted in settlement of a 2-year contract agreement with an hourly rate increase of 10¢ effective March 1, 1966, and 10½¢ effective March 1, 1967.

The contract with the Oil, Chemical, and Atomic Workers, consisting of 31 members in the Reactor and Hot Laboratory, continued with neither party requesting renegotiation.

The new system of meeting with the DALU Union Relations Committee three weeks in a row rather than on an *ad hoc* basis, coupled with informative exchange meetings held with the eight chief stewards every fourth week, has reduced the number of grievances and the time spent in grievance meetings and has improved communications between the Union and the Laboratory.

Employee Services

Following the most intensive and extensive review of the total insurance benefit program in the

history of the Laboratory, the following changes were effected.

1. In the Group Medical Plan, major medical coverage was improved and provision of limited payments for diagnostic x-ray and laboratory tests was instituted. Ninety-five percent of all regular Laboratory employees are currently enrolled in this optional plan.

2. On January 1, 1966, a reduction in the eligibility period from 3 years to 1 year of Laboratory service for long-term disability insurance was effected. In addition, the maximum payment allowable under the plan increased from $500 to $1500 per month.

3. A $100,000 noncontributory group travel accident insurance policy for all regular, full-time employees became effective on November 1, 1965.

4. On March 1, 1966, a second life insurance option was incorporated into the present group term plan. Under this elective, called Supplemental II, employees may carry total group life insurance up to ≈3 times their base annual salary. Of the 72% of all regular employees currently enrolled in the Supplemental I insurance plan, 88% have also chosen the Supplemental II option and are thereby covered under the total life insurance plan.

5. The coverage provided under the basic life insurance policy was extended from $25,000 to $40,000, with the total maximum reimbursable amount under the plan being $100,000.

During the year 19 employees retired and 113 received 10-year service awards. This year 20-year awards were inaugurated, with the Director making the initial presentation to Mrs. Mariette Kuper and Dr. Clarke Williams on June 7, 1966.

ARCHITECTURAL PLANNING

The following major facility projects with a total value of slightly more than $90,000,000 were initiated, under construction, or completed during fiscal 1966.

Tandem Van de Graaff Accelerator
High Flux Beam Research Reactor
Chemistry Building
Physics and Mathematics addition to Physics Building
Steam plant addition
AGS Service Building addition
Animal laboratories
Low-level radiation counting facility for clinical reseach
Lecture Hall–Cafeteria
Site utilities
AGS conversion

The contracts for architect-engineer and construction work were held by the AEC and administered by its Brookhaven Office with the exception of those for portions of the site utilities project which are held by Associated Universities, Inc., and administered at BNL by the Architectural Planning Division, which also acted on behalf of BNL in all other work to provide the liaison required from early planning through construction.

Smaller projects initiated or undertaken during fiscal 1966 amounted to $1,667,000 under the General Plant Projects program. There were more than 175 of these minor additions to, or modifications of, facilities for the research and supporting staff; many of these presented special engineering problems and required considerable engineering effort. The general plant projects exceeding $50,000 were as follows: Men's Residence Building, one-story office building addition to the AGS, alterations and additions for the Radiation Division of the Nuclear Engineering Department, and air-conditioning system improvements for the Instrumentation and Health Physics Department. As in the past, the Architectural Planning and Plant Maintenance Divisions worked closely to coordinate many of these projects; in several cases the Plant Maintenance Division undertook management of the construction.

Early in 1966 the Architectural Planning Division began preparing the facilities section (buildings) of the budget request for fiscal 1968. This involved site locations, preliminary building plans, cost estimates, and descriptive brochures for the projects listed below (total estimated cost, $11,050,000).

Nuclear Engineering Building, Phase II
Metallurgy Building addition
Technical Services Building
Electron Accelerator
Molecular Biology Laboratory

During fiscal 1966 the Division continued to assist the Accelerator Department in delineating the scope of the proposed AGS conversion program including estimates of costs for buildings, structures, utilities, and site work as well as layouts and site plans as required. Similarly, assistance was given to the Physics Department in connection with the proposed 14-ft cryogenic bubble chamber.

PLANT MAINTENANCE

Principal functions of the Plant Maintenance Division include maintenance and operation of all

Laboratory utilities, buildings, grounds, and heavy mobile equipment, operation of the Hot Laundry, and the provision of janitorial services. These functions have continued to grow to meet the needs of a growing Laboratory. Certain subsidiary responsibilities were separated into a new division (Staff Services) as of January 1, 1966, and are no longer functions of the Plant Maintenance Division. These included automotive vehicles, telephone service, mail distribution, housing, cafeteria operation, and travel arrangements.

In addition to maintaining and operating plant and facilities in general support of the research programs, the Division supplies skilled craftsmen and laborers for work directly on these programs. During fiscal 1966, 118 man-years of rigging, carpentry, electrical, plumbing, general labor, and similar work were expended in contributed technical services.

During the year the Division initiated facility modifications and major maintenance programs costing almost $900,000. Projects included extensive overhaul and improvement of warehousing facilities, with provision of ramps and leveling docks for effective use of mechanical materials-handling equipment. Five former Army buildings were moved to new locations and renovated to provide 30,000 sq ft of additional space for laboratories, offices, and modern, dormitory-type living facilities (see Figure 2). Another 10,000 sq ft was added to existing buildings. Provision was made for telephone trunk cables from the New York Telephone Company's new central office in Yaphank with the installation of a 3200-ft concrete duct system from the west boundary line to Upton Road.

Further progress was made in replacing overhead electric power and communications lines with underground facilities. During the past year the pole line along Upton Road south of Brookhaven Avenue and 9000 ft of pole line that formerly served the apartment area were replaced. More than five miles of overhead pole lines have now been removed; six miles remain.

Consultant services once again supplemented the efforts of the Division's technical staff. The services of consulting engineers were employed in analysis of the refuse disposal system and in evaluation of janitorial services and Hot Laundry operations.

The utilization of manpower and the distribution of costs within the Plant Maintenance Divi-

Figure 2. Men's Residence Building, completed early in 1966. The building was constructed from three 2-story barracks buildings that were relocated and rebuilt as a single complex. It contains 90 bedrooms, with central kitchen, dining, bath, and lounge facilities.

sion for fiscal 1965 and 1966 are summarized in Tables 5 and 6.

PLANT PROTECTION AND SECURITY

The Plant Protection and Security Division continued to perform its assigned functions during fiscal 1966.

Although the scope of the security function at the Laboratory has contracted substantially since Brookhaven's early days, the Laboratory continues nevertheless to maintain an extremely active security clearance program. At the end of fiscal 1966, about 675 employees and affiliates had active "Q" clearance and about 300 had active "L" clearance. These clearances are required in connection with classified material and documents at the Laboratory and also to give Brookhaven scientists and technical personnel full access, when necessary, to restricted data, both at BNL and at other laboratories and institutions.

The physical growth of the Laboratory and the expansion of its research programs have necessitated ever-increasing emphasis upon the Labora-

Table 5

Manpower Utilization

Type of work	Fiscal 1966		Fiscal 1965	
	Productive man-years	Percent of total work	Productive man-years	Percent of total work
Maintenance, repairs, and utilities operations	150	41	147	37
Major maintenance programs	2	1	7	2
Facility improvements	4	1	5	1
Research program support	116	32	97	25
Building janitor services	80	22	73	19
Decontamination	3	1	6	1
Hot Laundry operation	7	2	7	2
Conferences and miscellaneous services*		—	4	1
Telephone and telegraph services*	—	—	11	3
Transportation, housing, and mail services*	—	—	35	9
Total	362	100	392	100

*Transferred to the Staff Services Division January 1, 1966.

Table 6

Costs of Supplies, Materials, and Contracts

	Fiscal 1966	Fiscal 1965
Maintenance and utilities materials	$ 337,295	$ 346,523
Major maintenance materials and contracts	433,165	485,001
Facility improvement materials	521,128	375,254
Building janitor supplies	61,647	57,032
Decontamination	687	—
Hot Laundry	15,011	9,141
Fuel oil	416,503	333,877
Electricity	1,756,098	1,627,538
Gasoline*	—	25,468
Telephone, teletype, and mail*	—	348,285
Housing and cafeteria*	—	38,569
Total	$3,541,534	$3,646,688

*Transferred to the Staff Services Division January 1, 1966.

tory's plant protection program. The increase in this aspect of the Division's functions has been met through adaptation of industrial plant protection techniques and practices to the specialized requirements of Brookhaven. During fiscal 1966, use of closed-circuit television was made in the reactor complex, with gratifying results in effectiveness of operation and economy of manpower. The increase in Laboratory employment, coupled with a substantially greater number of persons visiting the Laboratory, has given rise to automobile traffic and parking problems, which have been effectively resolved.

