BNL 682 (AS-15)

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BROOKHAVEN NATIONAL LABORATORY

ANNUAL REPORT
July 1, 1961

Associated Universities, Inc.
under contract with the
United States
Atomic Energy Commission

BNL 682 (AS-15)
(General, Miscellaneous, and Progress
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Annual Report

July 1, 1961

BROOKHAVEN NATIONAL LABORATORY

Upton, Long Island, New York

Brookhaven National Laboratory is operated under a contract between the United States Atomic Energy Commission and Associated Universities, Inc. This, the twelfth in a series of unclassified Annual Reports, gives an account of the progress of the Laboratory during the period July 1, 1960 – June 30, 1961, 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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BNL 196 (AS-6) July 1, 1952
BNL 246 (AS-7) July 1, 1953
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BNL 364 (AS-9) July 1, 1955
BNL 426 (AS-10) July 1, 1956
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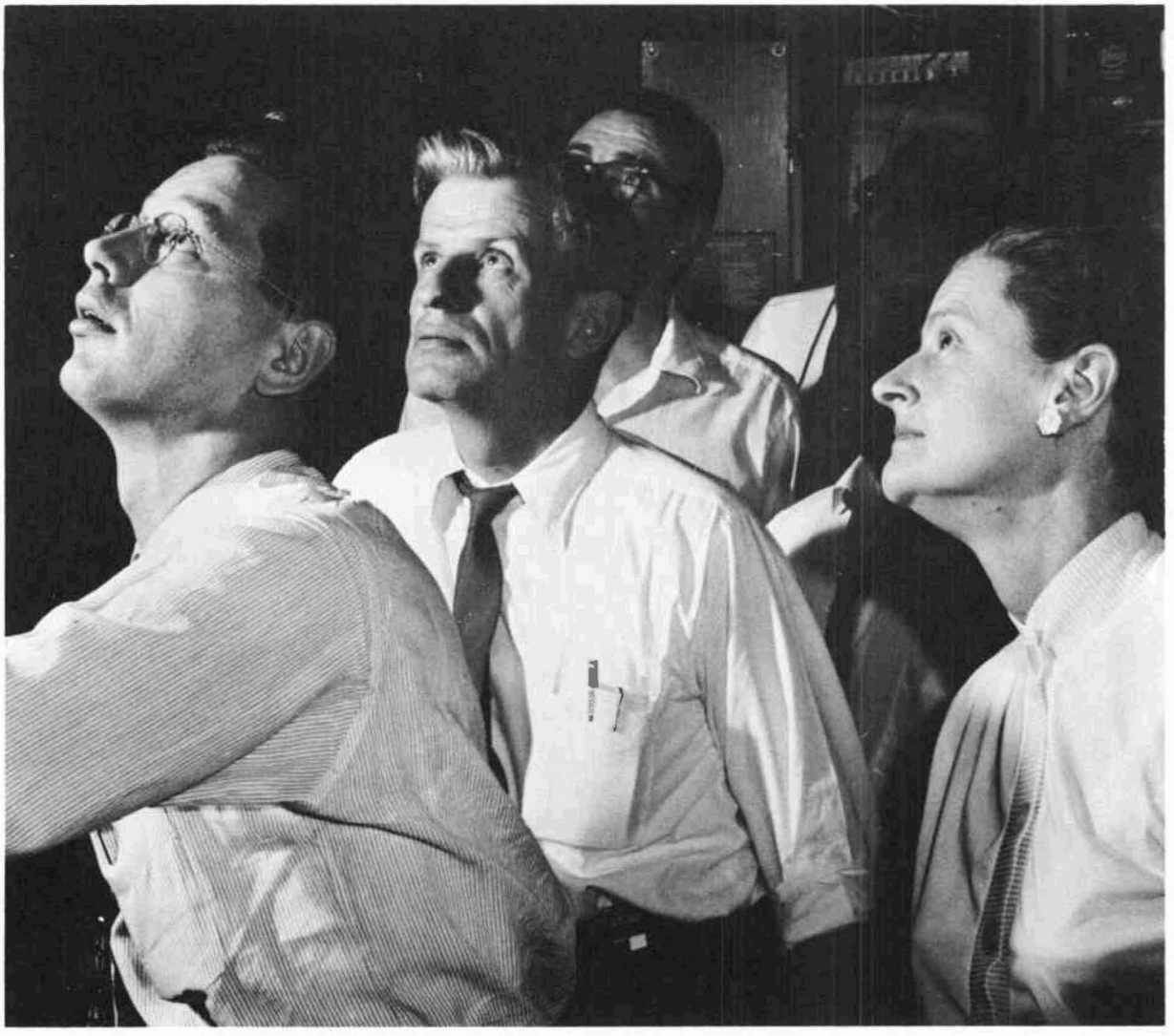
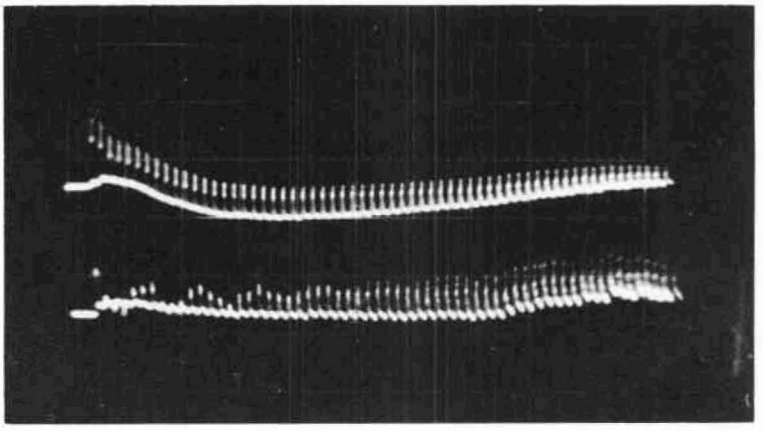
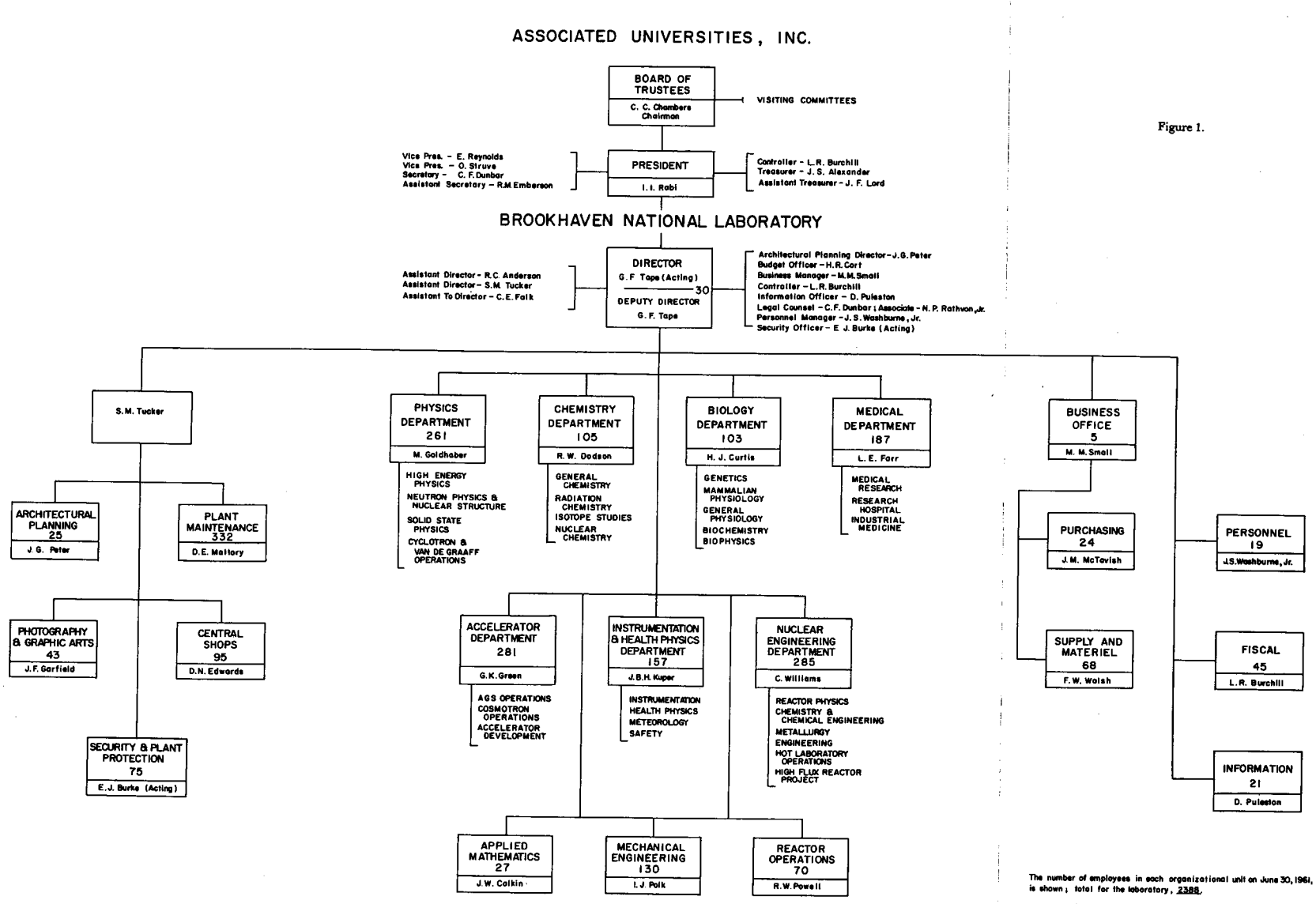


Control room scene at the Alternating Gradient Synchrotron
as the first full revolution of protons was obtained.



Oscillogram of the
first circulating beam.

Figure 1.



ORGANIZATION CHART

JUNE 30, 1961

The number of employees in each organizational unit on June 30, 1961, is shown; total for the laboratory, 2388.

Table 1

Organizational Expenditures – Fiscal 1959, 1960, 1961
(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	Subcontracts & Special Procurements	Power	Miscellaneous (Net)	Total Organizational Costs	% of Total	Scientific (Incl. Guests)	Others	Total
Physics & Chemistry Research	1961	5,831,438	191,771	159,766	2,196,171	110,902	342,521	—	8,832,569	34.4	280.0	431.5	711.5
	1960	3,867,825	202,370	129,020	1,088,434	130,681	130,386	—	5,548,716	26.5	232.5	284.0	516.5
	1959	3,061,815	136,965	121,780	948,083	327,064	24,527	—	4,620,234	24.8	209.0	202.0	411.0
Biology, Medicine & Biophysics Research	1961	2,301,162	76,928	90,853	554,921	3,642	—	(6,125)	3,021,381	11.8	103.0	215.0	318.0
	1960	2,002,118	77,678	79,408	580,596	2,562	—	(5,158)	2,737,204	13.1	96.5	196.5	293.0
	1959	1,799,455	60,616	86,270	464,580	21,324	—	(10,920)	2,421,325	13.0	97.5	180.0	277.5
Nuclear Engineering Research	1961	1,865,931	44,166	74,706	443,491	144,350	—	—	2,572,644	10.0	80.5	135.5	216.0
	1960	1,663,191	44,176	46,563	436,454	148,173	(179)	—	2,338,378	11.2	74.0	124.0	198.0
	1959	1,655,173	39,546	66,091	491,674	536,224	10,154	—	2,798,862	15.0	79.5	151.0	230.5
Isotope Development	1961	136,682	6,075	7,795	60,949	(2,198)	—	—	209,303	0.8	5.5	11.0	16.5
	1960	96,401	3,047	7,947	66,538	13,396	—	—	187,329	0.9	4.0	7.0	11.0
	1959	27,830	—	3,339	20,631	6,314	—	—	58,114	0.3	1.5	2.0	3.5
Training & Education	1961	29,635	3,643	21,167	15,291	5,664	—	(2,000)	73,400	0.3	2.5	3.5	6.0
	1960	27,180	411	32,736	44,486	4,277	—	—	109,090	0.5	2.0	4.0	6.0
	1959	11,974	3,924	3,703	4,545	—	—	—	24,146	0.1	5.5	—	5.5
Radiation Protection	1961	435,473	4,083	3,617	75,080	—	—	(1,115)	517,138	2.0	6.0	52.0	58.0
	1960	365,589	2,886	2,838	88,498	—	—	(1,985)	457,826	2.2	6.5	44.0	50.5
	1959	312,931	1,395	1,876	51,063	—	—	(3,675)	363,590	1.9	8.5	38.0	46.5
Supporting Scientific & Technical Services	1961	3,172,192	14,664	22,724	622,241	4,665	321,217	(167,786)	3,989,917	15.5	23.5	356.0	379.5
	1960	2,683,242	15,364	25,108	460,831	—	390,407	(191,770)	3,383,182	16.1	24.5	319.5	344.0
	1959	2,374,179	12,742	16,680	355,729	3,360	400,365	(278,709)	2,884,346	15.5	26.5	304.0	330.5
Security & Plant Protection	1961	596,392	833	502	11,620	—	—	1,946	611,293	2.4	—	77.0	77.0
	1960	563,172	754	795	13,371	—	—	2,894	580,986	2.8	—	77.5	77.5
	1959	528,953	698	609	7,240	—	—	2,407	539,907	2.9	—	80.0	80.0
Miscellaneous (including Lighting, T & T, Heating Fuels, Special Maintenance, etc.)	1961	—	—	(6,640)	172,465	—	311,453	697,911	1,175,189	4.6	—	—	—
	1960	—	—	2,416	175,618	—	347,818	728,851	1,254,703	6.0	—	—	—
	1959	—	—	653	158,757	—	293,720	707,613	1,160,743	6.2	—	—	—
General and Administrative	1961	3,805,697	35,614	126,328	505,433	(15,234)	—	(191,927)	4,265,911	16.6	6.0	533.5	539.5
	1960	3,424,033	19,715	92,011	559,725	(9,211)	—	(65,642)	4,020,631	19.2	5.0	502.5	507.5
	1959	3,144,536	23,936	80,034	369,155	2,554	—	(139,346)	3,480,869	18.7	7.0	479.0	486.0
Laboratory Total	1961	18,174,602	377,777	500,818	4,657,662	251,791	975,191	330,904	25,268,745	98.4	507.0	1,815.0	2,322.0
	1960	14,692,751	366,401	418,842	3,514,551	289,878	868,432	467,190	20,618,045	98.5	445.0	1,559.0	2,004.0
	1959	12,916,846	279,822	381,035	2,871,457	896,840	728,766	277,370	18,352,136	98.4	435.0	1,436.0	1,871.0
AUI Administration	1961	—	—	—	—	—	—	209,700	209,700	0.8	—	—	—
	1960	—	—	—	—	—	—	178,000	178,000	0.8	—	—	—
	1959	—	—	—	—	—	—	178,100	178,100	0.9	—	—	—
Total AUI and BNL	1961	18,174,602	377,777	500,818	4,657,662	251,791	975,191	540,604	25,478,445	99.3	507.0	1,815.0	2,322.0
	1960	14,692,751	366,401	418,842	3,514,551	289,878	868,432	645,190	20,796,045	99.3	445.0	1,559.0	2,004.0
	1959	12,916,846	279,822	381,035	2,871,457	896,840	728,766	455,470	18,530,236	99.3	435.0	1,436.0	1,871.0
Work for Others, Direct Costs Only	1961	75,896	1,910	3,388	45,537	62,590	—	—	189,321	0.7	7.5	7.0	14.5
	1960	64,051	2,289	4,841	60,127	7,158	—	—	138,466	0.7	6.0	6.5	12.5
	1959	49,964	2,031	1,815	68,395	549	—	8,314	131,068	0.7	4.5	4.5	9.0
Grand Total	1961	18,250,498	379,687	504,206	4,703,199	314,381	975,191	540,604	25,667,766*	100.0	514.5	1,822.0	2,336.5
	1960	14,756,802	368,690	423,683	3,574,678	297,036	868,432	645,190	20,934,511**	100.0	451.0	1,565.5	2,016.5
	1959	12,966,810	281,853	382,850	2,939,852	897,389	728,766	463,784	18,661,304†	100.0	439.5	1,440.5	1,880.0

*$433,401 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.
**$553,081 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.
†$420,606 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.

Introduction

The program and activities of Brookhaven National Laboratory during the fiscal year 1961 are described in this annual report. The progress and trends of the research program are presented together with a description of the operational, service, and administrative activities of the Laboratory. The scientific and technical details of the many research and development activities are covered more fully in scientific and technical periodicals and special reports of the Laboratory. A list of all publications published or submitted for publication during the year may be found in Appendix A.

RESEARCH PROGRAM

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

1. Fundamental studies of atomic nuclei, the particles that constitute them, and the forces involved in their structure. These studies, which are basic to all nuclear science and technology, involve the use of all the major machines of the Laboratory. They range from measurement of the properties of undisturbed nuclei to study of the violent disruptions resulting from nuclear fission and bombardment with high energy particles from the Laboratory's 30-Bev proton accelerator, the new Alternating Gradient Synchrotron (AGS).

2. Studies of the physical, chemical, and biological effects of nuclear radiation. In the fundamental phases the effects of radiation are utilized to study the characteristics of physical and chemical structures and to elucidate the more complex

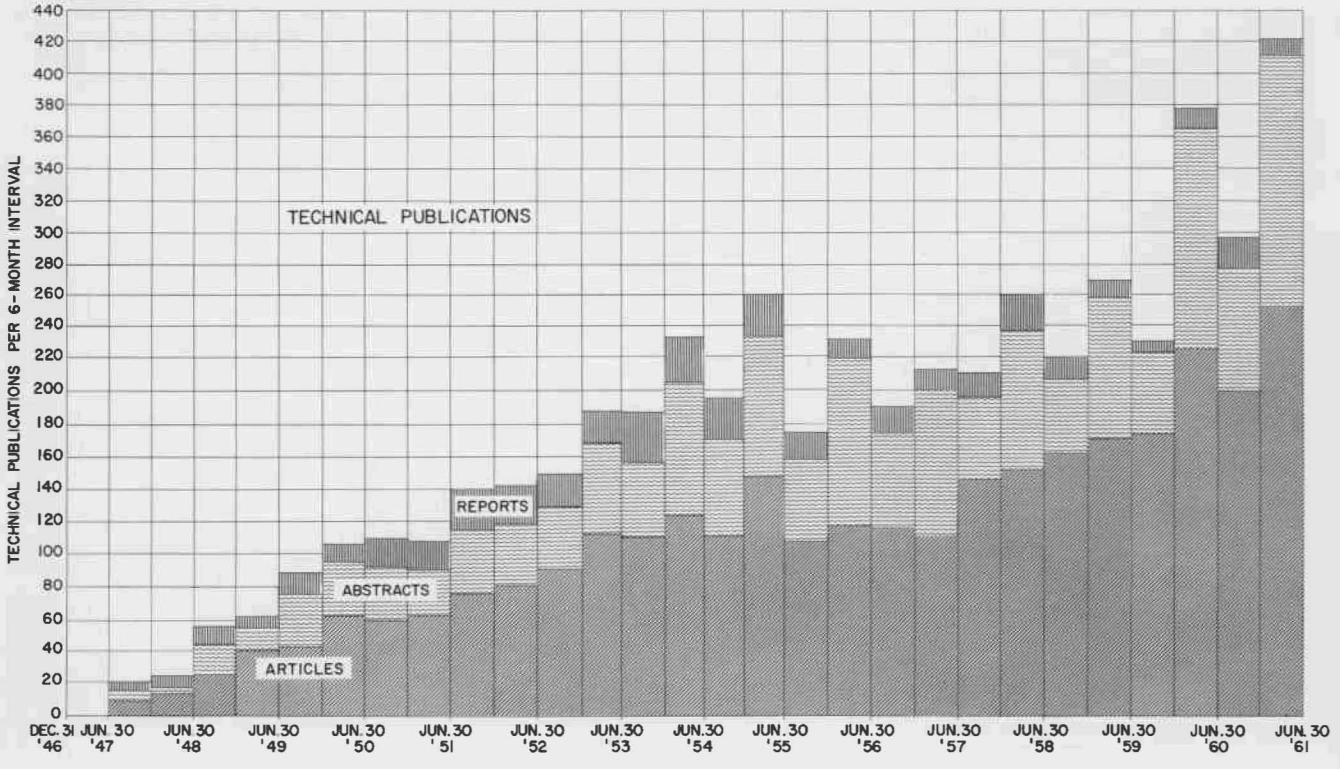


Figure 2.

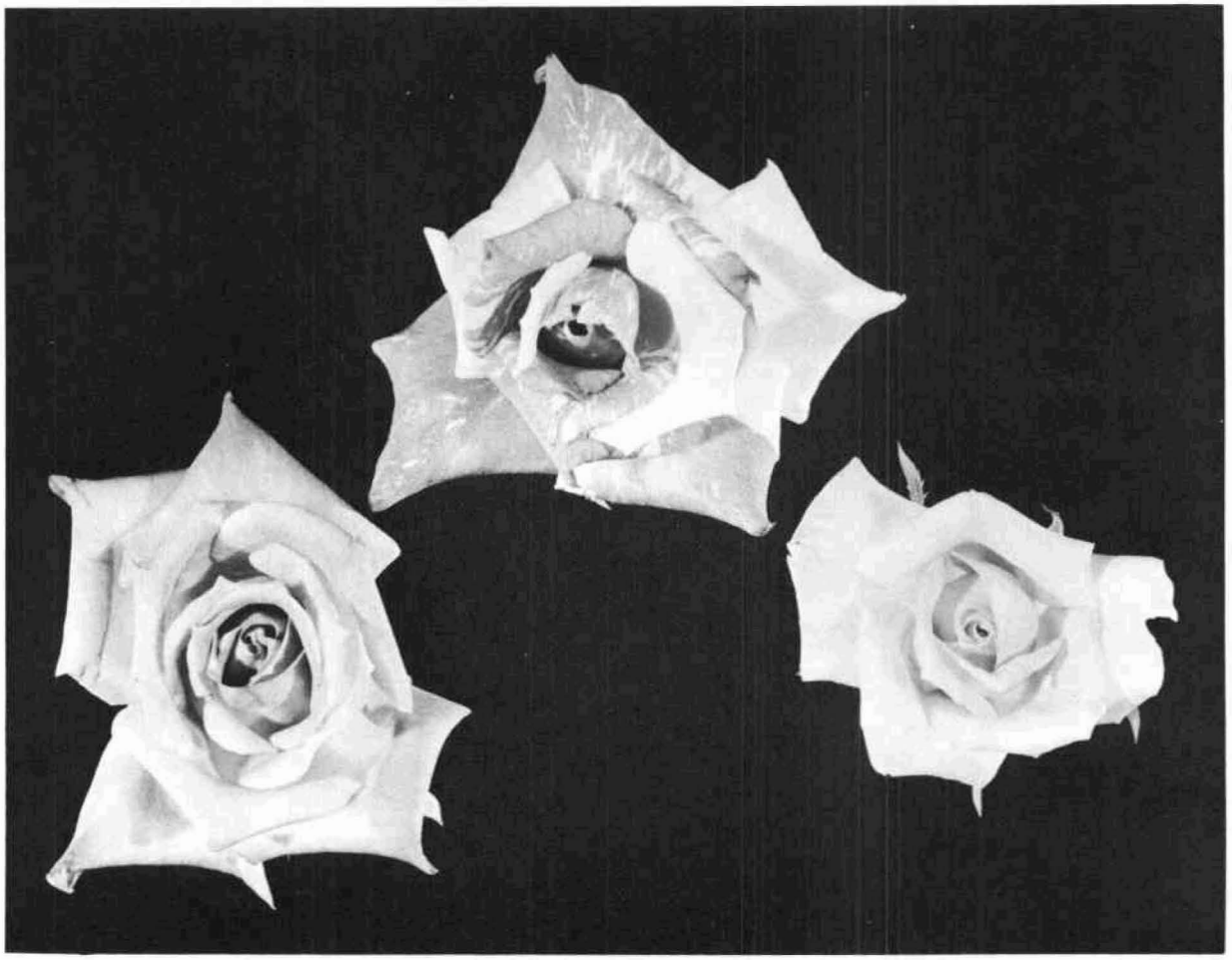


Figure 3. Effects of gamma radiation on Independence rose cuttings. Left, control with normal red petals; center, radiation has caused pinkish streaks; right, irradiation has resulted in an all-pink blossom.

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 disease, in the induction of genetic changes in plants or animals, and in the improvement of manufacturing processes.

3. The use of nuclear tools, such as neutrons, charged particles, gamma-rays, and isotopic tracers, in all branches of scientific research. In this broad and diversified field, which overlaps the one just mentioned, nuclear particles and radiations are used as tools in studying physical, chemical, and biological systems in their undisturbed states. Neutrons and other particles are used as probes; by observing their penetration and reflection, microscopic details of physical and chemical structure can be studied. Wide use is made of isotopic tracers in many fields to yield information on such matters as the mechanisms and rates of chemical reactions and biological processes.

4. Research and development, not necessarily itself of a nuclear nature, directed toward solving the problems of atomic energy development. The more basic aspects of this category include the chemistry of elements 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

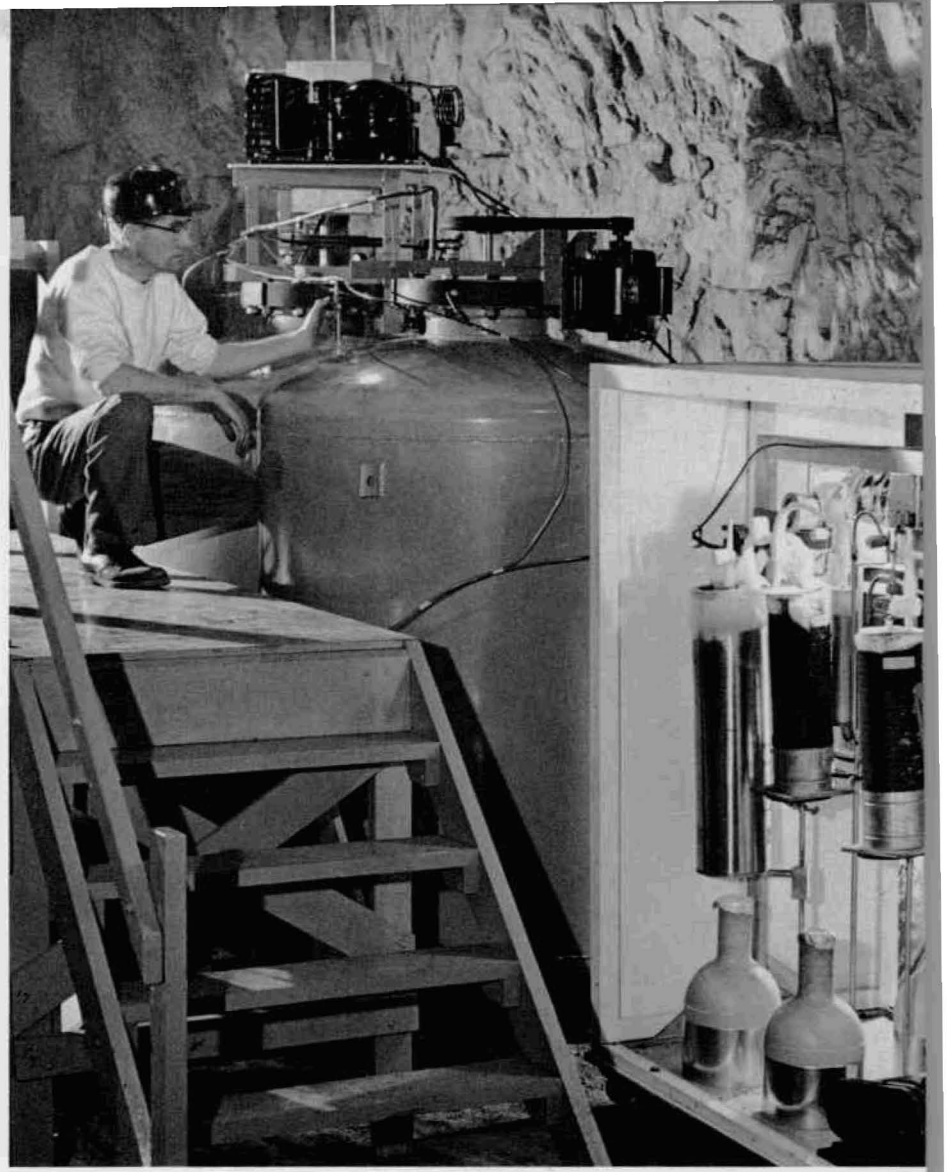


Figure 4. The Brookhaven solar neutrino experiment, installed 2300 ft below ground level in a limestone mine at Barberton, Ohio, owned by the Columbia-Southern Chemical Corporation, a division of the Pittsburgh Plate Glass Company. Left, two 500-gal tanks of perchloroethylene; right, equipment for removing radioactive Ar^{37} by sweeping the tanks with helium gas. (Photograph courtesy of the Pittsburgh Plate Glass Company.)

Figure 5. Aerial view of the Alternating Gradient Synchrotron. An L-shaped addition around the experimental area of the Target Building (lower center) is almost completed. To the right of the magnet ring is the structure being built to house the 80-in. bubble chamber. At the top of the picture is the Cosmotron Building.

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 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 the 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.

The general program of the Laboratory during the year has been strengthened in essentially all fields. The most striking growth, however, has taken place in the field of particle physics, in part because of the availability for research of the recently completed 30-Bev AGS and the extremely satisfactory and reliable performance of the 3-Bev Cosmotron. The increased opportunity for research afforded by the detailed character of the particle beams available and the greater amount of operating time permitted new and more complex investigations to be undertaken.

RESEARCH FACILITIES

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

Alternating Gradient Synchrotron

The AGS is a proton accelerator which operates at a nominal energy of 30 Bev. Construction of the accelerator itself was sufficiently advanced to permit preliminary testing in May 1960. On July 22, 1960, the injected proton beam was accelerated through transition energy to $\approx$7 Bev, and on July 29, 1960, acceleration to $>$30 Bev was achieved. Beam intensity was estimated to be $\approx 2\times10^{9}$ protons/pulse. Immediately after these initial trials, considerable effort was devoted to equipment modifications that would increase operational reliability and beam intensity. As operating experience was accumulated on the various machine components, it became possible to make additional improvements in the injected beam capture process and acceleration. Beam intensities close to 1×10^{11} protons/pulse were recorded in March 1961. Early in July, a linac beam bunch cavity was installed, and, after initial tests were completed, an average of 2.5×10^{11} particles/pulse were carried out to the end of acceleration, with intensities as high as 3×10^{11} particles/pulse being recorded.

The original performance specifications for the AGS have been exceeded in both energy and intensity. It has operated for extended running periods at 33 Bev with a 3.2-sec repetition period. At lower energies a shorter repetition period can be used, e.g., 0.8 sec at 10 Bev. These shorter repetion periods for accelerators of this size have the effect of increasing the available number of particles per unit time.

Initially the AGS was operated $\approx$60 hr per month. Approximately one-half of this time was used for high energy physics, and the remainder for accelerator studies. In March 1961 the accelerator was placed on 16-hr-per-day operation, 5 days per week.

Although construction of the basic machine has been completed, design and construction of targeting and beam transport equipment are continuing. Completion of the East Target Building, which will ultimately house much of the experimental equipment, is scheduled for August 1961. This new experimental area will permit the efficient arrangement of the complex beam transport systems for both primary and parasitic experiments scheduled in the high energy physics program.

Additional information on the AGS will be found in the section on High Energy Accelerators.

Cosmotron

Experiments at the Cosmotron, a 3-Bev proton synchrotron, are increasingly being designed to produce more precise quantitative information; as

a consequence, they require more complicated arrangements, more precise control of beam parameters, and longer periods of running time. Three external proton beams and several secondary beams from internal targets are used concurrently. The machine improvement program, including the complete shielding of the Cosmotron and the provision of an additional experimental area, has provided the required facilities to carry out experiments of the complexity now commonly encountered.

In the spring of 1961, Cosmotron operation was increased from 24 hr for 5 days per week to 24 hr for all 7 days. Improvements in beam intensity have continued, with reliable operating performance of 1 to 2×10^{11} protons/pulse being achieved. The availability of external proton beams has greatly reduced downtime for the purpose of setting up experiments. No major component failure occurred during the fiscal year.

Additional information on the Cosmotron is contained in the section on High Energy Accelerators.

60-in. Cyclotron

The 60-in. cyclotron accelerates protons to 10 Mev, deuterons to 20 Mev, and helium nuclei to 40 Mev. With deflected beams up to 50 μa, internal, deflected, and focused beams are available. During the past year this cyclotron was operated for some 60 people, 7 departments, and 10 outside institutions. Work for outside institutions, including those represented by guest scientists, accounted for $\approx$20% of the operating time. The principal areas of activity were nuclear reaction studies, the production of radioactive materials for subsequent study of the production of tracer materials, and the direct use of the beam for the study of biological systems. The introduction of solid-state counters has led to a considerable increase in studies of nuclear reactions and scattering phenomena. New dees have been installed, and the installation of an energy-analyzing magnet has been started.