The Laboratory's professional Fire Group maintained its excellent record in meeting potentially dangerous fire situations at the Laboratory. An active fire-inspection and fire-prevention program is a continuing and important aspect of the Fire Group's activities; close liaison with scientific and technical personnel engaged in research experiments and other activities presenting potential fire hazards is regularly maintained, with excellent results. During the year, fire-fighting equipment was increased and modernized; mutual-aid fire-fighting agreements with nearby communities have been continued; and training in fire-fighting has been accelerated.

Fortunately, there were no major fires at the Laboratory during fiscal 1966. Responses to fire alarms are tabulated below.

	1966	1965	1964
Responses on site	196	177	152
Responses off site	7	8	5
Investigations	106	104	47
Total	309	289	204

BUSINESS MANAGEMENT AND ADMINISTRATION

Comparative annual statistics for business operations and the distribution of personnel are given in Tables 7 and 8.

Purchasing

During the fiscal year economic conditions have led to a "seller's market." Prices continued to rise and materials were in short supply, which lengthened the time required for procurement. Despite these adverse conditions, the Division has been able to negotiate many attractive price and discount arrangements through expanded use of contract-buying concepts. These negotiations have resulted in documented cost reductions in excess of $900,000.

Early in the year, BNL was host to the 9th Annual AEC Prime Contractors Purchasing Seminar. At that time BNL initiated action with the other National Laboratories to pursue the possibility of a joint procurement effort of certain commodities used by all. The concept consolidates the material requirements of all the Laboratories into a single buying power enabling all to realize significant savings. In May BNL invited Argonne National Laboratory, Oak Ridge National Laboratory, Stanford Linear Accelerator Center, Los Alamos Scientific Laboratory, and Lawrence Radiation Laboratory (Berkeley and Livermore) to another meeting to discuss the feasibility, coordination, procedures, and implementation of this program.

In-house seminars and the periodic reviews of individual performance have greatly assisted in the development of Division personnel. Many goals established in the 5-year master plan are approaching fruition. The Purchasing Manual has been supplemented by new procedures covering

Table 7

Summary of Operations

	Fiscal 1966	Fiscal 1965
Number of procurements	38,191	37,307
Value of procurements	$28,100,000	$25,194,165
Number of receiving actions	46,539	46,010
Number of stores issues	340,914	383,601
Value of inventory turnover	$ 3,605,263	$ 3,189,000

In addition, excess serviceable equipment representing a cost avoidance of $2,343,100 has been acquired.

Table 8

Distribution of Personnel

Division	Staff	Technical and clerical	Fiscal 1966 total	Fiscal 1965 total
Purchasing	22	19	41	38
Supply and Materiel	11	81	92	91
Systems and Data Processing	14	14	28	24
Total	47	114	161	153

the development and use of the various types of contracts. The development of an electronic data-processing master purchasing file is near completion. A vendor coding system is operational, and a mechanized report system to expedite orders will be in operation soon. Investigations are also being made relative to the adoption of a mechanized check-with-order system to minimize administrative effort involved in payment for purchases. In addition, the Purchasing Division's 5-year plan is being revised to include new projects leading to eventual integration of the purchasing effort with the supply and materiel and fiscal operations.

An addition to the Purchasing Division's building has been completed recently. There now is adequate space for the normal conduct of operations, with some room for limited future expansion. The addition has also made possible a better work layout and the segregation of functional responsibilities within the Division.

Supply and Materiel

Improvements continue to be made in the Division's administrative as well as operational functions. All areas have undergone closer analysis and procedural change for long-range improvement. The Inventory Management Section has been reorganized into two separate functions: (1) the Requisition/Inventory Management Section, which will continue to review inventory items for bulk procurement on a long-term basis, and (2) the Quality Control Section, which will establish Federal Supply Schedule numbers for each inventory item, evaluate the adequacy of required design statements, conduct a continuing review of all inventory items to delete duplicate or obsolete materials, and maintain liaison with all Departments to add items to inventory that are currently procured directly.

In a joint effort with the Systems and Data Processing and Fiscal Divisions, new capital equipment record-keeping procedures have been instituted and the Property Record Catalog is undergoing complete revision.

A Capital Equipment Housecleaning Week resulted in the return of 470 pieces of idle equipment to the various equipment pools for reutilization or disposal. The program released valuable space for storage of equipment required for future use. All items placed in the central instrument pool have been reinventoried and included on machine records. This permits periodic machine-reporting of items in current inventory and dissemination of this information to possible users.

In an effort to maintain adequate storage facilities, a warehouse was completely renovated and enlarged primarily to provide additional storage for the high energy physics groups. Administrative control of equipment moving in or out of this complex is maintained on computer records to allow periodic review of all equipment stored in this building.

The Stores Section has continued to decentralize operations and whenever practical to locate materials closer to the consumer. A new stockroom has been added to the High Flux Beam Research Reactor complex, and a stockroom has been enlarged to provide ready access to a greater number of maintenance supplies.

Systems and Data Processing

The Division expanded its services during the year in the areas of facilities budget and expense reporting, personnel expense forecasts, purchasing operating and statistical reports, and daily reporting of certain classes of budget and expense items. New procedures for printing, handling, and reconciling pay checks were instituted. Improvements and refinements were made in the supply and materiel inventory applications, capital equipment records, health physics reports, and the job labor and material cost system. Substantial modifications were made to personnel, payroll, and communications reports, and the salary review reporting system was revised, rewritten, and simplified.

This work represents the bulk of the Division's short-range plan established last year. As these projects have been completed, implementation of the Division's intermediate-range plan has started. The intermediate-range plan provides for converting present automatic data-processing operations from the Univac solid state computer to a more efficient and flexible "third generation" computer. The new computer, in turn, will provide the on-line capabilities required for the Division's long-range plans.

During the past year detailed system specifications were prepared and submitted to various computer manufacturers for their recommendations. Seven formal proposals were received and carefully evaluated. It was determined that an IBM 360 Model 30 tape-and-disk system would best meet the Laboratory's long-range administrative data-processing needs. Installation of the system is planned for the last quarter of calendar 1967.

Use of the present Univac computer has continued to expand. Current usage is in excess of 18 hours per day. Projections based upon past use indicate that the system will reach its effective capacity during the first quarter of fiscal 1967. Performance of the Univac solid state computer has been good, averaging nearly 95% up-time.

The Division has been strengthened during the year by the establishment of a separate data control function and the transfer of program maintenance to the Operations Group. Personnel development through formal evaluation and review and periodic counseling has continued. Promotion from within the Division has provided opportunities for supervisory personnel to advance to the professional classifications of systems analyst and programmer.

Staff Services

The Staff Services Division was established as such on January 1, 1966, having functioned prior to that time as a group within the Plant Maintenance Division.

The Staff Services Division consists of 61 persons, including housing, travel, and mail clerks, telephone and teletype operators, automobile and truck mechanics, janitors and matrons, and appropriate supervisory personnel.

The Division provides the following services for the Laboratory staff and visitors:

Housing. On-site housing includes 1 to 4-bedroom family units, men's and women's residences, and guest houses. The quality and quantity of on-site housing have been improved. A total capacity for nearly 800 persons is fully utilized each summer. Billeting, billing, and janitorial maintenance are accomplished by the Housing Office. The triennial rental rate survey pursuant to Bureau of the Budget Circular No. A-45 was initiated; completion is expected early in fiscal 1967.

Travel. A complete Travel Office is maintained. Tickets, travel reservations, and accommodations are obtained for all personnel traveling in an official capacity. Tickets and associated reservations for space and cars for more than 6000 trips were handled this year.

Telecommunications. Telephone, telegram, and teletype services for the Laboratory are operated by the Division. At present 1780 lines and 2800 phones are installed, 15% more than in fiscal 1965. This increase is due in large part to the completion and occupancy of the new buildings for Chemistry, Physics, and Applied Mathematics.

Mail. A mail distribution service is maintained to effect frequent pickup and delivery of United States and interoffice mail at each of 88 Laboratory mail drops. As the result of the increase in volume of mail, $\approx$10% per year, an additional mail clerk was employed this year, and the frequency and method of distribution of mail were modified to effect three deliveries and pickups of mail per day at most mail drops. In addition, several standard distribution lists are maintained and an Elliott Dymatic 7000 addressing machine is employed to facilitate efficient distribution of material to appropriate personnel.

Transportation. A pool of $\approx$25 vehicles is maintained. Vehicles are issued on a trip basis for accomplishment of official business. In addition, limited driver service is available when use of a passenger-operated vehicle is not practicable.

Motor Vehicles. The entire fleet of vehicles is acquired, maintained, assigned for use, rotated in assignment, and readied for disposal by the Division. Most vehicles are assigned to user departments or divisions and operated on a subpool basis to eliminate the need for drivers, dispatchers, and radios. Total mileage this year was 1.5 million, or $\approx$450 miles per employee.