18-in. Cyclotron

The 18-in. cyclotron accelerates protons to an energy of 3 Mev. The external beam is focused on a Zr-T target 30 ft from the machine, and monoenergetic neutrons are produced through the $T(p,n)He^3$ reaction. The beam-bunching inherent in the acceleration process in the cyclotron results in neutron pulses from the target of 1 to 2×10^{-9}-sec duration. Neutron scattering experiments are carried out which utilize the time-of-flight techniques made possible by the pulsed character of the neutron beam. A proton beam current of 130 to 150 μa is used routinely, but current as high as 200 μa has been used occasionally. The peak current in the pulse of protons can therefore be as high as 10 ma.

Electrostatic Generator

This accelerator has been operated for research on a routine basis with protons, deuterons, alpha particles, and He^3 ions with beam currents up to 75 μa and energies up to 3 Mev. During the past year the machine was operated for research during 384 8-hr shifts and 46 8-hr shifts were used for maintenance or modifications on 268 scheduled days.

The accelerator is equipped with a radio-frequency beam-pulsing system in the high voltage terminal. The beam pulse duration of $\approx4\times10^{-9}$ sec is typical of such installations, and this system can be used to measure nuclear lifetimes comparable to the pulse duration. A new external radio-frequency beam-sweeping system has been constructed and installed in one of the beam tubes. This apparatus produces beam pulses of 1 to 2×10^{-9}-sec duration, separated by $\approx130\times10^{-9}$ sec. The duration of the beam time on target is further reduced by slanting the target so that it coincides with the profile of the beam from the sweeping plates. In this way, the beam pulse time may be compressed by a factor of $\approx$20, and it is estimated that the beam duration on target is $\approx0.08\times10^{-9}$ sec. This apparatus is used with a scintillator mounted on a fast phototube and a time-to-pulse-height converter of the time vernier type to measure nuclear lifetimes in the 10^{-10} to 10^{-8}-sec range. Measurements are now in progress on the lifetimes of the first excited states of B^{10} and C^{15}.

Graphite Research Reactor

The in-pile and beam facilities of the Brookhaven Graphite Research Reactor (BGRR) 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 $\approx2\times10^{13}$ neutrons/cm^2-sec. To maintain reactivity requirements, the loading was gradually expanded from 548 to 575 channels. A total of 937 fuel elements were replaced during the years, with burn-up of discharged elements averag-

ing 38%. The reactor operating cycle was changed from two to three weeks to obtain longer uninterrupted operating periods and to reduce the overtime work necessitated by more frequent shutdowns.

Certain changes in specialized facilities have been made during the year. The shielding tank that had been used in a position on top of the reactor since 1950 was removed to provide space for other experiments. It was no longer used sufficiently to warrant its maintenance. The medical facility, which also occupies a top position, is in the process of being removed, since the Medical Department now has available its own research reactor.

Approximately 38 reactor holes are assigned to BNL research departments. Other reactor holes are assigned for use by outside organizations under various cooperative arrangements. Some 12 different outside organizations have availed themselves of reactor facilities other than routine irradiation services.

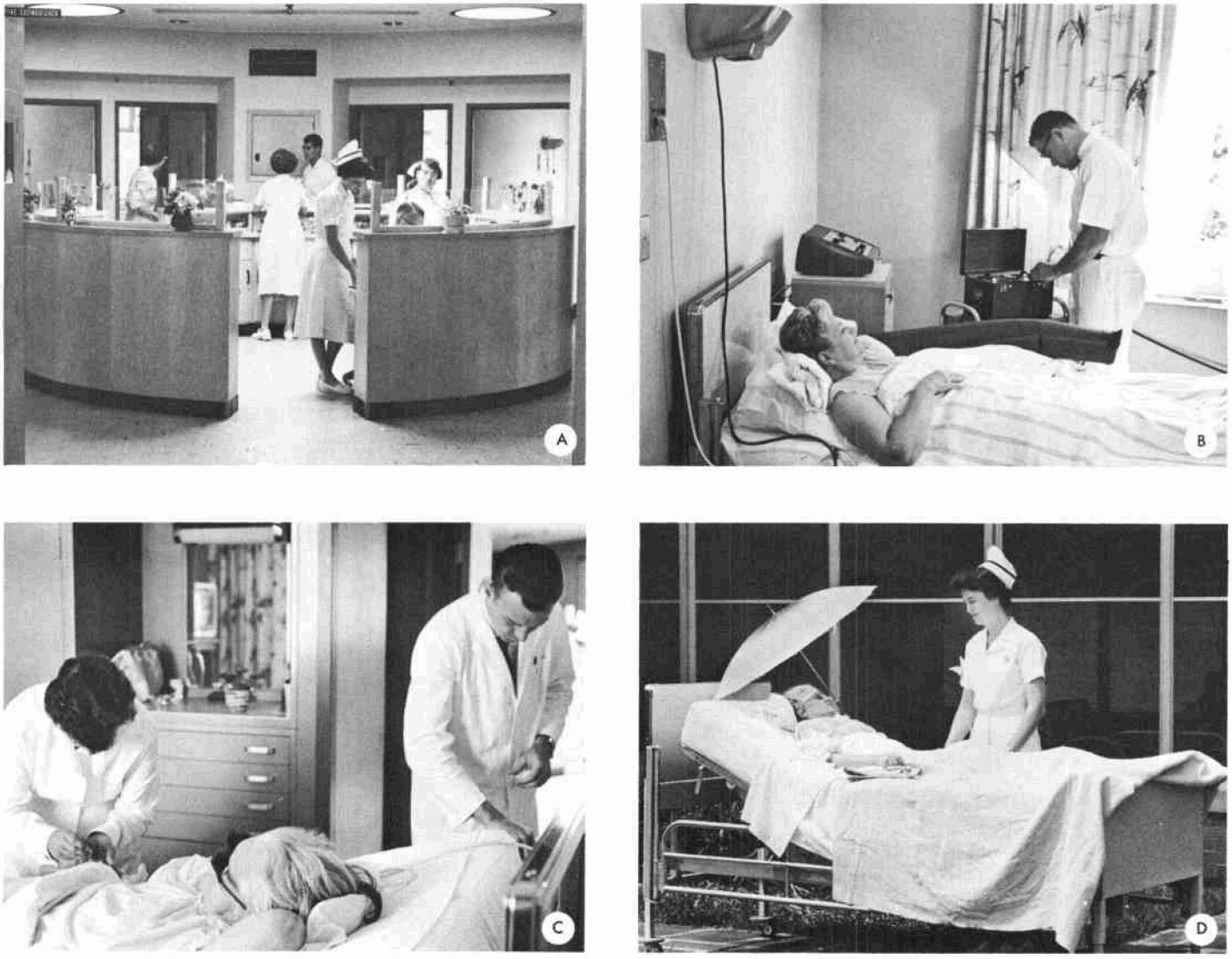


Figure 6. Patient facilities and care at the Medical Research Center. (A) Each ward has a central station for the nursing staff, and each patient has an individual room. (B) Patient receiving physiotherapy to arm. (C) Interior of room with medical technicians taking samples from patient. (D) Patient taking the sun in one of the courtyards.

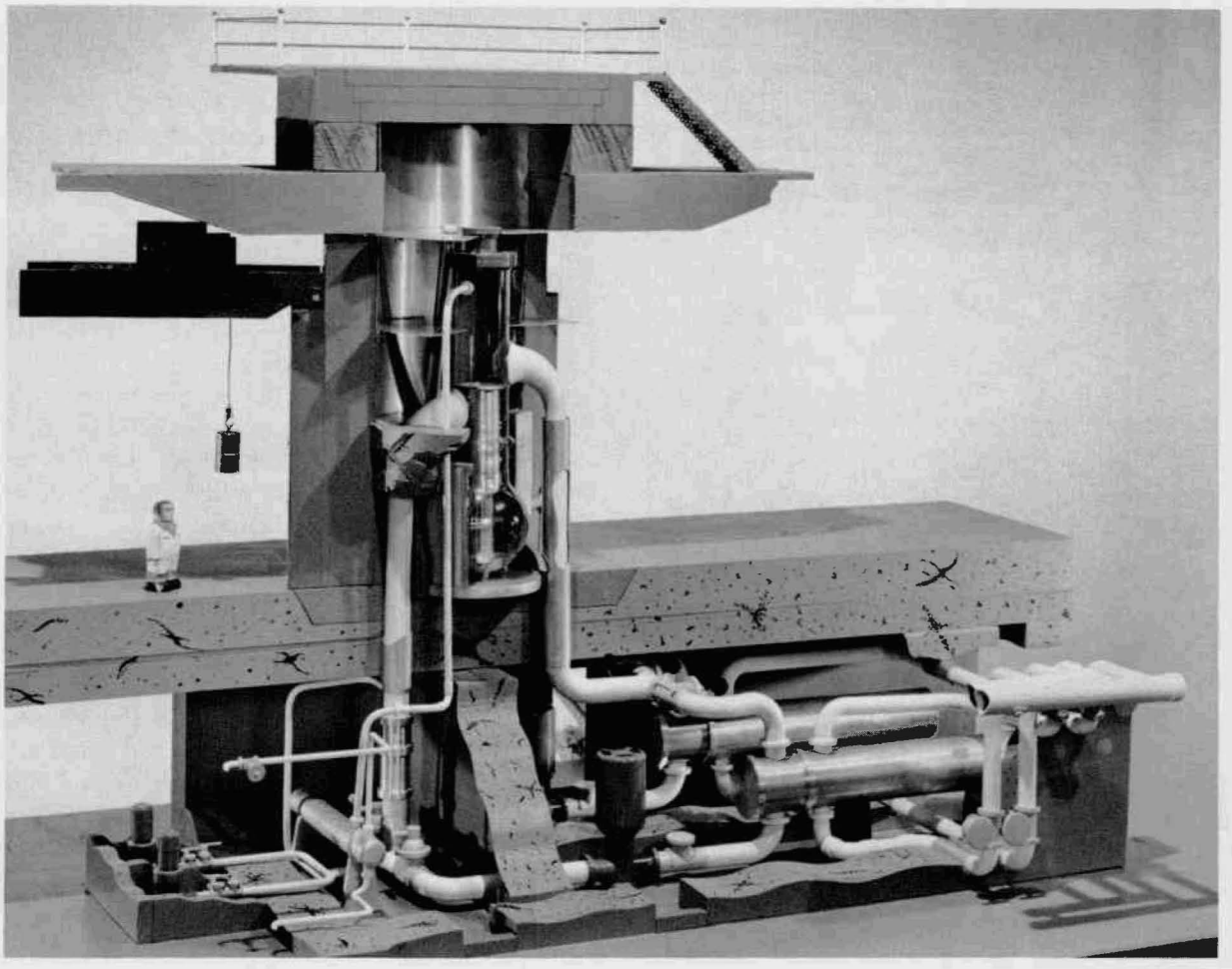


Figure 7. Model of the High Flux Beam Research Reactor (HFBR) currently in the design stage. The HFBR will be housed in a three-level, tank-type building. Neutron beam experiments will occupy the entire main floor. The auxiliary machinery for the reactor complex and a canal for spent fuel elements will be in the basement. The reactor will be operated from the upper level.

Medical Research Reactor

The Medical Research Reactor (MRR) was constructed for the sole purpose of exploring the possible applications of nuclear reactors to the study of man and his diseases. Each salient feature of the reactor was designed in relation to its use for therapy and diagnosis or in the advancement of basic medical science. Operation on an intermittent basis is demanded by the nature of the research program. Operating power levels up to 3 Mw have been approved for continuous operation, and levels up to 5 Mw are permitted for intermittent periods not to exceed 10 min.

Certain modifications made in the primary water system in connection with an over-all change in the Medical Research Center system to conserve well water resulted in increased primary cooling flows. Because it was possible that fuel elements might float at the higher flow rate, an orifice plate was installed in the inlet water line to the reactor, and a fuel hold-down device similar to an upper grid plate was installed above the core. This change was completed in March 1961.

The MRR was operated 227 times during the year for a total of 665 Mwh.

Hot Laboratory

The Hot Laboratory, which is adjacent to the BGRR, contains extensive facilities for the analysis, processing, and development of highly radio-

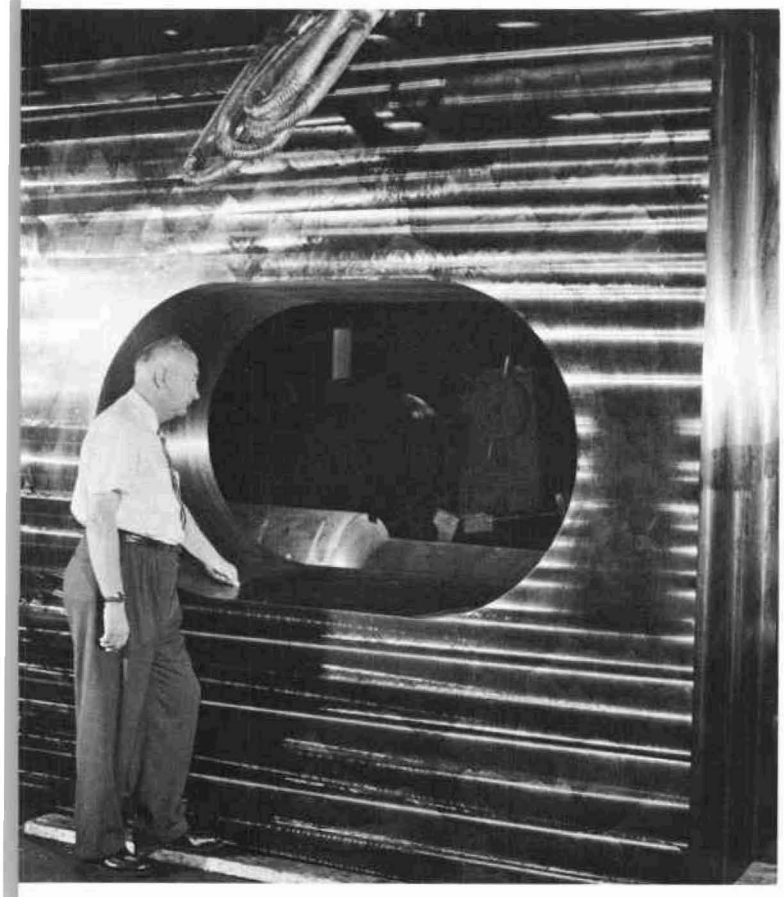


Figure 8. Window for 80-in. liquid hydrogen bubble chamber magnet. This window serves as part of the magnetic circuit and also forms part of the vacuum chamber. The opening allows the hydrogen chamber to be illuminated and photographed.

active materials. It includes three hot cells in which chemical operations can be performed remotely while under observation by periscope. A larger hot cell of the cave type is now in full operation for the physical examination of materials, especially metals of high activity.

Critical Assembly Laboratory

The Critical Assembly Laboratory provides specialized facilities for research in reactor physics and for reactor development studies. It comprises two critical assembly areas, each with an operating console and assembly room. One of these rooms contains a small, water-cooled, graphite-reflected neutron source reactor for exponential studies. This laboratory also includes a pulsed Van de Graaff neutron source for diffusion experiments and reactivity measurements. Additional facilities are now being added and are described in the section on new construction.

MAJOR RESEARCH FACILITIES UNDER DESIGN AND CONSTRUCTION

High Flux Beam Research Reactor

Preliminary design of the Brookhaven High Flux Beam Research Reactor (HFBR) was completed in September 1960, and detailed design is $\approx$50% complete. Building designs have advanced to the point where groundbreaking is anticipated early in the fall of 1961. This reactor is designed to meet the need for greater neutron fluxes than are available from the BGRR, especially in the epithermal range. The HFBR is cooled and moderated by heavy water and contains a heavy water reflector; it is fueled with enriched uranium. The core consists of 28 ETR-type flat plate fuel elements housed in a shroud in the lower spherical portion of the reactor vessel. Cool D_2O, pumped into the upper cylindrical part of the vessel, flows downward inside the shroud through the fuel elements and is discharged into the bottom of the vessel; it then flows upward outside the core and leaves from an outlet pipe at the upper part of the vessel to be cooled by heat exchange with water from cooling towers.

Outside the core vessel is a water-cooled thermal shield. This secondary vessel provides emergency containment to keep the core covered with D_2O in the event of a leak in the primary vessel. The 16 control rods are divided, with 8 main rods operating above the core and 8 auxiliary rods operating below the core. There are 6 standard horizontal beam tubes; 5 are tangent and 1 is radial with respect to the core. The radial tube will be used for fast chopper time-of-flight experiments in which neutrons of resonance energy are required. Other beam tubes are expected to be used for diffraction work. There are also 2 dual beam tubes, designed to accommodate 2 diffraction setups, and 1 cold neutron beam tube. In addition, 3 thermal and 4 fast vertical irradiation thimbles are provided.

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

This reactor, which is expected to deliver a peak thermal flux of $\approx 7 \times 10^{14}$ neutrons/cm^2-sec and epithermal fluxes of ≈ 1 to 2×10^{15} neutrons/cm^2-sec, will be used primarily as a source of high intensity external thermal and epithermal neutron beams for studies in the physical sciences.

The architect-engineer work is being done by the Lummus Company under contract to the Atomic Energy Commission. The reactor will be located on Rutherford Hill southeast of the BGRR's cooling tower. A preliminary summary hazards report has been prepared by the Brookhaven technical staff and submitted to the AEC. Action by the AEC is anticipated during the summer of 1961.

80-in. Hydrogen Bubble Chamber

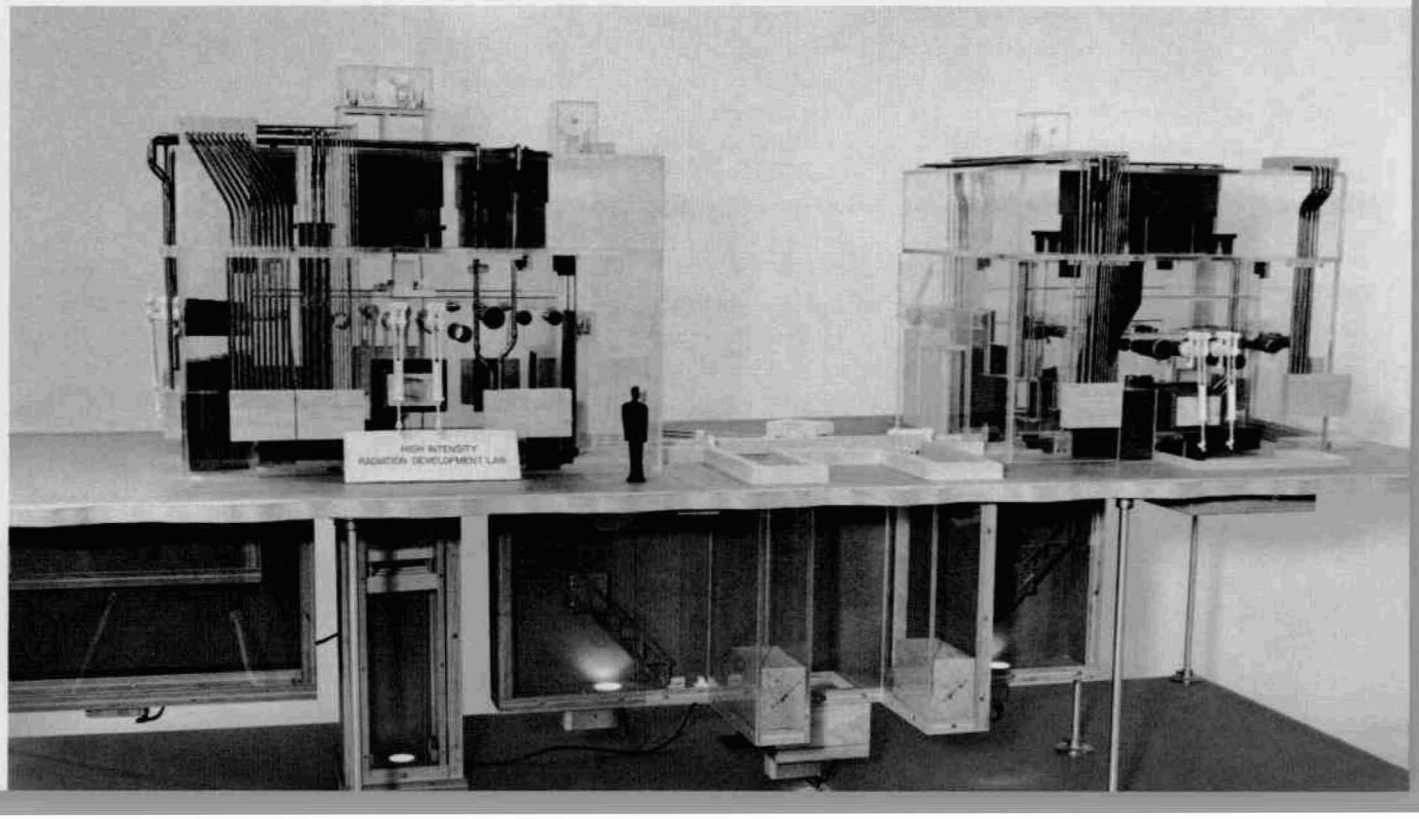
Design, fabrication, and assembly of the BNL 80-in. liquid hydrogen bubble chamber is making good progress. Design of the major components is essentially finished. The 450-ton magnet yoke with carriage, copper coils, and vacuum chamber is in fabrication. The stainless steel, liquid hydrogen chamber body and associated parts have been cast. A new material called Kromarc-55 has been selected for these castings because of its very favorable properties for this particular application. A full size 81×30-in. test glass window, 6½ in. thick, weighing ≈ 1450 lb, and about one-quarter tempered, has been delivered and is being ground and polished. In order to obtain a very lightweight piston (36 in. in diameter with a weight of ≈ 200 lb) for expanding the chamber, development work is being performed by an industrial firm on a piston of cellular construction. Other smaller components are also being fabricated. Large compressors and test equipment are already being installed. Development work is still continuing on the optical system, particularly with respect to the retrodirective illumination. An optimum light source with associated components is under construction.

Construction of a building to house the chamber, a shielding block house, and all controls and power equipment is in progress in an area north of the AGS. Considerable detailed assembly and testing work will be necessary before the chamber is completed during the second half of 1962.

High Intensity Radiation Development Laboratory

Ground was broken for the 15,000-sq ft High Intensity Radiation Development Laboratory

Figure 9. Model of the High Intensity Radiation Development Laboratory (HIRDL) currently under construction. The preparation cell (right) will be used to encapsulate radioactive Co^{60} strips in stainless steel sheaths. Subsequently it can be used for irradiation experiments or other experiments requiring remote handling. Between the preparation cell and the irradiation cell (left) is a canal for the transportation of the cobalt sources by remote-handling methods. In the irradiation cell, materials will be exposed to the radiation sources for high level irradiation studies and evaluation of various geometric arrangements of sources.



(HIRDL) on November 28, 1960. This laboratory will be used to obtain engineering data on a variety of radiation sources in the million-curie range and to develop more efficient techniques for handling large-scale radiation sources. This information is essential for the design of future irradiation facilities for use in a wide variety of applications of radiation energy.

The total level of radiation expected to be employed in this laboratory is approximately two million curies. Most of the sources will be of Co^{60} and Cs^{137}; spent reactor fuel elements will also be used as sources of radiation.

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 will be prepared for experimental use.

Most of the foundation work, the canal, and the concrete foundations for the cells are completed. The steel shell of the building has been erected, and the building is now being closed in. Contracts for most of the specialized cell and auxiliary equipment have been placed.

GENERAL CONSTRUCTION PROGRESS

The complex of structures originally designed to house the Alternating Gradient Synchrotron and its ancillary equipment is nearing completion. An addition to one wing of the Service Building and the 60,000-sq ft L-shaped extension to the Target Building should both be ready for occupancy late in the summer of 1961. The building being constructed to house the 80-in. bubble chamber and its associated equipment is located on the outer side of the AGS tunnel northwest of the Target Building. It will be necessary to broach this tunnel to provide for a conjunction section through which beams can be taken from the AGS to the bubble chamber facility. Broaching of the ring will not be undertaken until the spring of 1962 in order that AGS downtime can be held to a minimum.

Phase I of the Nuclear Engineering Building, with an area of $\approx$38,000 sq ft, was completed and occupied in June 1961; it houses many of the Department's activities in the field of chemistry and chemical engineering. Design of a small volatility studies laboratory has been completed. Construction was delayed because of funding problems but is now expected to start in the fall of 1961.

The needs of the Nuclear Engineering Department will be further met in 1962 when an addition to the Metallurgy Building and an addition to the Critical Assembly Area, both under construction, are expected to be completed. The Metallurgy Building addition will provide ten general laboratories and office facilities in a total area of 13,800 sq ft. Rearrangements of some of the existing specialized laboratory facilities are planned. The Critical Assembly Facility will provide two critical assembly cells with better arrangements and greater flexibility for the handling of critical experiments. In addition, necessary supporting facilities and fuel storage, office, and computational space will be provided.

The new Physics Building, which will provide $\approx$104,000 sq ft of laboratory and office space for activities of the Physics Department now housed in ten temporary buildings, is well under way. Completion is scheduled for the end of 1961. The building includes a two-story laboratory section containing 27 general laboratories together with special laboratories for work in nuclear moments and solid state physics, for scanning and data analysis work connected with the emulsion and bubble chamber programs in high energy physics, and for other specialized supporting work. It is already clear that the space provided by this building will be inadequate to meet the total needs of the rapidly growing physics program, especially in the area of high energy physics.

Several one and two-room efficiency apartments to house visiting scientists are now under construction. These units comprise a total of 60 rooms that can be used in various combinations to accommodate 38 small family groups and will supplement the quarters converted from Army medical units in 1947. These additional accommodations were much needed, since in recent years the Laboratory has been unable to house all its visitors. Occupancy of these units is scheduled for late in 1961.

It is hoped that the master building plan for Brookhaven National Laboratory can be implemented expeditiously. First priority is being given to the provision of permanent laboratories of a type and size to meet the current and future needs of the Laboratory. The request for 1962 now before Congress includes for Brookhaven permanent laboratories for Chemistry and for Instrumentation and Health Physics, and a small addition to the Cosmotron complex to provide laboratories, offices, and shop space. Brookhaven will request

Figure 10. The recently completed Nuclear Engineering Building (first phase).

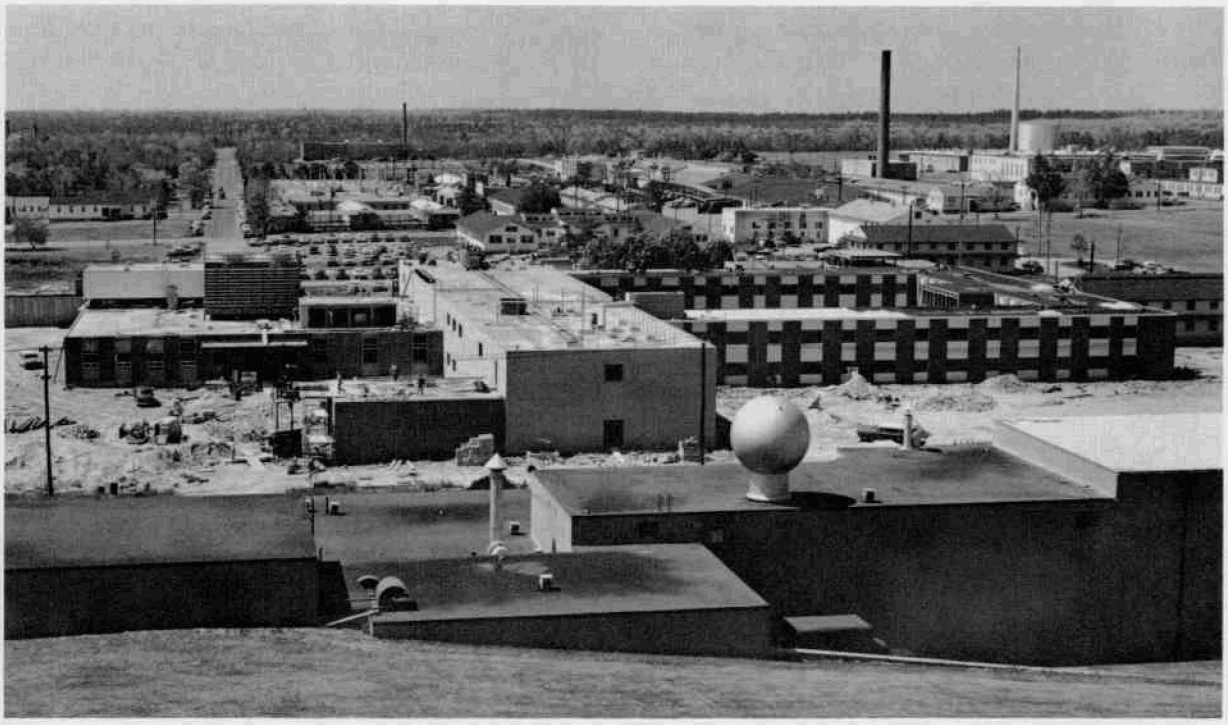


Figure 11. The new Physics Building, showing status of construction as of May 1961. In the foreground is the Cyclotron–Van de Graaff Building.

a continuation of this program for future years in order that the former Army buildings still in use, which were modified after the Laboratory took over the Camp Upton site, will ultimately be replaced by suitable permanent constructions.

PERSONNEL

The total number of employees at Brookhaven National Laboratory on June 30, 1961, excluding temporary employees, Research Collaborators, and guests, was 2388. This represents a net increase of 263, or slightly more than 12% for fiscal 1961. The salaried scientific staff including salaried visitors increased from 385 to 437 during the same period; this increase was divided approximately equally between regular staff and visitors. It should also be noted that in the category of nonsalaried visitors the number of scientists affiliated with the Laboratory on May 31 increased from 347 in 1960 to 406 in 1961. These visitors are not at Brookhaven on a full-time basis, but about one fourth to one third of them are on site at any given time. Excluding Research Associates, $\approx$450 visiting scientists worked at the Laboratory during the year. These individuals were affiliated with 185 different institutions.

Postdoctoral Research Associates, who are classified as visitors, accounted for an all-time peak of $\approx$80 man-years of effort. These appointments are essentially one-year postdoctoral fellowships with a possibility of renewal for a second year. Of the 94 Research Associates holding appointments on May 31, 51 were foreign scientists.

Summer visitors continue to play a substantial role in the Laboratory's program. Arrangements have been made for almost 300 visiting scientists and students to work at the Laboratory during the summer of 1961. Half are staff members from colleges and universities, industrial organizations, and other institutions, while the remainder are students.

Several years ago the criteria for appointment to the Brookhaven scientific staff were revised to require that the appointee hold a Ph.D. or M.D. degree or have the equivalent experience. As a result, the composition of the scientific staff has tended to increase at the Ph.D. or M.D. level, while the number of persons with Bachelor's degrees has tended to remain constant. Approximately 60% of the regular scientific staff, 90% of the salaried visitors, and 70% of the nonsalaried visitors hold Ph.D. or M.D. degrees.

ADMINISTRATION

The organization of the Laboratory as of June 30, 1961, is given in Figure 1. Dr. L.V. Berkner,

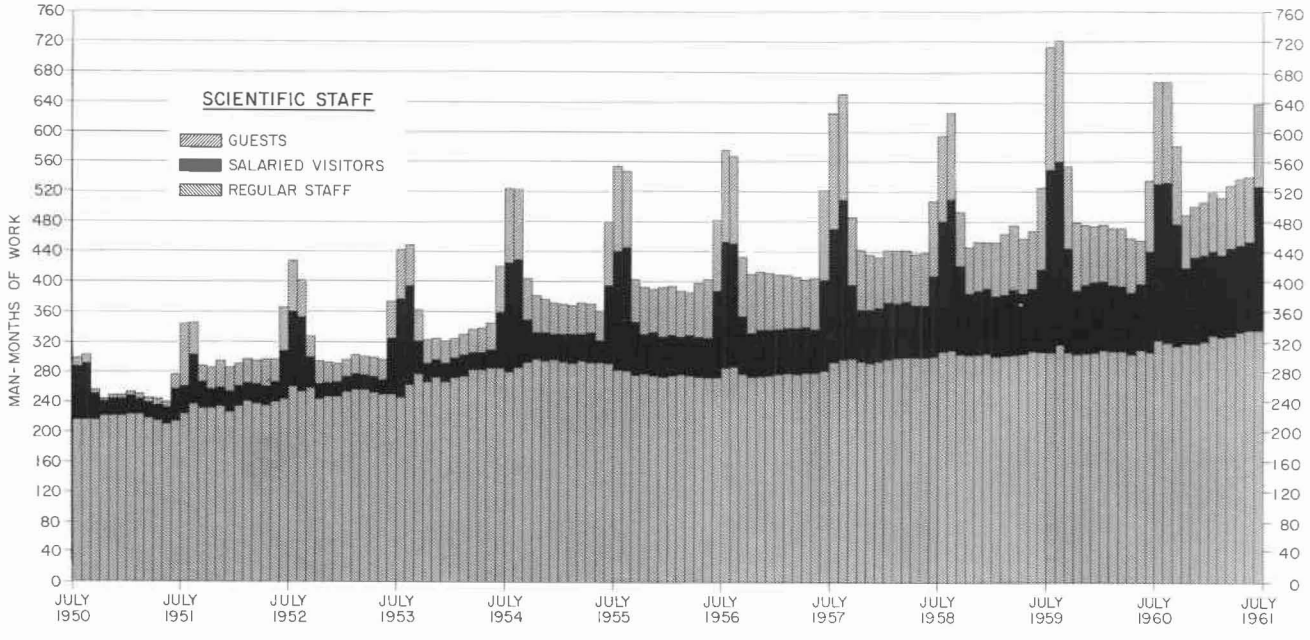


Figure 12.