Food Service. Food service is provided by a concessionaire in the dining room of the Brookhaven Center, in a cafeteria, and by an assortment of vending machines. Maintenance of the buildings and equipment employed and direct liaison with the concessionaire are responsibilities of the Division.

Special Staff Services. The Laboratory is host annually to more than 150 scientific seminars, conferences, and other meetings. Each requires all or some of the above services and in some instances additional services unique to the situation. The necessary planning, acquisition, and coordination of these services are additional functions of the Division.

Conferences, Public Information, and Education

The seventh annual series of George B. Pegram Lectures was delivered at the Laboratory on October 25, 27, and 29, 1965, by Dr. Richard Hofstadter, and the eighth on March 2, 4, 7, and 9, 1966, by Dr. Louis S.B. Leakey. The subject of the seventh series was "Academic Freedom and the Scientific Ideal." Dr. Hofstadter, an eminent

scholar and lecturer in American political history and higher education, developed his theories in three lectures entitled "The Old-Time College and the Age of Dogma," "The Impact of Nineteenth-Century Science," and "The Twentieth Century and Social Science." Dr. Leakey, British archaeologist and physical anthropologist, spoke on "A Review of Theories on Human Evolution and a Revision." He dealt with the theories of evolution and described his excavation work at Olduvai, Tanzania.

On January 13 Dr. Ralph Bunche was the first AUI Trustee Distinguished Lecturer. This lecture series was established by Associated Universities, Inc., to broaden the subject matter of lectures available at the Laboratory and to reflect the interest shown in the George B. Pegram Lectures. The Distinguished Lecture series calls for single talks by individuals outstanding in their fields of endeavor, without regard to their connection with science. Dr. Bunche chose as his title "U.N. Peacekeeping: Crisis and Prospect." The second lecture in this series was given on June 14 by Dr. Bentley Glass, eminent biologist and Academic Vice-President of the State University of New York at Stony Brook. His subject was "Genetic Continuity: The History of a Scientific Concept."

At the dedication of the High Flux Beam Research Reactor (HFBR) on April 22, Dr. Gerald F. Tape, US AEC Commissioner, delivered the dedicatory address. The ceremony was followed by a joint technical meeting of the New York Metropolitan Section of the American Nuclear Society and HFBR engineers and scientific experimentalists.

Among the large conferences held at the Laboratory during the fiscal year were the following: Conference on Inelastic Scattering of Neutrons by Condensed Systems, September 20 to 24; Symposium on Accelerator Radiation Dosimetry and Experience, sponsored by the AEC, November 3 to 5; the Seventh Symposium on Structure and Function of Polypeptide Hormones: Insulin, November 8 to 10; Joint Meeting of the Institute of Mathematical Statistics, the Biometric Society, and the American Statistical Association, April 27 to 29; and Brookhaven Biology Symposium No. 19, entitled "Energy Conversion by the Photosynthetic Apparatus," June 6 to 9.

In addition, a number of smaller meetings were held, such as the fifth meeting on Irradiation Effects on Reactor Structural Materials, July 27 to 29; the meeting of Division of Isotopes Development Contractors, October 7 and 8; the ninth annual Purchasing Agents Conference, October 12 to 14; the meeting of laboratory directors of various public health services, August 24 and 25; and many others. Informal meetings included one on the evaluation of nuclear data files, June 9 and 10, another on the effects of irradiation on structural materials, June 22 to 24, and several on accelerator development.

The Environmental Science Panel of the National Science Foundation met at Brookhaven on June 16 and 17; great interest was shown in the ecology forest.

The Physics Department sponsored a summer study session on Van de Graaff research, June 21 through July 16.

The sixteenth annual Visitors' Day for the general public on October 16 was attended by about 5000 persons. The twelfth annual High School Visitors' Day on October 30 was attended by about 5000 students from 187 high schools. The eighth annual College Visitors' Day on November 6 was attended by 1800 undergraduate students representing 81 colleges and universities. The second annual Open House for Nurses was held on May 11.

On February 11 the Laboratory held its tenth Science Youth Day in observance of Thomas Alva Edison's birthday. The 162 Suffolk County high school students attending this event concentrated on Brookhaven's newest research tool, the HFBR. After receiving a detailed description of the reactor and its experimental uses, they toured the facility.

During the year the following foreign groups visited the Laboratory: 16 officers from the French National Institute of Armament, September 27; 17 members of the International Electrotechnical Committee, September 27; 11 students from the University of Toronto, October 21; 8 members of a Japanese Radiation Chemistry Study Team, November 19; 10 USSR nuclear physicists, December 13 and 14; 8 Mexican students sponsored by the Experiment in International Living, January 11; 18 West German doctors, May 19; 7 members of the Japanese Science Council, May 27; 8 members of a Japanese Plutonium Medical Team, June 14; 6 members of a USSR delegation of medical tracer specialists, June 23; and 12 Canadian military officers, June 24.

On March 30 and 31 the Laboratory gave an extensive indoctrination into its research activities to the participants in Columbia University's Ad-

vanced Science Writing Program of the Graduate School of Journalism. Other visitors included 388 persons representing 9 professional groups, 313 teachers attending 8 National Science Foundation Institutes, a group of West Point cadets, students from Fort Hamilton Chaplain School, an AFL–CIO staff subcommittee, a group from the U.S. Civil Service Commission, a number of groups from various civic and professional organizations, and federal, state, and county officials. Nearly 2000 professional, governmental, and industrial representatives from the United States and foreign countries visited for short periods during the year. Continuing its program of public information to neighboring communities, the Laboratory arranged for 23 speeches by staff members to civic, educational, and other groups.

The Public Information Office continues to experience an increase in requests for information from students and teachers. Most of these are requests for assistance in the preparation of science projects and term papers. Technical information is also requested by many science writers, who are invited to visit the Laboratory whenever possible to gain first-hand impressions of the research projects in which they are interested. Most of the inquiries from the lay public and from students can be met adequately by mailing the appropriate literature from the extensive collection of pamphlets and reprints now available, but some require more personalized attention. Booklets and information sheets describing Brookhaven's important new research facilities, such as the HFBR, are prepared as necessary. There continues to be an increase in the number of press releases, prepared and disseminated by the Public Information Office, covering significant scientific developments at the Laboratory.

Appendix A

PUBLICATIONS, JULY 1, 1965 – JUNE 30, 1966

This list includes official Laboratory publications, abstracts of papers which were or will be presented at scientific meetings, and publications by staff members, consultants, and guests. All these listings result from work done at the Laboratory; they were submitted during the review period.* Abstracts are indicated by (A); letters to the editor, (L); and notes, (N). Acceptance for future publications is designated by (in press).

GENERAL PUBLICATIONS

Annual Report, July 1, 1965. BNL 929 (AS-19).
Annual Report, Nuclear Engineering Department, December 31, 1965. BNL 954 (S-68).
Conference Reports:
- Brookhaven Symposia in Biology No. 18. *Genetic Control of Differentiation.* BNL 931 (C-44).
- *Symposium on Inelastic Scattering of Neutrons by Condensed Systems, September 20-22, 1965.* L.M. Corliss, Editor. BNL 940 (C-45).
- *Proceedings of the Summer Study Group on the Physics of the Emperor Tandem Van de Graaff Region, June 21–July 16, 1965.* BNL 948 (C-46) (3 volumes).
- *Process Radiation Development Program Summaries, Fifth Annual Contractors Meeting, Brookhaven National Laboratory, October 7-8, 1965.* BNL 949 (C-47).

Brookhaven Lecture Series:
- 35. *The Problem of Development,* E. Caspari. BNL 976 (T-411).
- 42. *Mechanism of the Immune Response,* M.E. Koshland. BNL 912 (T-374).
- 46. *Passage of Charged Particles Through Crystal Lattices,* C. Erginsoy. BNL 944 (T-390).
- 47. *Chemical Crystallography,* W.C. Hamilton. BNL 930 (T-384).
- 49. *Neutrons as Magnetic Probes,* R. Nathans. BNL 946 (T-392).
- 50. *Symmetry Principles in Physics,* C.N. Yang. BNL 956 (T-397).
- 51. *Defects in Crystals,* G.J. Dienes. BNL 952 (T-395).
- 52. *Genetic Tobacco Tumors and the Problem of Differentiation,* H.H. Smith. BNL 967 (T-405).

High-Temperature Liquid-Metal Technology Review:
- Vol. 3, No. 4, August 1965. BNL 953 (PR-16).
- Vol. 3, No. 5, October 1965. BNL 962 (PR-17).
- Vol. 3, No. 6, December 1965. BNL 972 (PR-18).
- Vol. 4, No. 1, February 1966. BNL 980 (PR-19).
- Vol. 4, No. 2, April 1966. BNL 991 (PR-20).
- Vol. 4, No. 3, June 1966. BNL 50003 (PR-21).

Bibliographies:
- *Bibliography of Technical Publications and Reports of the Radiation Division, Brookhaven National Laboratory, January 1963–June 1965 Inclusive,* D.S. Ballantine and L.E. Kopp. BNL 943 (L-104).