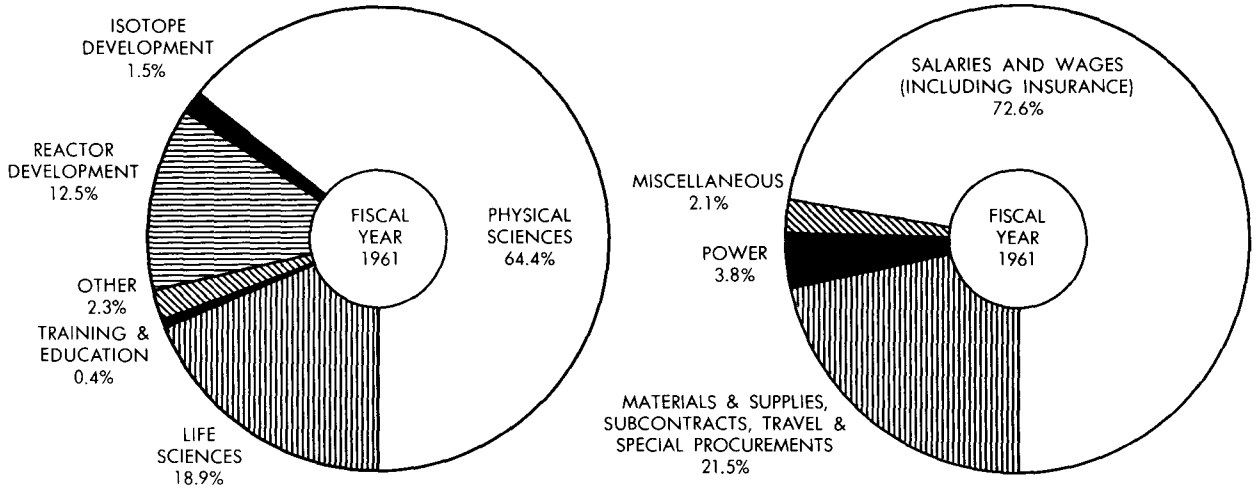
President of AUI since 1951, resigned on November 30, 1960, to become Director of the Graduate Research Center in Dallas, Texas. Dr. L.J. Haworth, Director of Brookhaven National Laboratory, was appointed President of AUI. In April of 1961 Dr. Haworth resigned as President of AUI and Director of Brookhaven National Laboratory to accept a Presidential appointment as Commissioner, United States Atomic Energy Commission. Mr. E. J. Reynolds served as interim President of AUI until the election of Dr. I.I. Rabi as President on April 21, 1961. Dr. G.F. Tape was appointed Acting Director of BNL and served until the appointment of Dr. M. Goldhaber as Director by the Board of Trustees on July 20, 1961. Dr. Tape will continue as Deputy Director.

Mr. M.M. Small was appointed Business Manager on November 1, 1960. The Supply and Materiel and Purchasing Divisions report to Mr. Small. Mr. James M. McTavish was appointed Purchasing Manager in May 1961.

Mr. S.M. Tucker was appointed Assistant Director on November 1, 1960, with continuing responsibility for Architectural Planning, Plant Maintenance, Photography and Graphic Arts, Central Shops, and Security and Plant Protection. Following the death of Mr. F.H. Williams in May 1961, Mr. E.J. Burke was appointed Security Officer and Head of the Security and Plant Protection Division.

In November 1960, the Accelerator Development Department and the Cosmotron Department were combined into the Accelerator Department under the Chairmanship of Dr. G.K. Green with Drs. J.P. Blewett and L.W. Smith serving as Deputy Chairmen.

Dr. J.W. Calkin was appointed Head of the Applied Mathematics Division in January 1961.



OPERATING COST DISTRIBUTION BY PROGRAMS

FISCAL YEAR	PHYSICAL SCIENCES	REACTOR DEVELOPMENT	LIFE SCIENCES	ISOTOPE DEVELOPMENT	TRAINING & EDUCATION	OTHER (NET)	TOTAL COST
1961	16,560,779	3,198,809	4,845,371	381,462	97,211	584,134	25,667,766
1960	11,775,522	3,421,837	4,584,337	315,310	166,300	671,205	20,934,511
1959	9,395,450	4,410,595	4,172,833	104,486	39,442	538,498	18,661,304

MAJOR CATEGORIES OF OPERATING EXPENDITURES

FISCAL YEAR	SALARIES AND WAGES	MATERIALS & SUPPLIES SUBCONTRACTS, TRAVEL & SPECIAL PROCUREMENTS	POWER	MISCELLANEOUS (NET)	OPERATING TOTAL
1961	18,630,185	5,521,786	975,191	540,604	25,667,766
1960	15,125,492	4,295,397	868,432	645,190	20,934,511
1959	13,248,663	4,220,091	728,766	463,784	18,661,304

Figure 13.

Table 2

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

	FY 1961		FY 1960		FY 1959	
	$	%	$	%	$	%
Scientific & hospital	5,220,768	92.0	2,760,196	85.2	1,597,742	71.3
Automotive & heavy mobile	198,411	3.5	201,234	6.2	267,452	11.9
Office machines & furniture	94,738	1.7	75,971	2.3	86,840	3.9
Shop equipment	136,201	2.4	142,141	4.4	154,332	6.9
Miscellaneous	24,462	0.4	62,842	1.9	133,195	6.0
Expenditures, Total	5,674,580	100.0	3,242,384	100.0	2,239,561	100.0
Proceeds from sales	(22,036)		(39,958)		(23,165)	
Expenditures, Net	5,652,544		3,202,426		2,216,396	

Table 3

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

	FY 1961			FY 1960			FY 1959		
		Man-years			Man-years			Man-years	
	Costs, $	Sci.	Others	Costs, $	Sci.	Others	Costs, $	Sci.	Others
Alternating Gradient Synchrotron									
Direct									
Salaries, wages, insurance	192,317	4.5	20.0	1,248,309	28.0	127.0	1,076,228	34.5	112.5
Materials, construction, etc.	2.486,877			2,249,780			6,859,692		
Subtotal direct	2,679,194			3,498,089			7,935,920		
Charges from organizational units	65,834			253,025			198,595		
Total	2,745,028			3,751,114			8,134,515		
Other, Including High Flux Beam Research Reactor and 80-in. Bubble Chamber									
Direct									
Salaries, wages, insurance	454,041	24.0	28.0	277,001	9.5	16.5	147,614	6.5	12.0
Materials, construction, etc.	7,174,253			4,446,120			4,223,724		
Subtotal direct	7,628,294			4,723,121			4,371,338		
Charges from organizational units	230,004			160,256			134,974		
Total	7,858,298			4,883,377			4,506,312		

FINANCE

The Laboratory's AEC-supported research was financed by five Divisions of the AEC, namely, Reactor Development, Research (Physical Sciences), Biology and Medicine (Life Sciences), Isotope Development, and Training and Education. The operating costs associated with the work for each program are shown in Figure 13; the major categories of operating expenditures are also shown. Table 1, on the reverse side of the organization chart (Figure 1), shows in detail the operating expenditures of the Laboratory on a broad organizational basis.

Table 4

Inventory at Close of Fiscal Year

Type of inventory	Fiscal year 1961	1960	1959
General stores*	$ 524,004	$ 448,487	$397,842
Precious metals and radium	84,648	87,668	73,621
Stable isotopes	37,644	23,413	26,494
Heavy water	672,330	679,535	443,820
Total	$1,318,626	$1,239,103	$941,777

*The number of months investment was 3.0 in 1961, 3.2 in 1960, and 3.4 in 1959.

BROOKHAVEN NATIONAL LABORATORY

COMPARATIVE BALANCE SHEET

Assets	June 30, 1961	June 30, 1960
Cash	$ 260,753	$ 681,682
Accounts receivable	88,071	84,488
Advances and prepaid expenses	89,930	82,038
Deposits	71,388	57,049
Inventories	6,129,188	1,294,527
Fixed assets (less reserves of $33,089,120 at June 30, 1961, and $28,824,428 at June 30, 1960)	76,589,179	58,244,540
Construction in progress	9,414,288	21,082,874
Total assets	$92,642,797	$81,527,198
Liabilities		
Accounts payable	$ 2,922,184	$ 2,699,885
Accrued payroll	214,270	104,969
Atomic Energy Commission	89,506,343	78,722,344
Total liabilities	$92,642,797	$81,527,198

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

The increase in total expenditures for fiscal 1961 is associated with a larger staff and with the acquisition of materials, supplies, and equipment, especially for high energy research. It must be remembered that the transition from construction of the AGS to its operation and use for research took place during the year. Not only were there major acquisitions of equipment, such as that for beam handling at the Cosmotron and AGS, but fabrication of components for the 80-in. bubble chamber was begun. Of the total increase in expenditures for operations and equipment, $\simeq$$6,000,000 or 83% was associated with the high energy physics program.

Table 2 shows expenditures for capital equipment. Here again, most of the increase is for scientific equipment essential to the program in high energy physics. A summary of expenditures for fixed assets (plant and equipment) is presented in Table 3. Table 4 sets forth inventories for which the Laboratory is responsible.

CONFERENCES AND PUBLIC INFORMATION

The second annual series of George B. Pegram Lectures was delivered by Dr. René Jules Dubos of the Rockefeller Institute. He chose the title "The Dreams of Reason" for these four public lec-

Figure 14. Dr. René Jules Dubos (center), Second Annual George B. Pegram Lecturer, with Mrs. Dubos and two members of the Lectureship Committee, Drs. R.C. Anderson (left) and S.A. Goudsmit.

Figure 15. High School Student Visitors' Day scene. An exhibit on the uses of radioisotopes as tracers in biological research is being shown to a group of students.

tures, which were held in the Laboratory's Theater on October 10, 12, 14, and 17 and dealt with the general themes of the philosophy of science and the scientist's place in the modern world. Subsequently, a book based on these lectures was published by Columbia University Press.

Three formal conferences were conducted at the Laboratory during the year. The Molecular Beams Conference, held November 3-5, was attended by 102 scientists representing 24 institutions. The Fifth Conclave on Nuclear Energy in Medicine, on the theme, Pediatricians, the Child, and Atomic Radiation, took place March 27-28 and was attended by 78 chairmen of departments of pediatrics from American and Canadian medical schools. The Fourteenth Annual Brookhaven Biology Symposium, on Fundamental Aspects of Radiosensitivity, held June 5-7, was attended by 100 scientists representing 56 institutions.

The Eighth Annual Naval Reserve Nuclear Science Seminar, on A Basic Workshop in Health Physics, was attended by 38 reserve officers from September 11-24.

During the year, 1237 persons representing 41 professional and technical groups paid one-day visits to the Laboratory to view its facilities and to learn about its research program. Additional visitors included 240 high school and college teachers receiving special training in the nuclear sciences at summer institutes sponsored jointly by the National Science Foundation and the AEC. Nine groups of graduate students, comprising 118 individuals, also visited for short periods to discuss with BNL scientists research problems in their fields of interest. More than 1400 professional, governmental, and industrial representatives from foreign countries made short visits during the year. The eleventh annual Visitors' Days held October 22 and 23 were attended by 13,450 individuals. The third annual College Student Visitors' Day for junior and senior college classes, held on October 28, was attended by 1152 students representing 75 colleges and universities. The seventh annual High School Student Visitors' Day held on October 29 was attended by 4459 students representing junior and senior classes in 165 schools.

The normal activities of the Public Information Office continue to increase, mainly because of the growing interest in the nuclear sciences shown by the public and by students.

PHYSICAL SCIENCES AND ENGINEERING

Physics

The research program in physics 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 (AGS), Cosmotron, 60-in. cyclotron, Van de Graaff accelerator, 18-in. cyclotron, and the Graphite Research Reactor at Brookhaven provide a wide range of energies and diversity of particles and radiation with which to carry out experimental investigations. The researches reported here will be described under the categories of particle physics, nuclear structure, neutron physics, atomic and molecular physics, and solid state physics. The theoretical scientists conduct their investigations in close association with the experimental scientists and provide stimuli for new approaches to the problem.

The work of Brookhaven scientists is enhanced by the presence 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 cross-fertilization of ideas and experience resulting from the presence of these visiting scientists is very important to an active research program.

PARTICLE PHYSICS

Research at the Cosmotron

In the investigation of the fundamental problem of understanding the forces between nucleons, the study of the π-nucleon system plays a major role. This aspect of the problem continues to occupy the attention of many experimentalists working with the Cosmotron.

Two basic mechanisms have been suggested to account for many of the features observed in pion-proton scattering and in pion production phenomena: the pion-nucleon interaction, and the pion-pion interaction. It has long been known that the pion-proton total cross section as a function of energy shows strong peaks (resonances) at several energies. This interaction at the resonance energies is sufficiently strong that the pion-proton system behaves in many ways like an excited state of the proton. This general behavior is described as the "isobar" model. Predictions of this model provide useful means of comparing theory and experiment. Some features of pion scattering and production appear to require, in addition to the pion-nucleon interaction, a strong interaction between pions. Since free pion-pion scattering cannot be directly observed in the laboratory at present, indirect methods must be used to deduce the features of the pion-pion interaction, which is one of the most interesting and challenging of the subjects now being investigated.

A group from the University of Wisconsin, using the BNL 14-in. hydrogen bubble chamber, has investigated the production of single pions by 2.0-Bev negative pions incident on hydrogen. The correlations in angle and momentum of the two outgoing pions showed dramatically the existence of a strong pion-pion interaction in the isotopic spin 1 state at 760 Mev. This discovery was quickly confirmed by a group from Yale University working with positive pions in the same energy range.

A BNL group has extended the energy range of work on angular distributions and momenta in negative pion-proton interactions in the 20-in. hydrogen bubble chamber. The observed momenta of the secondary particles agree fairly well with the predictions of the nucleon isobar model at the lower incident energies, but disagree at the higher energies, although even here nucleon isobaric states are still partially involved. The marked changes in nucleon center-of-mass angles to a predominantly backward distribution at higher energies indicate that the disagreement is due to the strong pion-pion interaction. Analysis of the data showed the existence of the resonant pion-pion state of isotopic spin 1 with a mass equivalent of 760 Mev, often called the "di-pion."

Proton-proton scattering experiments by a Brookhaven group, which had previously confirmed the existence of the lowest excited isobaric state ($T=\frac{3}{2}, J=\frac{3}{2}$) of the proton, have been continued. The results reveal evidence for the first time of the two higher excited states of isotopic spin $T=\frac{1}{2}$. These results and proton-proton interactions investigated with a hydrogen bubble chamber support new theoretical work at Brookhaven on the isobar model which has been extended to take account of multiple pion production in nucleon-nucleon and antinucleon-nucleon collisions. A counter group in collaboration with the University of Rochester is attacking the problem by a detailed determination of the momentum spectra of positive and negative pions produced in p-p collisions. Critical comparisons with the isobar model will be possible.

Two-prong events from elastic and inelastic collisions of 2.85-Bev protons in a BNL hydrogen bubble chamber were studied at Yale University. Mostly diffraction scattering was found for elastic collisions up to center-of-mass angles of 35°. No polarization of the incident protons, produced by scattering the primary Cosmotron protons off a carbon target, was observed. Inelastic two-prong events also showed agreement with the isobar model.

As already implied, there is at present no known way of constructing targets of free pions or neutrons. It thus has not been possible to measure many cross sections of fundamental importance, such as neutron-neutron, pion-neutron, pion-pion, etc., without side effects from other target constituents. However, Chew and Low have proposed a method of analyzing more complicated interactions so as to be able to predict these cross sections. A group from Yale University has carried out an experimental test of the validity of this method by measuring the cross section for the process $p+p\rightarrow p+n+\pi^+$ at a specific laboratory energy. With use of the Chew-Low method this measurement allows them to infer the total π^+-p cross section in a range of energies in which it has already been measured. The Chew-Low extrapolation shows excellent agreement with the data and indicates that such an extrapolation should show any π-π resonance as large as the $\frac{3}{2},\frac{3}{2}$ π^+-p resonance.