Informal Reports:
- *Alternating-Gradient Synchrotron Conversion Program.* BNL 9500.

Miscellaneous:
- *Neutron Cross Sections,* BNL 325, Second Edition, Supplement No. 2:
  - Vol. I, $Z = 1$ to 20.
  - Vol. IIA, $Z = 21$ to 40.
  - Vol. III, $Z = 88$ to 98.
- *The Randomly Packed Settled Bed Fast Reactor Concept [1000-MW(e) Reactor Design],* L. Green and M.M. Levine, Editors. BNL 887 (T-359).

Weekly Bulletin **19**, No. 5-52; **20**, No. 1-4.
Weekly Selected Reading List **18**, No. 14-52; **19**, No. 1-11.

STAFF PUBLICATIONS AND ABSTRACTS

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ADAIR, R.K. AND PRICE, N.J. Probable momentum spectra in the atmosphere of long-lived heavy triplets produced by primary cosmic rays. *Phys. Rev.* **142**, 844-51 (1966).

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ALDERMAN, J.C. AND MORGAN, G.H. Cosmotron magnetic field measurements. Presented at Intern. Symp. Magnet Technology, Stanford, Calif., Sept. 1965.

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BARTON, M.Q. Plans for a slow extracted beam at the AGS. In *Proc. 5th Intern. Conf. High Energy Accelerators, Frascati, Italy, Sept. 1965* (in press).

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*Also included are those listings from the last annual report [BNL 929 (AS-19)] for which complete reference information was not then available.

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SAMPLE, J.T. – See ALBURGER, D.E.; WILKINSON, D.H.

SANDWEISS, J. – See BALTAY, C.; FERBEL, T.; FIRESTONE, A.; GUIDONI, P.

SANFORD, J.R. – See PALMER, R.B.

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SHORE, F.J. – See SAILOR, V.L.

SHUTT, R.P. – See BALTAY, C.; BAMBERGER, J.A.

SILSBEE, H.B. – See CHAN, Y.W.

SIMPSON, W.D. – See FRIEDES, J.L.; PALEVSKY, H.

SKILLICORN, I.O. – See BARNES, V.E.; CRENNELL, D.J.; DORNAN, P.J.; PALMER, R.B.; SCHUMANN, T.G.

SLATTERY, P. – See BALTAY, C.

SMITH, J.R. – See BARNES, V.E.; YAMAMOTO, S.S.

SMOLUCHOWSKI, R. – See DIENES, G.J.

START, D.F.H. – See POLETTI, A.R.

STEARNS, R.L. – See FRIEDES, J.L.; PALEVSKY, H.

STEINSVOLL, O. – See ALPERIN, H.A.

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TAFT, H.D. – See BALTAY, C.; FERBEL, T.; FIRESTONE, A.; GUIDONI, P.

TAKAHASHI, K. – See GOLDHABER, G.S.

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THORNDIKE, A.M. – See BALTAY, C.; BARNES, V.E.; FIRESTONE, A.

TOTH, R.S. – See SATO, H.

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TURKOT, F. – See ANDERSON, E.W.; BLESER, E.J.; FUJII, T.; MCMAHON, T.J.; MENES, J.

TUTTLE, W.A. – See BAMBERGER, J.A.

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ZORN, G.T. – See FUJII, T.

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Reactor Division

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Aug. 1965	BNL 938 (T-388)
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Nov. 1965	BNL 960 (T-400)
Dec. 1965	BNL 965 (T-403)
Jan. 1966	BNL 971 (T-408)
Feb. 1966	BNL 975 (T-410)
Mar. 1966	BNL 979 (T-413)
Apr. 1966	BNL 984 (T-416)
May 1966	BNL 988 (T-419)
June 1966	BNL 995 (T-423)

PROTTER, S. – See BALDWIN, R.

TICHLER, P.R. – See BALDWIN, R.

Appendix B

OFFICERS AND SCIENTIFIC AND PROFESSIONAL STAFF

Maurice Goldhaber, *Director*
Clarke Williams, *Deputy Director*
Charles E. Falk, *Associate Director*
R. Christian Anderson, *Assistant Director*
William J. Catacosinos, *Assistant Director*
Rodney L. Cool, *Assistant Director*
G. Norris Glasoe, *Assistant Director*
Samuel M. Tucker, *Assistant Director*

G. Kenneth Green, *Chairman*, Accelerator Department
Yoshio Shimamoto, *Chairman*, Applied Mathematics Department
C.H.W. Hirs, *Chairman*, Biology Department
Richard W. Dodson, *Chairman*, Chemistry Department
Horner Kuper, *Chairman*, Instrumentation and Health Physics Department
Victor P. Bond, *Chairman*, Medical Department
Warren E. Winsche, *Chairman*, Nuclear Engineering Department
George H. Vineyard, *Chairman*, Physics Department
Irving J. Polk, *Head*, Mechanical Engineering Division
Robert W. Powell, *Head*, Reactor Division

J. Georges Peter, *Director*, Architectural Planning
H. Russell Cort, *Budget Officer*
(retired June 30, 1966)
Lewis R. Burchill, *Controller*
Dennis Puleston, *Information Officer*
Charles F. Dunbar, *Legal Counsel*
N. Peter Rathvon, Jr., *Associate Counsel*
Joseph S. Washburne, *Personnel Manager*
Edward J. Burke, *Security Officer*

Accelerator Department

G. Kenneth Green, *Chairman*
Roger R. Adams
Christopher Agritellis
John C. Alderman
Theodore Alper
Lamar T. Baker*
David A. Barge
Mark Q. Barton
Kenneth Batchelor
(assigned from Rutherford High Energy Laboratory, England)
Gerald W. Bennett
Arnold Benton
David Berley
Richard A. Beth
John W. Bittner
John P. Blewett
Richard B. Britton
Hugh N. Brown
Theodore Carides
Charles A. Casey
Richard L. Cassel
Renate W. Chasman
Richard D. Clark*
George W. Cornish, Jr.
James G. Cottingham
Joseph A. Curtiss
Per Fridtjof Dahl
Gordon T. Danby
Donald A. Davis
Edward W. Dexter
Henry M. Doupe
Emory G. Egler
Arthur J. Enright
Arnold V. Feltman
Theodore Fishman*
Horst W. J. Foelsche
Eric B. Forsyth
John D. Fox
Robert S. Frankel
William R. Friskin*
John J. Gabusi
William Gefers
Salvatore T. Giordano
Joseph W. Glenn, III
Harald Hahn
Henry J. Halama
Joseph P. Hannwacker
William E. Harrison, Jr.
John C. Herrera
Robert S. Hulliger
John W. Jackson
David D. Jacobus
(on leave from Massachusetts Inst. of Technology)

*Terminated before July 1, 1966.

Kurt Jellett
Henry Kasha
Ralph R. Kassner
John T. Keane
Vincent J. Kovarik
John H. Lancaster
Ronald F. Lankshear
Robert A. Larson
Lawrence B. Leipuner
Gerald S. Levine
Su Tang Lin
Isador J. Livant
Walter Livant
Robert E. Lockey
Anthony J. Longano*
Robert A. Loper
Edward A. MacDougall
Alfred W. Maschke
Lowell McLean
Andrew J. McNerney
Christoffel H. Meijer*
Walter W. Merkle
William Michaelson
William H. Moore, Jr.
Gerry H. Morgan
Peter A. Montemurro
Donald W. Mueller
(assigned from Los Alamos Scientific Laboratory)
Ronald J. Nawrocky
Albert C. Nerenberg
Tetsuji Nishikawa*
(on leave from Univ. of Tokyo, Japan)
Barbara Ann Norman
Eileen C. O'Donnell
Arthur N. Otis, Jr.
George Parzen
Robert L. Pease
Jens C. Pettersen
Martin Plotkin
Sepp J. Prunster
(on leave from Physikalisches Staatsinstitut, Institut für Experimentalphysik, West Germany)
Eugene C. Raka
George Rakowsky
Karl H. Reich*
(on leave from CERN, Geneva, Switzerland)
Raymond H. Rheaume
David S. Robertson
Everett J. Rutan
William B. Sampson
Ralph T. Sanders
James R. Sanford
Albert J. Schoenemann
Mykola Sereda
Joseph F. Sheehan, Jr.
Edward E. Shelton
Malcolm H. Slade
(postdoctoral appointment)
Theodorus J.M. Sluyters
Lyle W. Smith
Anastasios Soukas
Joel W. Spinner
Julius Spiro
Raymond J. Stefanski
(graduate student from Yale Univ.)
Colin D. Stewart
Robert C. Talsma
Arthur Tranis
Clarence M. Turner
Arie van Steenbergen
Uriel Vogel
Ching Lin Wang
Thomas P. Wangler
(postdoctoral appointment)
Robert J. Warkentien*
Arnold R. Watts
Theodore L. Werntz
George W. Wheeler
Richard L. Witkover
Harold Wroe*
(on leave from Rutherford High Energy Laboratory, England)

*Terminated before July 1, 1966.