Another important phase of research in particle physics is the study of the strong interactions of the strange particles: the Ξ, Λ, and Σ-hyperons, and the kaons (heavy mesons). Here, too, resonances have appeared in the data and have excited much interest. Strong momentum correlations in the reaction products from $K^-+p\rightarrow\Lambda+\pi^++\pi^-$ first observed at Berkeley have been shown to be due to the existence of a resonance in the Λ-hyperon–pion system, called the Y^*, whose mass equivalent is 1385 Mev. This is a baryon state of strangeness -1 and isotopic spin 1 which decays by strong interaction into a $\Lambda+\pi$. Another kaon reaction in the pure $T=1$ state, $K_2^0+p\rightarrow\Lambda+\pi^++\pi^0$, has been studied by a Brookhaven-Yale collaborative group using the 14-in. hydrogen bubble chamber. Their result confirms the existence of the Y^* state in $T=1$. Investigation of the spin, parity, and decay branching ratio of the Y^* has not yet yielded conclusive results. Their results also show no strong evidence for resonance in the ($\Sigma^{\pm}$-$\pi^{\mp}$) or (Σ^+-π^+) systems. It was concluded that the branching ratio for $T=1$ of $(\Sigma^{\pm}\text{-}\pi^{\mp})/(\Lambda\text{-}\pi^0)\leqslant 10\%$.

Theoretical considerations show that the behavior of the cross section for the production of strange particles near threshold yields information on their parity. In particular the cross section amplitude for the production of $\Lambda+K$ from π^-+p is predicted to show a cusplike form at the threshold for $\Sigma+K$ production. Experimentalists from Columbia University have investigated a very small energy range near threshold with the BNL 20-in. hydrogen bubble chamber. Analysis of the angular distribution and polarization of the production process is in progress. A Brookhaven group has measured the production of $\Lambda+K^0$ as a function of energy from Λ to the Σ threshold. A detailed knowledge of the partial wave amplitudes of this process together with the detailed data at the Σ threshold from the Columbia experiment may allow a determination of the relative Σ-Λ parity. So far, the angular distributions at 0.795 and 0.835 Bev indicate that at least two partial waves are involved in the production mechanism. The analysis is being continued.

An experiment using an electrostatically separated beam of positive pions was designed by a group from Yale University to study the production of Σ^+-hyperons in hydrogen. The reaction is $\pi^++p\rightarrow\Sigma^++K^+$. Below the threshold for production of a pion in addition to the Σ-hyperon and kaon, the conservation laws of strangeness and charge require this to be the only way in which strange particles may be produced by positive pions on protons. The total cross section for Σ^++K^+ production shows a rise with increasing energy,

which indicates that both S and P wave production are important. In addition, higher angular momentum states are required to fit the angular distribution of the Σ^+ particles which changes rapidly with energy over the interval 0.980 to 1.260 Bev of the incident pion. The results at 1.090 Bev are consistent with the hypothesis of charge independence. The polarization of the Σ^+ was found to be small at this energy.

The analysis of an experiment by a Brookhaven group to measure the production of strange particles from 2.85-Bev protons in a hydrogen bubble chamber has been completed. The results for Σ^+, Σ^0, and Λ are in general agreement with a one-pion exchange model. Production of K-pairs at this energy is extremely rare. The same exposures yielded information on the cross sections and on momentum and angular distributions in collisions resulting in four charged particles, involving two or more pions. These results are in reasonable agreement with the isobar model.

Detailed momentum spectra of K^+ production from p-p collisions at two angles have been determined by a BNL counter group. The observed spectrum shows results that depart greatly from a simple phase space prediction, peaking in the region of 1.4-Bev/c laboratory momentum. Since K^+ production is at present not well understood, the results of this experiment are expected to provide a good test of various hypotheses under consideration (one-pion exchange, kaon exchange, and effective final state interactions).

The role of the leptonic mode in the decay of the Σ^--hyperon ($\Sigma^- \rightarrow e^- + \nu + n$) can yield important information regarding the universal Fermi coupling of hyperons. The first clear-cut example of this decay mode was discovered in a propane bubble chamber exposure to π^--mesons by workers from Columbia University. A careful analysis of all the exposures is being carried out to establish the rate.

A group from MIT performed a counter experiment using a 250-channel hodoscope of scintillation counters to study charged kaon decay modes. The setup permitted a measurement of the range of the muons in the decay $K^+ \rightarrow \pi^+ + \mu^+ + \nu$. The energy spectrum of the muons is still being analyzed, but it agrees with phase space calculations at the high energy end. It also appears that the branching ratio found for the decay into two pions or a muon and a neutrino does not agree with previous emulsion data.

The nonconservation of parity in hyperon decay allows the determination of the direction of polarization of hyperons. Since the magnetic moment, if any, is parallel or antiparallel to the direction of polarization, its direction is determined by a measurement of the decay products of the hyperon. A measurement of the magnetic moment of the hyperon can be made by measuring the angle through which the magnetic moment is rotated when passed through a known magnetic field. This magnetic moment is a fundamental quantity that is intimately related to the properties of the particle and should lead to new insight into its structure. Two experiments using different detection techniques have been performed in an attempt to measure the magnetic moment of the Λ-hyperon. One, using a diffusion chamber, has been carried out by a group from Argonne National Laboratory; another, using the spark chamber technique, was the result of collaboration between groups from BNL, ANL, MIT, and NYU. The photographs obtained in these experiments are now being measured, and the data are being analyzed.

Research at the Alternating Gradient Synchrotron

During the year the AGS came into operation, providing a primary beam of up to 33-Bev protons with intensities as high as 2.5×10^{11} protons/pulse. In addition to producing high energy secondary particles, the very high primary proton energy also results in a greatly increased flux of lower energy secondary particles. The intense beams produced result in much more rapid and accurate measurements involving nucleons, antinucleons, pions, and kaons.

The first experimental program undertaken was an extensive survey of these secondary particle beams produced by 10 to 30-Bev protons incident on aluminum or beryllium targets. For maximum utilization, measurements were made simultaneously by five groups from Brookhaven, Princeton University, and the University of Illinois by means of beam channels provided at several angles from 4¾° to 90° with respect to the target. This program had a dual purpose: (1) to provide detailed information, for use in planning future experiments, concerning the secondary intensities as a function of angle, momentum, and primary beam energy; and (2) to provide data for the study of particle production characteristics leading to both phenomenological and theoretical analysis of the basic high energy particle production mecha-

nisms. Individual particle mass identification was effected by magnetic analysis of the charged particle beams, coupled with a counter telescope containing a focusing gaseous Cerenkov counter or a time-of-flight measurement which selected the appropriate velocity interval of the particular particle being studied. In general the results show reasonable agreement with a much less extensive survey previously carried out at CERN, but the higher primary energy available from the AGS results in enhanced intensities of antiprotons and kaons. The large number of deuterons, tritons, and He^3 particles observed is not understood in detail. It is hoped that some of the properties of nuclear aggregates may be determined from a systematic study of the production of these heavier particles.

By using the new higher momenta secondary particles available at the AGS, the first bubble chamber runs were made. About 100,000 survey photographs of positive and negative particles interacting in hydrogen were taken. These were exploratory exposures preliminary to four new lines of investigation:

1. A search for new particles by a group from Yale University.

2. A search for the process of diffraction dissociation of the proton into the Λ-K^+ system by a group from the University of Wisconsin.

3. A study by a BNL group of the production of strange particles by K^--mesons using Cerenkov counters and a spark chamber to identify the incoming K^--meson.

4. A study of the production of hyperon-antihyperon pairs by a group from the University of Pennsylvania using electronic techniques to label the incoming antiproton.

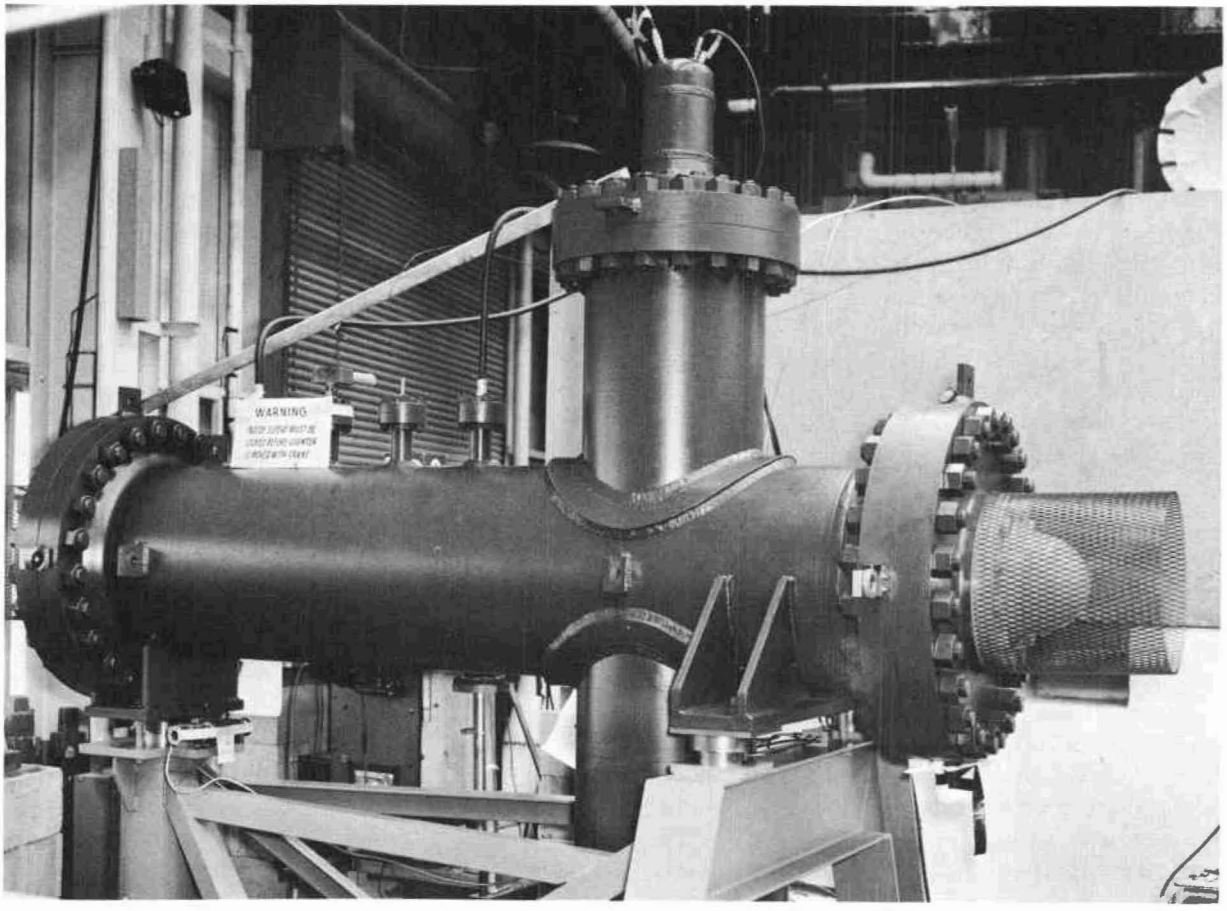


Figure 1. A high resolution gaseous differential Cerenkov counter used during the beam survey and total cross section experiment at the Alternating Gradient Synchrotron. Such a counter, in conjunction with a momentum-defining magnet, provides the only feasible method at present for the identification of the individual particles in the high energy beams produced by the AGS.

Another objective of the survey was to obtain information on the background conditions at the AGS. At the particular chamber location used for these exposures, acceptable photographs were possible in the secondary momentum range from 5 to 11.5 Bev/c; at higher momenta the muon background became prohibitive.

The first experiments designed on the basis of the survey program were total cross section measurements by two BNL groups using two new 220-liter, 10-ft-long, liquid hydrogen targets. One group investigated the behavior of the $\bar{p}$-p and p-p total cross sections as a function of proton momentum from 5 to 20 Bev/c. Similar work has been done at CERN in the region up to 10 Bev/c. The detailed behavior of the $\bar{p}$-p cross section in this new higher energy range is of considerable general interest and is also of specific interest from the point of view of testing a general theorem proposed by Pomeranchuk. This theorem states that at a sufficiently high energy (which is not quantitatively predicted) the total cross section of particles and antiparticles incident on nucleons must be equal. The previous work at CERN indicated that the p-p total cross section was more or less constant in the region 5 to 20 Bev/c, while the $\bar{p}$-p total cross section was considerably larger but slowly decreasing at 10 Bev/c. The workers at

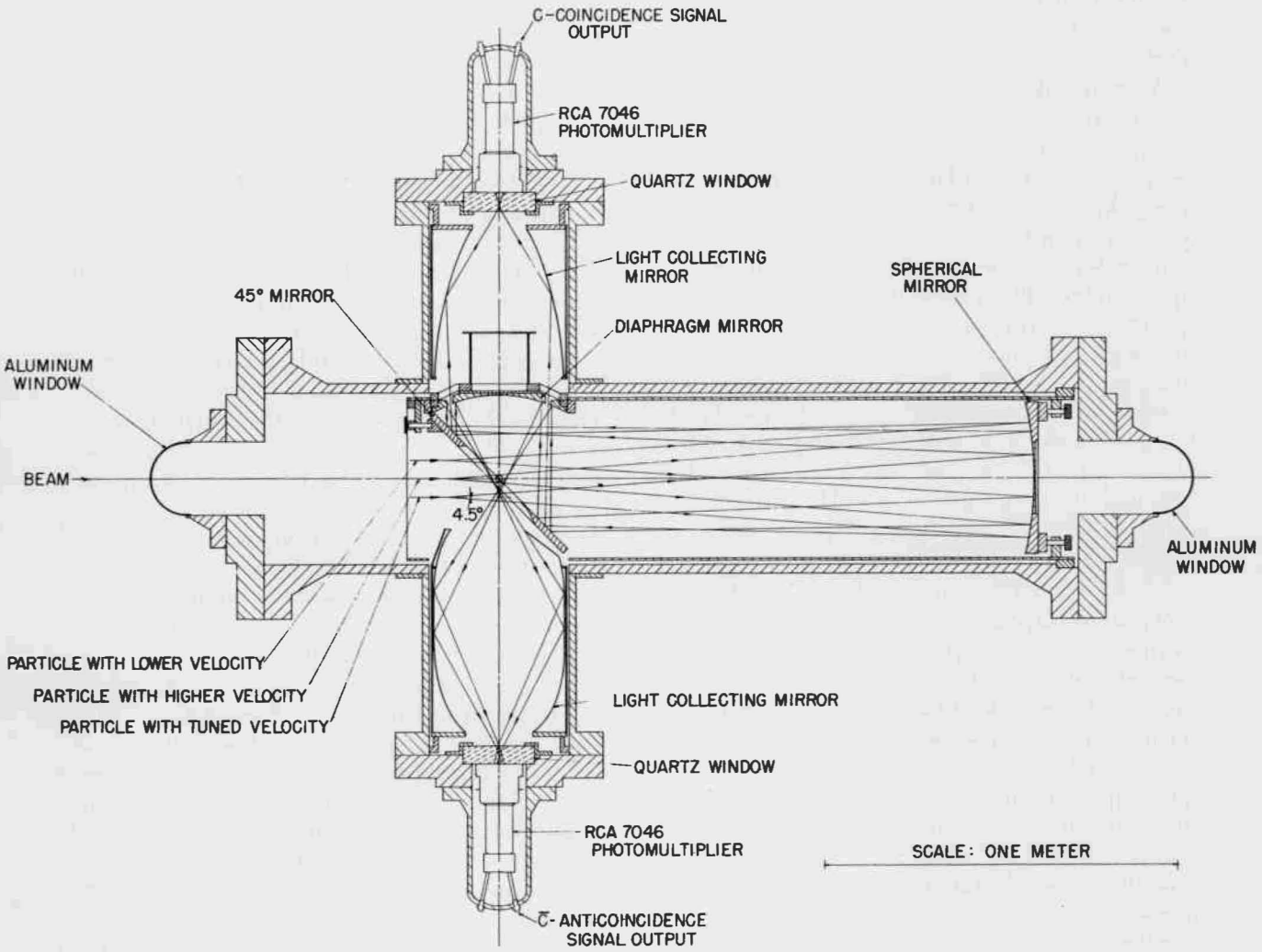


Figure 2. Schematic drawing of the Cerenkov counter in Figure 1, showing the light paths for particles of different velocities. The "tuned" velocity is determined by the momentum and mass of the particle being detected. This velocity is selected by varying the gas pressure, in this case CO_2. The counter is capable of distinguishing K-mesons from π-mesons at momenta as high as 20 Bev/c where the relative velocity difference is only 2.8×10^{-4}.