Applied Mathematics Department

Yoshio Shimamoto, *Chairman*
Barry S. Arbeit
Elliott H. Aucrbach*
George A. Baker, Jr.
Roger R. Baldwin
Lydia Bargiuk
Roquez Bejarano
Steven Bender
David R. Beaucage*
Kenneth J. Brightman
Alfred G. Burns
John R. Cannon*
Hong-bo Chiang
Robert Cohen*
John E. Denes
Dennis Eisen
Kenneth R. Fannin
Margaret C. Frantz
Jerry M. Friedman
Kurt Fuchel
John H. Halton*
Arthur D.S. Harris
Janet I. Head
Sidney Heller
Jeanne C. James
Joseph Kahane
Anatoly Kandiew
Sidney Kaplan*
Minato Kawaguti
Isidore Kleiner
Leslie L. Lawrence
Alvin A. Legerlotz
March Leopold
Irwin Lewis
Joel H. Malament*
Robert B. Marr
Bruce A. Martin
John P. Milazzo*
Noboru Nakanishi*
Stanley J. Osher
Larry S. Padwa
Ilse H. Perlman
Joel D. Pincus
Marc Platt
George Rabinowitz
Dysart A. Ravenhall
Nechemiah Reiss
Stuart S. Rideout
Edward R. Ross*
Robert N. Salerno
Carole J. Sawner
Arthur B. Scott
Joseph B. Seif*
Susan M. Sevian
Morris Skibinsky
Sebastian A. Sora*
Irwin Steinberg
Morris M. Strongson
Melvin Tainiter
Irene R. Thurber*
James K. Thurber
Ralph A. Trondle
Betty Weneser
Annette L. Woodbury*

Biology Department

C.H.W. Hirs, *Chairman*
Susan Abraham*
(on leave from Univ. of Kerala, India)
Emory T. Adams, Jr.
(postdoctoral appointment)
Nicholas Alonzo
Karl P. Baetcke
(postdoctoral appointment)
Donald G. Baker
Diana C. Bartelt
Arnold M. Becker
Chittranjan Bhatia
(postdoctoral appointment)
Clara A. Bjerknes
Guy Blaudeau
Robert W. Briggs
John R. Broich*
Marcello C. Buiatti
(postdoctoral appointment)
Alice J. Burton
Regina Ann Butera
Roger W. Carlson
Barbara A. Cartwright
Robert P. Carty*
(postdoctoral appointment)
David J. Chapman
(postdoctoral appointment)

David T. Clarkson
(postdoctoral appointment)
William J. Cole
(postdoctoral appointment)
Nicholas C. Combatti
Howard J. Curtis
Carol A. Czernick
Rosemarie Dearing
Milislav Demerec
(retired December 31, 1965)
Marilyn S. Doscher
(assigned from American Cancer Society, Inc.)
Florence T. Dunne
Winston R. Dykeman
Marshall G. Elzinga
(postdoctoral appointment)
Frieda M. Englberger
Murray J. Ettinger
(postdoctoral appointment)
Daniel S. Fackre
David L. Filmer*
Donald E. Foskct*
Aurelie M. France
(graduate student from Tulane Univ.)
Masaki Furuya*
Walter J. Geisbusch
Om K. Ghei
(postdoctoral appointment)
Ashish K. Ghosh
(postdoctoral appointment)
Joseph S. Giordano, Jr.
David M. Glick
(postdoctoral appointment)
Benjamin F. Graham, Jr.
(on leave from Grinnell College)
Bill Greenberg
Lewis J. Greene
Eleanor Grist
Kenneth L. Grist
Gary E. Hart
(postdoctoral appointment)
William S. Hillman
Geoffrey Hind
Mary H. Hines
Yoshihiko Hirono
(postdoctoral appointment)
David G. Hoare*
(postdoctoral appointment)
William G. Hopkins*
(postdoctoral appointment)
Sadao Ichikawa
(postdoctoral appointment)
Ikuo Ino
Alexandra H. Jahn
Andrew L. Johnson
Leela M. Joshi*
Helen J. Kelly
Mary E. Kirtley*
(postdoctoral appointment)

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J. Raymond Klein
Donald Koenig
Daniel E. Koshland, Jr.*
Marian E. Koshland*
Willard L. Koukkari
(postdoctoral appointment)
Bernt W. Krebs
(postdoctoral appointment)
Jadwiga H. Kycia
Sanford A. Lacks
H. George Latham, Jr.
Myron C. Ledbetter
Robert A. Love, Jr.
Timothy G. Marples*
(postdoctoral appointment)
Dorothy M. McFadyen
Jerome P. Miksche*
Jean H. Moutschen
(on leave from Univ. of Liège, Belgium)
Charles H. Nauman
G. Gopalan Nayar*
(on leave from Atomic Energy Establishment, Trombay, India)
Leslie F. Nims
John M. Olson
Theresa F. Petty
Virginia Pond
Sheldon B. Pravda
Allen Rebuck*
Vernon N. Reinhold
(postdoctoral appointment)
Meir Rigbi*
(on leave from Hebrew Univ., Jerusalem, Israel)
Anne F. Rogers
Richard N. Ruffing
John J. Ruscica
Kenneth E. Sanderson*
Lloyd A. Schairer
Duane D. Schroeder
(graduate student from Tulane Univ.)
Judith M. Scheppele*
Susan S. Schwemmer
Roslyn Shapanka
Elliott N. Shaw
Lewis M. Siegel*
(postdoctoral appointment)
Harold W. Siegelman
Harold H. Smith
Robert L. Smith
(postdoctoral appointment)
Arnold H. Sparrow
Rhoda C. Sparrow
Sylvia S. Springhorn
Elizabeth Stanton
Robert Steele
F. William Studier
Barbara J. Swisher
Keith H. Thompson
John J. Tilley, Jr.
Kathryn E. Treible

Alan G. Underbrink
(postdoctoral appointment)
Jack Van't Hof*
Richard H. Wagner*
(postdoctoral appointment)
Henry Weiner*
(postdoctoral appointment)
Robert H. Whittaker*
(on leave from Brooklyn College, City University of New York)
Curtis M. Wilson*
(assigned from U.S. Department of Agriculture at Univ. of Illinois)
Robert G. Woodley
George M. Woodwell
Ruth V. Wright
Shizuko Yagi
Kunio Yamakawa*
(assigned from Ministry of Agriculture and Forestry, Japan)
Joseph D. Yourno

Chemistry Department

Richard W. Dodson, *Chairman*
Hans-Joachim Ache*
Augustine O. Allen
Alan Appleby*
(postdoctoral appointment)
Knut Bachmann
(on leave from Technische Hochschule, Darmstadt, West Germany)
Bernard R. Baker
Elizabeth W. Baker
Allan L. Bednowitz
(postdoctoral appointment)
Benon H. Bielski
Jacob Bigeleisen
Jean P. Bocquet
(NATO Fellow)
Daeg S. Brenner
(postdoctoral appointment)
John S. Butterworth*
(postdoctoral appointment)
Christos S. Capellos
(postdoctoral appointment)
Joseph C.Y. Chen
(on leave to Univ. of Colorado)
David R. Christman
Yung Yee Chu
James C. Cobb
Teresa J. Conocchioli
Philip Coppens
Lester M. Corliss
C. Brian Cragg*
(postdoctoral appointment)
James.B. Cumming
Eileen P. D'Arcy
Raymond Davis, Jr.
Thomas Dorfmuller
(assigned from Federal Ministry for Scientific Research, West Germany)

Stanton Ehrenson
Norman Elliott
Nils E. Erickson
(postdoctoral appointment)
Robert A. Esterlund
(postdoctoral appointment)
Fraser Fanale*
(postdoctoral appointment)
Fausta R. Faucitano
(on leave from Univ. of Pavia, Italy)
Gian P. Felcher*
Eena-Mai Franz
Simon Freed
(retired December 31, 1965)
John J. Freeman*
(postdoctoral appointment)
Gerhart Friedlander
Lewis Friedman
Janusz M. Gebicki
Anna Giardini-Guidoni*
(assigned from Comitato Nazionale por l'Energia Nucleare, Rome, Italy)
James R. Grover
Philipp Gutlich*
(on leave from Technische Hochschule, Darmstadt, West Germany)
Robert J.C. Hagemann
(on leave from Commissariat à l'Énergie Atomique, Saclay, France)
Edwin J. Hamilton*
Walter C. Hamilton
Garman Harbottle
(on leave to IAEA, Vienna, Austria)
Julius M. Hastings
Shiu Kwong Ho*
(postdoctoral appointment)
Jerome Hudis
Heinrich E. Hunziker
(postdoctoral appointment)
Adolph P. Irsa
Takonobu Ishida
Malayappa Jeevanandam
(postdoctoral appointment)
Karin Karlstrom
(assigned from Columbia Univ.)
Seymour Katcoff
Edward O. Kazimir
(graduate student from Fordham Univ.)
John D. Kelley
Charles L. Kibby
(postdoctoral appointment)
Kent A. Klanderman
(postdoctoral appointment)
Walter Kunnmann
Roger A. Lalancette*
(graduate student from Fordham Univ.)
Sam J. LaPlaca
Anne M. Lautzenheiser*

*Terminated before July 1, 1966.

Elliot Lebowitz
(graduate student from Columbia Univ.)
Jacob B. Leventhal
(postdoctoral appointment)
Peter Lieberman
(graduate student from Brooklyn College, City University of New York)
Ross McPherson
(postdoctoral appointment)
George H. Megrue*
(postdoctoral appointment)
Joe V. Michael*
(postdoctoral appointment)
Elizabeth G. Moorhead
(postdoctoral appointment)
Thomas F. Moran
Stamatios G. Mylonakis
Beverly J. Nine
A. Edward Norris*
(postdoctoral appointment)
Elinor F. Norton
John C. Norvell
(graduate student from Yale Univ.)
Catherine T. Paul
Morris L. Perlman
Franz Plasil
(postdoctoral appointment)
Arthur M. Poskanzer*
Carol S. Redvanly
Paul L. Reeder*
Louis P. Remsberg, Jr.
Slobodan V. Ribnikar
(on leave from Boris Kidrich Inst. of Nuclear Science, Yugoslavia)
J. Keith Rowley
William Rubinson
Reuben M. Rudman
(postdoctoral appointment)
Edward V. Sayre
Oliver A. Schaeffer*
Stuart E. Scheppele
(postdoctoral appointment)
Elmer O. Schlemper*
(postdoctoral appointment)
Harold A. Schwarz
Stanley Seltzer
Frederick J. Silkworth, Jr.
Morris Slavin
(retired June 30, 1966)
Richard D. Spratley
(postdoctoral appointment)
Raymond W. Stoenner
Norman Sutin
Robert Thomas
(postdoctoral appointment)
Sydney O. Thompson
Benjamin van Zanten
(on leave from Vrije Universiteit, Amsterdam, Netherlands)
Michael J. Welch
(postdoctoral appointment)
Ralph E. Weston, Jr.
Hans Michael Widmer
(on leave from the Swiss Federal Inst. of Technology, Zurich)
Ronald Withnell
Alfred P. Wolf
Max Wolfsberg

Instrumentation and Health Physics Department

Horner Kuper, *Chairman*
Abraham Arnold
John W. Baum
Robert M. Brown
Michael J. Butler
Robert J. Champagne
Robert L. Chase
Lester A. Cohen
Robert D. Colvett
Frederick P. Cowan
D. Gerd Dimmler
Carl H. Distenfeld
Joachim Fischer
Charles W. Flood, Jr.
Charles F. Foelix
John A. Frizzola
Lee Gemmell
William J. Hartin
William A. Higinbotham
Andrew P. Hull
John F. Jacobs
Marco A. Jamini
Mary Anne Kelley*
Hobart W. Kraner
Peter S. Littlefield
Jorge Llacer*
Robert O. McClintock
Charles B. Meinhold
Constance M. Nagle
Anthony Nappi
Casimir Z. Nawrocki
Michael J. O'Brien
David Ophir
James P. Palmer
Howard R. Pate
Smith G. Pearsall
Leigh F. Phillips
Margaret A. Poole
David W. Potter
Seymour Rankowitz
Gilbert S. Raynor
Edwin J. Rogers
Martin J. Rosenblum
Jesús Sanchez-Izquierdo
(on leave from Junta de Energía Nuclear, Madrid, Spain)
Edward J. Scalsky
George E. Schwender
Barry J. Shepherd
Stanley I. Silverman
Irving A. Singer

Maynard E. Smith
Branko Souček
(on leave from
Inst. Ruder Boskovic, Yugoslavia)
Robert J. Spinrad
Raymond W. Stong
Sanford E. Wagner
Gaylord N. Wall
Stanley Wood
Anthony H. Yonda, Jr.*

Mechanical Engineering Division

Irving J. Polk, *Head*
Richard W. Aichroth
Richard C. Albert
Joseph E. Allinger
Richard C. Amari
Robert D. Baldwin, Jr.
Joseph A. Bamberger
Alden J. Bamslaben
Paul Bezler
Thomas J. Blair
Robert Blesch
(on leave from
Argonne National Laboratory)
Frank P. Brooks
Donald P. Brown
Thomas W. Brown
Robert H. Browne
Vernon J. Buchanan
Leonard N. Chimienti
Henry O. Courtney*
Thomas M. Coyle
Rudolph Damm
Jack E. Detweiler
Basil De Vito
Arthur C. Dick
Julius J. Diener
Carlo Ferraro, Jr.
Carl R. Flatau
Edward H. Foster
Donald W. Gardner
Robert J. Gibbs
Eugene O. Glittenberg*
Jules B. Godel
Carl L. Goodzeit
Charles L. Gould
Pierre Grand
Philip E. Greenberg*
John J. Gries*
Melvin E. Griffing
John J. Grisoli
Eugene E. Halik
Charles R. Hedberg
John J. Hennessy
Paul K. Hinkley*
Rudolph S. Hodor
Kenneth C. Hoffman
Daniel Hoober
John N. Hopping, Jr.
Hendrik Houtsager
Hank C.H. Hsieh
Donald W. Huszagh
Eugene Jablonski
Jack E. Jensen
Marshall G. Jones
David A. Kassner
Andrew Kevey
John T. Koehler
Calman Lasky
Nathan Levenson
Boris M. Lomonosoff
Joseph Lypecky
Stanley J. Majeski
Paul Mandel
John G. Marinuzzi
Robert J. McCracken
Raven B. McKenzie-Wilson
Thomas F. McKinley
Hugh T. McTeague
Anthony P. Meade
Kurt F. Minati
Mordechai Montag
George Nugent
Adolph Oltmann
Frederick O. Pallas
Francis C. Pechar
Paul A. Pion
Carl J. Pozgay
Clive E. Reed
Morris Reich
Louis E. Repeta
Wesley G. Ripperger
George Ritzert
Stewart Senator
Albert P. Schlafke, Jr.
William J. Schneider
Joseph C. Schuchman
Anthony Semplicino
Donald B. Sisson
Gerard E. Tanguay
Charles Theisen
Harvey J. Thomas
Reese D. Thomas
Helmuth Thorwarth
Dietrich Trocha
Vincent Troisi, Jr.
Stanley L. Ulc
John C. Walker
William G. Walker
Thomas P. Walsh*
Irving J. Winters, Jr.
Donald H. Wright

Medical Department

Victor P. Bond, *Chairman*
Emil R. Adamik
John O. Archambeau*
Robert B. Aronson
Harold L. Atkins
John L. Bateman
(assigned from Columbia Univ.)
Drori Ben-Ishay*
(on leave from Univ. of Cincinnati)
Mervyn C. Berman
(on leave from
Univ. of Cape Town Medical School,
Republic of South Africa)
Donald C. Borg
Salvador Bozzo*
(on leave from Univ. of Chile, Santiago)
Arland L. Carsten
Arjun Dev Chanana
Stanton H. Cohn
Spencer L. Commerford
Robert A. Conard, Jr.
George C. Cotzias
Eugene P. Cronkite
Lewis K. Dahl
Nicholas Delihas
Ruth M. Drew
Ralph G. Fairchild
Arnaldo C. Foradori
(on leave from Univ. of Chile, Santiago)
Rosemary A. Gellene
James Z. Ginos
Michael L. Greenberg
(on leave from
Mt. Sinai Hospital, New York)
Ernest A. Gusmano
Leonard D. Hamilton
Lawrence V. Hankes
Max W. Hess*
Darrel D. Joel
Horton A. Johnson
Stanley L. Johnson
(medical associate)
Panayotis G. Katsoyannis
Charles W. Kim
(medical associate)
Knud D. Knudsen
Anthony F. Lo Monte
Robert A. Love
Harvard Lyman
Georges R. Mathieu
(on leave from
Fondation Curie, Paris, France)
Harley W. Moon*
(on leave from Univ. of Minnesota)
Nobuyoshi Oji
(on leave from
Osaka Univ. Medical School, Japan)
Paul S. Papavasiliou
Mildred Pavelec
Nina B. Pluss
Edwin A. Popenoe
Kedar N. Prasad
Paul N. Reilly
James S. Robertson
Charles V. Robinson

*Terminated before July 1, 1966.