Brookhaven have confirmed the previous CERN results on the $\bar{p}$-p cross section with better experimental precision. They found from a preliminary analysis of the data that this cross section decreases slowly from 10 Bev/c to 20 Bev/c, while the p-p cross section remains about constant over this momentum region. Thus Pomeranchuk's theorem is apparently still not satisfied at these momenta.

Measurements of the total cross section for positive and negative kaons on hydrogen up to 20 Bev/c were carried out simultaneously by the other BNL group. The cross section for K^- is somewhat higher than that for K^+, and both are nearly constant over the momentum range investigated. Pomeranchuk's theorem is equally applicable to these measurements, and again the results show that it does not hold in this range of momenta.

In 1931 P.A.M. Dirac showed that the existence of a magnetic monopole (a single north or south pole) would not be incompatible with quantum mechanics and would demonstrate a new fundamental reciprocity between electricity and magnetism requiring a quantization of electric charge. A number of unsuccessful attempts have been made to find these monopoles, using both cosmic rays and accelerators. There are, however, reasons to believe that monopoles could have escaped detection in cosmic-ray experiments and are perhaps too heavy to have been produced by previously existing accelerators. The new energy range available at the AGS thus made a new search desirable. Physicists from Brookhaven and Harvard collaborated in this effort, which established a very small upper limit of 5×10^{-41} cm^{-2} for the production cross section of monopoles by 30-Bev protons.

Princeton experimenters working simultaneously with another beam channel investigated the effects on particle yields of possible secondary interactions in the producing nucleus. The target for the primary proton beam was aluminum alternated with beryllium, or carbon alternated with polyethylene. Preliminary results indicate that deuteron production in aluminum is enhanced by more than a factor of two over that in beryllium, and that antiproton annihilation in the producing nucleus does not affect the antiproton yields in any substantial way.

A beam of diffracted protons was produced from another target section of the AGS to permit more complete utilization of the Target Building. The very small energy loss in diffraction scattering provides protons with essentially the primary beam energy. These 30-Bev protons were used to make emulsion stack exposures for BNL, the University of Rochester, the University of Washington, the University of Illinois, and the Atomic Energy Research Institute of Seoul, South Korea.

This same beam was employed to establish the absolute cross section for the production by protons of C^{11} (half-life, $\approx$20 min) from carbon and of Na^{24} (half-life, $\approx$14 hr) from aluminum. These two activities are very useful in monitoring proton beam intensities.

All equipment is now ready to set up a separated antiproton beam of $\approx$3.5 Bev/c. The beam makes use of two electrostatic separators and several focusing and deflecting magnets. The calculations indicate that a pion contamination of considerably less than 10% can be expected. Slight modification of the arrangement will also produce K^- and K^+ beams of $\approx$2.5 Bev/c. Major runs in these beams, involving various groups, are planned with the 20-in. hydrogen chamber.

Much of the work in particle physics is accomplished with bubble chambers ($>$1,500,000 exposures were made at BNL this year). At the present time scanning, measuring, and computing of results still constitute the major bottleneck in bubble chamber research. A modern large computing machine now being installed at Brookhaven will alleviate the delays in computing. Delays in measuring, which are now the most serious, are to be largely remedied by a "Hough-Powell" flying spot measuring device for which a prototype instrument has been developed in cooperation with the laboratories at CERN and Berkeley. This device will measure bubble chamber photographs at $\approx$50 times the rate possible with existing measuring engines, while maintaining the high precision required. An analysis system built around the new instrument is under development. In the early models of the system, film is scanned (on scanning tables provided with rough measuring and digitizing equipment) for detection of events of interest, and a rough numerical description of each event is then transmitted to a punched card. The flying spot measuring instrument transmits directly to the computer precision coordinates describing all tracks and events on the photograph. The computer is then able to use the rough human description to select the coordinates for the desired event. In later stages of system development, the computer can be expected to take responsibility for event recognition in at least the simpler cases.

Theoretical work at Brookhaven, besides that already mentioned on the isobaric model, has involved studies of the $K^- + p$ interaction and of the K^* (a virtually bound state of the antikaon and a charged meson) and its decay modes and the phenomenological aspects of associated production. Some of the aspects of strange particle conservation laws and their relation to the weak interactions were also investigated.

A theoretical contribution has been made to the problem of the determination of the neutron form factor. To this end, calculations of the effects of final state interactions on inelastic e-d scattering were extended to include relativistic and mesonic corrections by using the techniques of dispersion relations. These calculations have been completed.

NUCLEAR STRUCTURE

The researches in this field may be divided into two broad classifications: those dealing with studies of the characteristics of unstable (radioactive) nuclei, and those concerned with the characteristics of the instantaneous products of a nuclear reaction. Studies of the ways in which an unstable nucleus is produced and reverts to a stable nucleus, through the radioactive decay process, yield information on the characteristics of the energy levels of the nuclei involved. Characteristics such as the spin, parity, and lifetime are sought and analyzed to obtain the systematics of the decay process.

Researches dealing with observations of the instantaneous products of a nuclear reaction also yield information about the characteristics of energy levels of nuclei. Some energy levels can be observed both in radioactive decay and in nuclear reaction studies, while others can be observed only in nuclear reactions, because of their very short lifetimes. As the techniques in electronic circuits have developed it has become possible to observe lifetimes as short as 10^{-11} sec with reasonably high precision. The ways in which nuclear energy levels may be excited and the systematics of the level structure, in isotopes consisting of different num-

Figure 3. A view of the AGS experimental area during the total cross section measurements. The beam shielding, electronic counting arrays, and some of the power supplies for the secondary beam magnets are shown. One of the gaseous Cerenkov counters, surrounded by shielding, is partially visible in the lower right-hand corner.

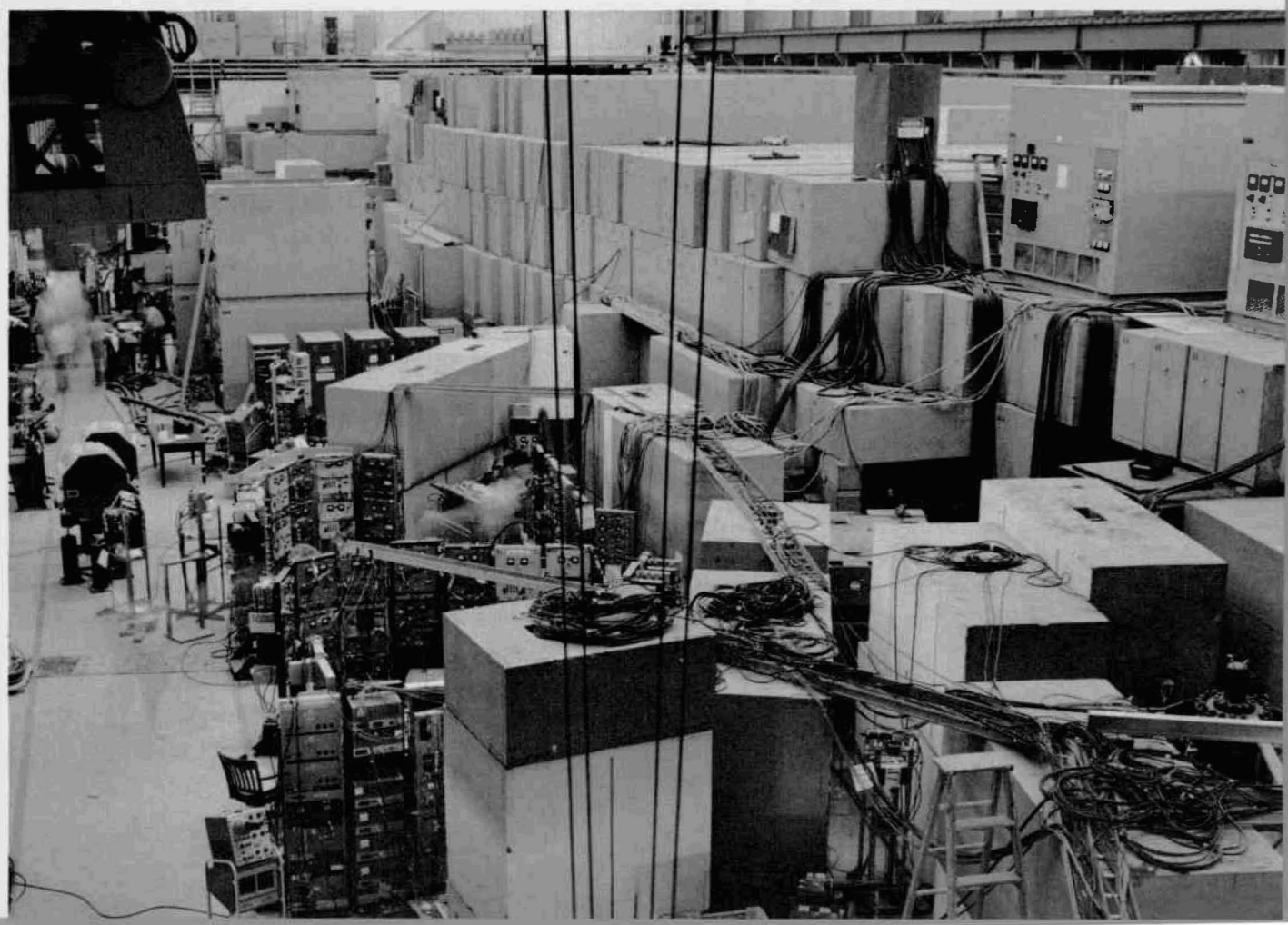


Table 1

Ratios of Reduced Transition Probabilities

	Strong coupling	Os^{186}		Os^{190}	
		D-F	Exptl.	D-F	Exptl.
$\frac{(2,2)\rightarrow(0,2)}{(2,2)\rightarrow(0,0)}$	1.43	3.02	2.1 ± 0.2	8.52	6.3 ± 1.0
$\frac{(2,3)\rightarrow(2,2)}{(2,3)\rightarrow(0,2)}$	∞	16.4	160 ± 80	14.9	23 ± 6
$\frac{(2,3)\rightarrow(0,4)}{(2,3)\rightarrow(0,2)}$	0.40	1.63	1.0 ± 0.2	5.29	$\leqslant 12.5$
$\frac{(2,4)\rightarrow(0,4)}{(2,4)\rightarrow(0,2)}$	2.94	≈ 25	9.3 ± 2.0	43.5	59 ± 49

The symbols in parentheses in the first column identify the state from which or to which a transition takes place. The first number denotes the band of which the state is a member (0, ground-state band; 2, band built on second 2+state), and the second number denotes the spin of the state.

bers of protons and neutrons, are the basis for the formulation of theories of the fundamental structure of atomic nuclei.

Studies on the recoil-free emission and resonant absorption of nuclear gamma-rays (the Mössbauer effect) have been extended to include the radioactive isotope Sn^{119m}. The hyperfine structure of the resonant gamma radiation is determined by measuring the transmission of a resonant absorber as a function of the relative velocity between source and absorber.

For the well-known case of the 14.4-kev radiation from Fe^{57}, magnetic fields sufficiently strong to split the hyperfine components are already present at the iron nuclei in the metal and many of its compounds because of their ferromagnetic properties. For nonmagnetic materials, such as tin, the macroscopic magnetic fields available in the laboratory are generally too weak to resolve the Zeeman components. The Sn^{119m} source was therefore prepared by diffusing the metal into a magnetic lattice of iron. The magnitude of the magnetic field induced at the source nuclei was then sufficient to resolve the six absorption minima resulting from the resonant absorption of the 24-kev $\frac{3}{2}+\rightarrow\frac{1}{2}+M1$ radiation as a function of the relative velocity with respect to a single absorber of grey tin metal. The middle component of each triplet could be enhanced or suppressed, in accordance with the theoretical radiation patterns for $M1$ radiation, by observing the gamma-rays emitted by the source either perpendicular or parallel to an externally applied magnetic field. With the known magnetic moment of the ground state, the splitting parameters obtained from these measurements yield a value of 0.672 ± 0.025 nuclear magnetons for the magnetic moment of the first excited state of Sn^{119} and an effective magnetic field at the tin nuclei in the iron environment of $(78.5\pm2.0)\times10^3$ oersteds. A shift of 4.24×10^{-8} ev was observed in the energy of the gamma-ray between source and absorber due to the dependence of the electron density at the nucleus on the chemical environment.

From studies of radioactive decay schemes it was previously shown that the energy levels of Os^{190}, which are populated in the decay of Ir^{190} (12 day) and of Ir^{190m} (3 hr), are best explained by using a weakly deformed, axially nonsymmetric nuclear model, as suggested by Davydov and Filipov. It was also established that the low-lying levels in Os^{188} and Os^{186} form a gradual transition from the pattern in Os^{190} to the level patterns of the strongly deformed nuclei in the rare earth region. Studies of the decay of Ir^{186} (15.5 hr), made in collaboration with a member of the Chemistry Department, have identified ≈100 electromagnetic transitions in the decay of Ir^{186} from which a level scheme of Os^{186} has been constructed. The levels include a rotational band based on the ground state and another one based on a second 2+ state, with spin sequence 2,3,4,5,6, even parity. Table 1 lists the ratios of reduced transition probabilities from levels of this second

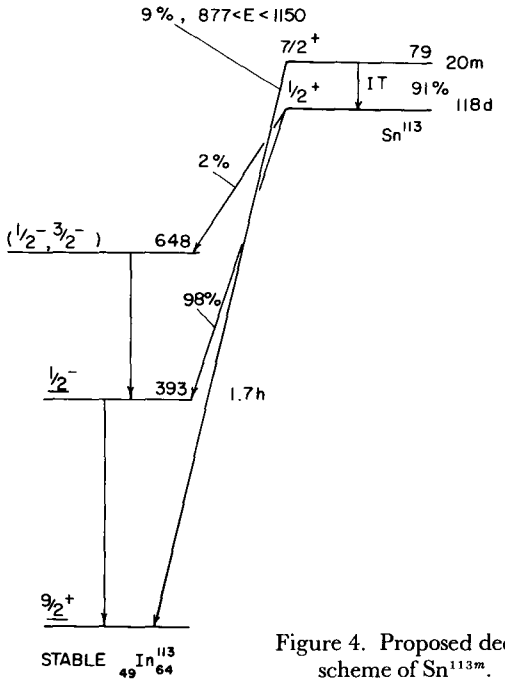


Figure 4. Proposed decay scheme of Sn^{113m}.

band to other levels in this band and to levels of the ground-state band for Os^{186} and Os^{190}. These experimental ratios are compared with the predictions of the strong coupling model of Bohr and Mottelson (second column) and of the Davydov-Filipov model. It is seen that in every case the results are between the predictions of these two models, but closer to the Davydov-Filipov values.

Recent calculations by Kisslinger and Sorensen, which include the short-range "pairing force" between nucleons, promise to make possible a detailed understanding of the spectra of heavier nuclei. The first calculations were made for nuclei with either a closed proton shell or a closed neutron shell, but they will be extended to nuclei with one or two nucleons added to, or missing from, the closed shells. Among the properties predicted by the pairing correlation model are the spins, parities, and energies of levels, and the transition probabilities between levels. The level schemes of several tin (closed proton shell, $Z=50$) and antimony ($Z=51$) isotopes recently studied are therefore of special interest.

The isomeric transition in 20-min Sn^{113m}, which had been reported to be $M4$, in agreement with the shell model, has been shown to be $M3$, as predicted by Kisslinger and Sorensen. In addition, a $(9\pm2)\%$ electron capture branch from the isomeric state was established. Spin assignments for the Sn^{113} isomers following from this work are included in the decay scheme shown in Figure 4.

Table 2

Isotope	E, kev	$\tau_{1/2}$, sec	Retardation factor
Sn^{117}	161	$(3.1\pm0.3)\times10^{-10}$	60
Sb^{123}	161	$(6.4\pm0.5)\times10^{-10}$	124

Two half-life measurements of low energy $M1$ transitions, both leading to the ground states, were carried out by the delayed coincidence method. Table 2 lists the isotopes in which the transitions take place, their energies, half-lives, and retardation factors (compared to the single-particle estimates).

The two-step isomeric transition in Sb^{122m} has been studied, and the decay schemes of the isomers Sb^{124m_1} (1.3 min) and Sb^{124m_2} (21 min) have been completed. Results have also been obtained on the decay of Sb^{115} (30 min).