Arthur Sakamoto*
Herbert Savel
Lewis M. Schiffer
Max A. Schmaeler
Gerald P. Schwartz
(medical associate)
Arlen R. Severson
(assigned from National Inst. of Health)
Walton W. Shreeve
Clyde R. Sipe
Richard D. Stoner
Rita F. Straub
Pierre A. Stryckmans
(on leave from Inst. Jules Bordet, Brussels, Belgium)
Monohar A. Tilak*
George M. Tisljar-Lentulis
Andrew M. Tometsko
Edgar A. Tonna
Anthony C. Trakatellis
Donald D. Van Slyke
Adrianus A. van Soestbergen*
Melvin H. Van Woert
Roderich W. Walter
(assigned from The Mount Sinai Medical and Graduate Schools, New York)

Nuclear Engineering Department

Warren E. Winsche, *Chairman*
Peter D. Adams
George Adler
Jacek J. Arkuszewski*
(on leave from Inst. of Nuclear Research, Warsaw, Poland)
Arnold L. Aronson
Seymour Aronson
Michael J. Attardo
(graduate student from Columbia Univ.)
Clemens Auerbach
Allan Auskern
David S. Ballantine
Charles B. Bartlett
Wishvender K. Behl
(postdoctoral appointment)
Morris Beller
Fritz Bloch
John S. Bookless
William Bornstein
Joseph S. Bryner
Albert W. Castleman, Jr.
John Chen
Jack Chernick
Joe G.Y. Chow
Evelyn A. Cisney
Brian E. Clancy
(assigned from Atomic Energy Commission, Australia)

*Terminated before July 1, 1966.

John T. Clarke
Peter Colombo
John F. Conant
Helen R. Connell
Noel R. Corngold
Anita J. Court
Hywel A. Davies
(postdoctoral appointment)
Russell N. Dietz
Robert F. Doering
Roy F. Domish
John J. Dorning, Jr.
(graduate student from Columbia Univ.)
Kenneth W. Downes
Kanat Durgun
(on leave from Technical Univ. of Istanbul, Turkey)
Orrington E. Dwyer
James J. Egan
Leonard C. Emma
Lester G. Epel
Seymour G. Epstein
Jack Fajer
Peter T. Fallon
Antonio G. Faucitano
(on leave from Univ. of Pavia, Italy)
Joan F. Felberbaum
Stephen W. Feldberg
Albert H. Fleitman
Markley H. Flom
Jack J. Fontana
Joseph Forrest
Bernard R. Fox
Leonard Galanter
Meyer Garber
Sarman Gencay*
(on leave from Çekmece Nuclear Research Center, Istanbul, Turkey)
Althea Glines
Murrey D. Goldberg
Rubin Goldstein
Robert W. Goodrich
Barry M. Gordon
Leon Green
Margaret W. Greene
David H. Gurinsky
John C. Hasson
(graduate student from Polytechnic Inst. of Brooklyn)
Loranus P. Hatch
Michael A. Helfant
Robert L. Hellens
Eric Hellstrand
(on leave from AB Atomenergi, Sweden)
Joseph M. Hendrie
Raymond J. Heus
Frank B. Hill
Manny Hillman
Leif R.D. Hjarne
(on leave from AB Atomenergi, Sweden)
Peter J. Hlavac

Ting-Chang Ho*
(graduate student from Polytechnic Inst. of Brooklyn)
Henry C. Honeck*
Masao Hori*
(assigned from Japan Atomic Energy Research Inst., Tokai-mura)
Frederick L. Horn
Chia-Jung Hsu
Robert J. Isler
Stanley D. James
Carl L. Johnson
Richard Johnson
Stuart C. Jones*
Sheldon Kalish
Otto F. Kammerer
Herbert M. Katz*
John J. Kelsch
Peter W. Kendall*
(postdoctoral appointment)
Richard L. Kiefer*
(postdoctoral appointment)
Mary T. Kinsley
George Kissel
Ann Marie Kistner*
Carl J. Klamut
Paul J. Klotz
Herbert J.C. Kouts
Henry Kramer
Theodore J. Krieger
Otto A. Kuhl
(deceased June 10, 1966)
Lawrence E. Kukacka, Jr.
Maret Kukk*
Daniel F. Leahy
Dean T. Lee*
(graduate student from Polytechnic Inst. of Brooklyn)
Gerald S. Lellouche
Melvin M. Levine
Steven Lewkowitz
George C. Lindauer
Hans Ludewig
(postdoctoral appointment)
Joseph Lukeian
Donald R. MacKenzie
Benjamin Magurno
Bernard Manowitz
Michael W. Maresca
(deceased January 18, 1966)
Hiroyuki Matsunobu*
(assigned from Nippon Electric Co., Ltd., Kawasaki, Japan)
Victoria L. May
David K. McGuire*
(postdoctoral appointment)
James J. McNicholas
S. Bradford McRickard
Donald J. Metz
Paul A. Michael
Julius Milau

Francis T. Miles
Hiroshi Mizuta
(on leave from Nippon Atomic Industry Group Co., Ltd., Tokyo, Japan)
André J. Mockel
(on leave from Université Libre de Bruxelles, Belgium)
Jacobus G. Mohr*
(graduate student from New York Univ.)
Sophie O. Moore
Said F. Mughabghab
Albert C. Muller
Leonard Newman
Akira Nishihara
(assigned from Asahi Glass Company, Ltd., Yokohama, Japan)
Philip F. Palmedo
Guyon P. Pancer
Raymond J. Parsick
Arthur Paskin
Sol Pearlstein
James P. Phelps
Richard C. Potter
(postdoctoral appointment)
James R. Powell, Jr.
Richard M. Powers*
Thomas F. Prach
Glenn A. Price
Jacob Pruzansky
Surendra N. Purohit
(on leave from AB Atomenergi, Sweden)
Chad J. Raseman
James J. Reilly, Jr.
Powell Richards
Francis X. Rizzo
Anthony Romano
Michael A. Rothbart
Alexander Sabosto
Jerome Sadofsky
Francis J. Salzano
César A. Sastre
Clifford H. Scarlett
Ursula M.R. Schulze
Donald G. Schweitzer
John T. Sears
Bal Raj Sehgal
Thomas V. Sheehan
Eiji Shikata
(assigned from Japan Atomic Energy Research Inst., Tokai-mura)
Louis M. Shotkin
Robert M. Singer
Louis M. Slater
John L. Speirs
Suresh C. Srivastava
(postdoctoral appointment)

*Terminated before July 1, 1966.

Louis G. Stang, Jr.
John R. Stehn
Meyer Steinberg
Thomas E. Stephenson
Gerald Strickland
Herbert Susskind
James W. Sutherland
Ignatius Ning-Bang Tang
Silvio J. Tassinari
Morton A. Tavel
(postdoctoral appointment)
Richard J. Tivers
Walter D. Tucker
William J. Tunney
Edwin J. Tuthill
James O. Tveekrem
John D. Van Norman
Stephen J. Wachtel
Jean I. Wagner
Jekutiel J. Wagschal
(postdoctoral appointment)
Charles H. Waide
Gajanan S. Wamanacharya*
(assigned from Atomic Energy Establishment, Trombay, India)
John R. Weeks
Eugene V. Weinstock
Allen J. Weiss
Jerome Weiss
Gordon M. Wells*
(assigned from United Kingdom Atomic Energy Authority, Winfrith, England)
George G. Weth
Robert G. Wilson
Virginia H. Wilson
Henry H. Windsor
Edward Wirsing, Jr
Richard H. Wiswall, Jr.
Hiromi Yamakita*
(on leave from Government Industrial Research Inst., Nagoya, Japan)
Lowell Yemin
(postdoctoral appointment)
Wen-Shi Yu
Martin S. Zucker

Physics Department

George H. Vineyard, *Chairman*
David E. Alburger
Peter Alexander*
Rahim A. Al-Kital
(IAEA Fellow)
Harvey A. Alperin
(assigned from U.S. Naval Ordnance Laboratory)
José L. Alvarez-Rivas
(assigned from Junta de Energía Nuclear, Madrid, Spain)
Eric W. Anderson
(postdoctoral appointment)
W. Scott Andrus
(graduate student from State University of New York at Stony Brook)
Richard Arndt
Alick Ashmore
(on leave from Queen Mary College, London, England)
Amos Avni
(IAEA Fellow)
Trevor C. Bacon*
Charles P. Baker
Winslow F. Baker*
Virgil E. Barnes
Robert H. Bassel
John A. Benjamin
Robert H. Bergoffen
Bernard T. Bertman
(postdoctoral appointment)
Mulki R. Bhat
Edward J. Bleser
M. Hildred Blewett*
Harry R. Blieden
Frank A. Blood, Jr.
(postdoctoral appointment)
Haywood Blum
Martin Blume
Gunter Brunhart
John S. Butterworth
(assigned from U.S. Army Research Office, Durham, N.C.)
Richard A. Carhart
(postdoctoral appointment)
Allan S. Carroll
(postdoctoral appointment)
Yau W. Chan
Chellis Chasman
Robert E. Chrien
Eugene L. Church
(assigned from Frankford Arsenal)
Jack A. Cockrill
Victor W. Cohen
Isaac W. Cole
George B. Collins
Philip L. Connolly
Philip I. Connors*
(graduate student from Pennsylvania State Univ.)
Martyn J. Cooper
(postdoctoral appointment)
Ernest D. Courant
David E. Cox
Paul P. Craig
David J. Crennell
Kathleen M. Crennell
Bernard B. Culwick
Stephen A. Cutler
Arthur C. Damask
Christopher J.S. Damerell
(assigned from Rutherford High Energy Laboratory, England)

Myron Danzig
William C. Delaney
Edward der Mateosian
James A. Di Carlo
(postdoctoral appointment)
George J. Dienes
Robert P. Di Nardo
(graduate student from Stevens Inst. of Technology)
William P. Dodd
Jean V. Domish
Peter J. Dornan
(postdoctoral appointment)
Guy T. Emery
Victor J. Emery
Cavid Erginsoy
Kenneth J. Foley
Hugie L. Foote, Jr.
William B. Fowler
Paola Franzini*
B. Chalmers Frazer
Joseph L. Friedes
Tadao Fujii*
Giorgio M. Giacomelli
(on leave from Univ. of Bologna, Italy)
Eli Glazer
Allen N. Goland
Malcolm Goldberg
Gertrude S. Goldhaber
Samuel A. Goudsmit
John J. Gould
Paolo Guidoni
(on leave from Univ. of Rome, Italy)
Frederick J. Hamilton
Edward L. Hart
Donald L. Hartill
(graduate student from California Inst. of Technology)
Patrick J. Herley
(assigned from Picatinny Arsenal)
Arthur Herschman
(Editor of The Physical Review*)*
Benjamin H. Hertzendorf
William J. Hilger
David G. Hill
Akio Honma*
(on leave from Tokyo Univ. of Education, Japan)
Henry W.K. Hopkins*
John Hornbostel
Paul V.C. Hough
James J. Hurst, Jr.
George J. Igo
(on leave from Los Alamos Scientific Laboratory)
Edgar W. Jenkins*
Shelby P. Jessup
Robert A. Johnson
Tom Joldersma
(graduate student from Ohio Univ.)

*Terminated before July 1, 1966.

Keith W. Jones
Roger S. Jones
Sidney H. Kahana
George R. Kalbfleisch
Walter R. Kane
Paul B. Kantor*
(postdoctoral appointment)
David T. Keating
Peter J. Kemmey
(assigned from Picatinny Arsenal)
Stuart H. Kern
Tadashi Kikuchi
(assigned from Syracuse Univ.)
Ottmar C. Kistner
Thomas A. Kitchens, Jr.
Joshua K. Kopp
(on leave to Commissariat à l'Énergie Atomique, Saclay, France)
Saul Krasner
(assigned from Picatinny Arsenal)
Tzee-Ke Kuo*
(postdoctoral appointment)
Thaddeus F. Kycia
Kwan Wu Lai
Franklin T. Langdon
Boran A. Leontic
Frank S. Levin*
(postdoctoral appointment)
Paul W. Levy
Kelvin K.Y. Li
(postdoctoral appointment)
Seymour J. Lindenbaum
Frederick P. Lipschultz
(postdoctoral appointment)
Max Lipsicas
Georges W. London
Robert I. Louttit
William A. Love
Dierk Luers
Arne Lundby
(assigned from CERN, Geneva, Switzerland)
Mario A. J. Mariscotti
(on leave from Univ. of Buenos Aires, Argentina)
Eugene R. Marshalek*
(postdoctoral appointment)
Peter L. Mattern
(postdoctoral appointment)
James B. McGuire*
(on leave from Florida Atlantic Univ.)
Michael McKeown
Thomas J. McMahon
(assigned from Carnegie Inst. of Technology)
Daniel McSweeney
Jack Menes
Filippo Menzinger
(postdoctoral appointment)
Louis Michel
(on leave from Inst. des Hautes Études Scientifiques, Bures-sur-Yvette, France)

Vincent J. Minkiewicz
(postdoctoral appointment)
John A. Moore
Thomas W. Morris
Bernard Mozer
Alfred H. Mueller
(postdoctoral appointment)
George T. Mulholland
Yorikiyo Nagashima
(assigned from Univ. of Rochester)
Joseph A. Nardi, Jr.
Robert Nathans
Salvatore Oliva
John W. Olness
James J. O'Reilly*
Yona Oren*
(postdoctoral appointment)
Tom Oversluizen
Satoshi Ozaki
Harry Palevsky
Robert B. Palmer
Robert S. Panvini
(postdoctoral appointment)
Peter D. Parker
(on leave to Yale Univ.)
Laurence Passell
Simon Pasternack
(Editor of The Physical Review*)*
Helmut Paul
(on leave from Osterreichische Studiengesellschaft für Atomenergie, Vienna, Austria)
Ronald F. Peierls
Robert H. Phillips
Stanley J. Pickart
(assigned from U.S. Naval Ordnance Laboratory)
Jerry L. Pietenpol
(postdoctoral appointment)
Edward D. Platner
Alan R. Poletti
Louis K. Potter, Jr.
David C.L. Price
(postdoctoral appointment)
Albert G. Prodell
Carroll A. Quarles, Jr.
(postdoctoral appointment)
Dusan Radojicic
David C. Rahm
R. Ronald Rau
A. Lincoln Read*
Neville W. Reay
(assigned from Univ. of Rochester)
Lazer Resnick*
(postdoctoral appointment)
Clarence R. Richardson
Dennis E. Rimmer
(assigned from United Kingdom Atomic Energy Authority, Harwell, England)
Robert A. Ristinen
Donald K. Robinson*

Paul C. Rogers
David C. Rorer
(postdoctoral appointment)
Jerome L. Rosen
(assigned from Univ. of Rochester)
Henry Ruderman*
Vance L. Sailor
Mark Sakitt
(postdoctoral appointment)
Edward O. Salant
(retired June 30, 1966)
Nicholas P. Samios
John T. Sample
(on leave from Univ. of Alberta, Canada)
James M. Scarr
(postdoctoral appointment)
Robert I. Schermer
Richard W. Schopps
Ivan Schroeder
(assigned from National Bureau of Standards)
Thomas G. Schumann
(postdoctoral appointment)
Arthur Z. Schwarzchild
Anisbert S. Sequeira
(IAEA Fellow)
Gen Shirane
Ralph P. Shutt
Ian O. Skillicorn
Gary A. Smith
John R. Smith*
(postdoctoral appointment)
Joseph E. Smith
John H. Sondericker
Robert L. Stearns*
(on leave from Vassar College)
Olav Steinsvoll*
(on leave from Institutt for Atomenergi, Norway)

*Terminated before July 1, 1966.

Rudolph Sternheimer
Leo Stodolsky
(postdoctoral appointment)
David L. Stonehill
Richard C. Strand
Myron Strongin
Andrew W. Sunyar
Richard J. Sutter
Jacques Teiger*
(on leave from Centre National de la Recherche Scientifique, France)
Pedro A. Thieberger
(postdoctoral appointment)
Dallas G. Thompson
Alan Thorndike
John A. Tjon
(on leave from Univ. of Nymegen, Netherlands)
Peter D. Townsend
(assigned from Picatinny Arsenal)
George L. Trigg
(Asst. Editor, Physical Review Letters*)*
T. Laurence Trueman
Frank Turkot
William A. Tuttle
Hiromichi Umebayashi
(postdoctoral appointment)
Erminia Vaccari
Jesús E. Vaz
(graduate student from Univ. of Kansas)
Martinus J. Veltman
(on leave from CERN, Geneva, Switzerland)
Robert L. Warasila
Ernest K. Warburton
Oren A. Wasson
(postdoctoral appointment)
Richard E. Watson
Medford S. Webster
Harvey E. Wegner
David M. Weigand

Joseph Weneser
Gian Carlo Wick
(on leave to Columbia Univ.)
Colin Wilkin
(postdoctoral appointment)
Erich H. Willen
Ernest Windschauer
Estarose Wolfson
Refael Yaari*
Sukeyasu S. Yamamoto*
Joel R. Yellin
(postdoctoral appointment)
Luke C.L. Yuan
Charles A. Zuroff

Reactor Division

Robert W. Powell, *Head*
Frederick Allenspach
Michael H. Brooks
William J. Brynda
Paul Colsmann
George Demirjian*
Francis A. Dugan
John J. Floyd
Gerald C. Kinne
Paul E. Mamola
Charles L. Osborne
John A. Penney
Jack E. Phillips
dePuyster G. Pitcher
Seymour R. Protter
Walter H. Reed
Ronald J. Reyer
Donald B. Sisson*
Dudley Thompson
Paul R. Tichler
Anthony C. Wood
(assigned from Atomic Energy Commission, Australia)

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