The level structures of Sn^{118} and Sn^{120} were obtained from decay studies of Sb^{118} and Sb^{120} (6 day). Level energies and spin sequences for the two highest levels in both isotopes were found to deviate from those reported in the literature. The new results were based on measurements of lifetimes carried out by the delayed coincidence method and on angular correlation studies. Retardation factors of $\approx1.5\times10^4$ for $E1$ $(5-\rightarrow4+)$ transitions and of 16 and 250 respectively for $E2$ $(7-\rightarrow5-)$ transitions in Sn^{118} and Sn^{120} were obtained.

The mean life of the first excited state of Tl^{203} ($Z=81$, closed shell at 82) at 279 kev, determined by the delayed coincidence method to be $\tau=(4.05\pm0.08)\times10^{-10}$ sec, agrees very well with the recent determination by B. Deutsch and F. Metzger, based on the resonance fluorescence method.

The qualitative agreement of the measured values reported here with the predictions of the model, wherever the latter are available, is encouraging.

A program for the investigation of the gamma-rays emitted by various elements following thermal neutron capture has been carried out under the auspices of Brookhaven National Laboratory and the Aeronautical Systems Division of the United States Air Force. Coincidences are measured between high energy capture gamma-rays detected by a three-crystal pair spectrometer and

lower energy gamma-rays detected by a single scintillator. As the high energy gamma-rays populate individual levels in the product nucleus, the coincident spectra display the patterns of de-excitation of these individual levels, selected from what is ordinarily a highly complex spectrum of capture gamma-rays. The use of enriched isotopes combined with the observation of coincidences with established gamma-rays permits the assignment of transitions to individual isotopes. Properties of the energy levels are thus established, and the gamma-ray cascades also provide information on the neutron binding energy and properties of the state formed in neutron capture. With a new experimental arrangement that provides higher coincidence counting rate, lower background, and improved energy resolution, isotopes of iron and chromium have been reinvestigated, and a number of new features of their level schemes have been established.

Current interest in the question of fluctuations in the yield of gamma-rays emitted following neutron capture in individual resonances in U^{238} and other isotopes has prompted study of capture gamma-rays in $U^{238}+n$. The strong 4.06-Mev capture gamma-ray of $U^{238}+n$ has been found to consist actually of at least three gamma-rays. A new capture gamma-ray with an energy of 3.81 Mev has been found. The binding energy of the last neutron in U^{239} is found to be 4.76 Mev from a study of the gamma-ray cascades.

Coincidence results have also been obtained on the neutron capture of Te^{123} and scandium. Among several newly established facts concerning the de-excitation of the product nuclei is the finding that a level in Te^{124} at 3.07 Mev, which is populated by a strong primary capture gamma-ray transition, de-excites chiefly via a 0.365-Mev transition to a previously established level at 2.70 Mev.

Preliminary studies have been made of Se^{76}, Se^{77}, Ir^{191}, and Ir^{193}. The gamma-ray cascades established yield values of 6.45 and 6.30 Mev, respectively, for the binding energy of the last neutron in Ir^{192} and Ir^{194}.

The work on the determination of the electron-neutrino angular correlation coefficient for the decay of He^6 is continuing under the cooperative program between Columbia University and Brookhaven National Laboratory. New developments in the electronic circuits have made it possible to accumulate data more rapidly than previously.

Studies of the gamma decay of the 7.66-Mev second excited state of C^{12} were continued with the Van de Graaff accelerator during the past year. This level is thought to be responsible for the burning of helium in "red giant" stars through the fusion of three helium nuclei. The emission of an alpha particle is the predominant mode of decay; energy is released and the build-up of heavy elements occurs only if the level decays to the ground state of C^{12}, either directly or by a 3.23–4.43-Mev gamma cascade transition through the 4.43-Mev first excited state of C^{12}. The 7.66-Mev ground-state transition was observed in 1959. In recent work using proton-gamma-gamma triple coincidence measurements on the $B^{10}(He^3,p)C^{12}$ reaction, evidence for the cascade gamma transition was obtained. The 3.23-Mev gamma branch was found to be $(3.3\pm0.9)\times10^{-4}$ per decay of the 7.66-Mev level. This branch is stronger than the direct ground-state transition by a factor of 50.

The 7.66-Mev "helium-burning" level of C^{12} is also fed in the beta decay of B^{12}. Background effects prevented the observation of the gamma decay of the level in coincidence measurements of B^{12} radioactivity, although an upper limit was established consistent with the measurements on the $B^{10}(He^3,p)C^{12}$ reaction.

The conservation of parity in strong interactions was investigated in studies of the alpha decay of excited states in O^{16} produced by the $N^{15}(d,p)N^{16}(\beta^-)O^{16*}$ reaction with the Van de Graaff accelerator. An energy level in O^{16} at 8.88 Mev is fed during the beta decay of 7-sec N^{16}. Alpha emission from this state, which is known to be $2-$, to the $0+$ ground state of C^{12} is energetically allowed but should be strictly forbidden by selection rules if parity is conserved. A solid-state alpha-particle detector was used in the search for alpha emission from this level. The experiment to date has established 7×10^{-13} as an upper limit for the value of F^2, the intensity of the parity nonconserving part of the nuclear wave function. This number is ≈3 orders of magnitude lower than has been obtained in any other type of experiment designed to test the conservation of parity in strong interactions. Further refinements of this experiment are now in progress.

NEUTRON PHYSICS

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

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

A study of the diffusive motions of molecules in liquids by cold neutron scattering experiments has shown that molecules tend to remain for some time (10^{-12} to 10^{-13} sec) in the field of their neighbors before making a diffusive jump. As a corollary it might be possible to observe "damped phonons" in the liquid state, at temperatures not too far above the melting point. In an attempt to observe such an effect, cold neutron measurements have been made by using a single crystal of lead and observing the change in line width of a longitudinally polarized phonon as the crystal melts. The phonon is chosen to lie at the edge of the Brillouin zone and consequently has a wavelength comparable to the interatomic spacing. As the temperature of the sample increases, the line width increases. The line, although very broad, is observed to persist at temperatures as high as 50°C above melting, and can be interpreted as a high frequency phonon of very short lifetime, probably <5 times its period.

Studies have been made of the spectra of scattered neutrons from various organic compounds in order to decide on a good design for a cold neutron moderator in the Brookhaven High Flux Beam Research Reactor. A program has been started to calculate the characteristics (transmission, time resolution, and velocity resolution) of various rotating shutter configurations as the basis for designing a cold neutron monochromator for this new reactor.

At the joint BNL-Chalk River fast chopper project a comprehensive study of the 7.25, 7.6, and 7.92-Mev gamma-rays resulting from neutron capture in 13 resonance levels in $Pt^{195}+n$ has been completed. The size distribution of transition probabilities for a single line is very broad and is found to be consistent with a Porter-Thomas distribution, i.e., a χ^2 distribution of the sum of the transition probabilities to the ground state or the first two excited states is found to be quite narrow, and shows that when the compound nucleus emits strongly to one state it radiates weakly (on the average) to the others. This "anticorrelation" of transition probabilities probably accounts for the fact that the 4.06-Mev gamma-ray previously studied in $U^{238}+n$ showed a relatively small change in transition probability from level to level. As mentioned above in connection with the work on capture gamma-rays, it is now known that this 4.06 "line" consists of at least three different gamma-rays. Although such an anticorrelation effect in transition probabilities is not expected from present theoretical ideas, the results in platinum and uranium seem to establish this effect quite conclusively.

An accurate determination of the resonance parameters of the 132-ev level in Co^{59} has been made with the fast chopper at the BGRR. The basic point of interest here is the assignment of spin of the compound state, which can be either $J=3$ or 4. In favorable cases ($\Gamma_\gamma \ll \Gamma_n$), a measurement of the peak cross section is enough to assign the spin, provided the error is small. This method has been used to show that the spin assignment is $J=4$. This cobalt resonance has wide use as a means for determining resonance flux in the 100-ev region in reactors. The resonance capture integral has not been known very well because of the fact that $\Gamma_\gamma \ll \Gamma_n$. To determine Γ_γ, the gamma-ray spectrum was measured in the resonance and at thermal energy by using the fast chopper at Chalk River. These spectra were shown to be the same, and from a measurement of the neutron flux in the resonance and at thermal energy it was possible to determine the radiation width. From these results the following parameters were determined: $\Gamma=5.20\pm0.20$ ev, $2g\Gamma_n=5.90\pm0.13$ ev, $\Gamma_\gamma=0.366\pm0.031$ ev, and $J=4$.

The resonance capture of Sm^{152} has also been studied because of the importance of this nuclide as a fission product of $Pu^{239}+n$. The resonance integral is essentially determined by the 8.1-ev level. Previous comparisons of integral measurements with results calculated from resonance parameters have shown disagreement. The following set of parameters has been obtained: $E_0=8.10\pm0.02$ ev, $\Gamma=(205\pm15)\times10^{-3}$ ev, and $\Gamma_n=(77\pm3)\times10^{-3}$ ev. The resulting calculated resonance integral is now in agreement with the latest integral measurements.

The equipment for making measurements with polarized, monochromatic neutrons and polarized target nuclei has been used on a routine basis. The system consists of a neutron crystal spectrometer and a cryostat for cooling the nuclear sample located on the spectrometer "arm." Monochromatic, polarized neutrons in the energy range from 0.06 to $\approx$15 ev are obtained by Bragg reflec-

tion from a magnetized cobalt-iron single crystal. The cryostat was designed for one and two stages of adiabatic demagnetization; thus samples can be cooled to $\approx 0.1°$ and $\approx 0.01°$K. By connecting the nuclear sample directly to the helium bath, experiments can be performed at any temperature between 4.2° and 0.95°K. The temperature used for a particular experiment depends upon the type of sample and the mechanism needed to produce the polarization. The objective of this program is to assign spins of slow neutron resonances by measuring the transmission of neutrons parallel and antiparallel to the nucleus. In most cases information on hyperfine splitting (h.f.s.) can also be obtained from the measurements.

Transmission experiments were carried out with Ho^{165}, polarized at 0.95°K in a polycrystalline sample of holmium ethyl sulfate. Since the h.f.s. is known to be extremely large in this case, a reasonable degree of polarization could be obtained at this temperature. The measurements lead to $J=4$ for the spins of two resonances at 3.96 and 12.8 ev. The neutron polarization can be obtained at 3.96 ev by comparing the measured effect with the calculated effect on the basis of the known h.f.s., and the value obtained from a double scattering experiment agrees with the measured value at thermal energies.

Transmission experiments were also performed with holmium metal at 0.95°K to obtain the nuclear polarization and hence information on the h.f.s. In this case the study of the depolarization of the beam traversing the nuclear sample was rather important. A large value of the nuclear polarization was also found for the metal sample. This value indicates that the magnetic field at the holmium nucleus is of the order of 5×10^6 gauss. A single crystal of holmium metal was used to measure the transmission effect at thermal energies. The sign of the effect was the same as in the above two resonances.

By using one stage of adiabatic demagnetization, samples of samarium ethyl sulfate and samarium double nitrate were cooled to 0.07°K. The spins of the first two resonances in Sm^{149} at 0.096 and 0.87 ev were measured to be $J=4$. These samples were kept below 0.1°K for periods exceeding 20 hr on one initial demagnetization.

Routine neutron cross section measurements, including studies of Dy^{164}, Ho^{165}, Eu^{151}, Sm^{152}, and Hf, have been continued with the high resolution crystal spectrometer. Measurements of control rod material were carried out to make quantitative determinations of the boron content for several AEC contractors.

Under the cooperative program between Columbia University and Brookhaven National Laboratory, studies of nuclear and molecular phenomena are being conducted with a single-crystal neutron spectrometer located at the BGRR. Emphasis has been placed on precision cross section measurements at thermal and subthermal neutron energies. The neutron absorption cross sections of four samples of normal boron commonly used as a cross section standard and reactor loading standards have been measured at neutron energies between 0.00291 and 0.1 ev. The resulting cross sections were:

	σ_a(2200 m/sec), barns
Argonne-Brookhaven standard boron	764±3
New Argonne standard boron	761±3
Westinghouse-Bettis standard boron	764±3
A.C.S. reagent grade H_3BO_3	762±2

These results show that the isotopic composition of these four samples is identical to within 0.5%.

At the request of the Neutron Cross Section Advisory Group, the total cross section of Pu^{239} has been measured between 0.00291 and 0.1 ev to provide data of greater accuracy for use in reactor design and for testing theories of the fission process.

The mass distribution of fission fragments in the thermal neutron fission of U^{235} has been investigated by using a deposit of U^{235} on a VYNS film midway between two solid state detectors. The mass distribution is derived from the energies of the fission fragments by the relation $M_1/(M_1+M_2) = E_2/(E_1+E_2)$. In one set of measurements, an electronic dividing circuit computed the ratio $E_2/(E_1+E_2)$ yielding the mass distributions for the fragments. In a second set of measurements, the mass distributions were measured at fixed values of the total kinetic energy of the fragments between 114 and 196 Mev. These were obtained by observing the kinetic energy distribution of one fragment in coincidence with a given (E_1+E_2) as selected by a single-channel analyzer. The mass distribution as a function of the total fragment energy thus obtained shows that the peak-to-valley ratios in these distributions increase with increasing total fragment energy.

In cooperation with the Chemistry Department of Columbia University, studies have been continued on the slow neutron scattering cross sections

of various chemical compounds. These measurements have been extended to study the low temperature crystal structure phases of NH_4I and NH_4Cl. A definite correlation is observed between the slopes of the scattering cross section vs neutron wavelength curves and the rotational freedom of the ammonium ion in these compounds. Moreover, a sharp increase in cross section is observed for NH_4I in moving through a first-order phase change at $T=-12°C$, corresponding to a change from hindered to one-dimensional free rotation for the ammonium ion. These results are being correlated with the chemical binding and freedom of motion of the protons in the various hydrogenous compounds. The Krieger-Nelkin theory has also been used to fit the data for NH_3 gas and benzene.

The neutrons produced by the $T(p,n)He^3$ reaction from the 3-Mev protons accelerated in the 18-in. cyclotron are being used in studies of the angular distributions of elastically scattered neutrons from oxygen. These distributions are being measured for neutron energies between 1.5 and 2.2 Mev with greater precision than heretofore possible in the angular range $+0.93 \leqslant \cos\theta_{cm} \leqslant -0.97$. The particular incident neutron energies are chosen to avoid appreciable contributions to the scattering from several large resonances in the total neutron cross section of oxygen. The polarization of the $T(p,n)He^3$ neutrons from the target is evident in the oxygen scattering data and is therefore being studied simultaneously.

ATOMIC AND MOLECULAR PHYSICS

The atomic beam apparatus has been improved to permit measurements of hyperfine structure to be made with great precision. Cs^{134m} has been studied with the following results: nuclear magnetic moment, $\mu=1.0964\pm0.0002$ nm; hyperfine splitting, $\Delta\nu=3{,}684{,}578{,}640\pm175$ cycles/sec; and the calculated hyperfine anomaly with respect to Cs^{133}, ${}_{133}\Delta_{134}=-0.0138\pm0.0002$. This anomaly is the highest yet observed for any element. The precision of measurement of $\Delta\nu$ was limited by the frequency standard in use at that time.

A study was made on Rb^{85} and Rb^{87}, both stable, to obtain data of greater precision and to compare the values of $\Delta\nu$ with the measurements made by other investigators using the optical pumping method. For this work it was possible to collaborate with the U.S. Army Signal Research and Development Laboratory, who furnished a cesium atomic frequency standard and some rf generating equipment. The measurements yield the following information: $\Delta\nu_{85}=3{,}035{,}732{,}460\pm5$ cycles/sec, and $\Delta\nu_{87}=6{,}834{,}682{,}664\pm5$ cycles/sec, referred to $\Delta\nu_{Cs^{133}}=9{,}192{,}631{,}770$ cycles/sec. The errors in these measurements were to an appreciable extent due to the errors in the atomic frequency standard. The value for Rb^{87} agrees very closely with that obtained by optical pumping and also with the value very recently reported by Dr. L. Essen at the National Physics Laboratory in Teddington, England. The nuclear magnetic moment of Rb^{85} was measured to be 1.34821(5) nm and the atomic g factors were in the ratio $g_{85}/g_{87}=1.000002(4)$. These measurements agree with the modified Breit-Rabi formula to within one part in 10^8. A similar study of Na^{24} has yielded a preliminary value of $\Delta\nu=1139.325(3)$ Mc/sec.

In collaboration with the Physics Department of the University of Wisconsin, measurement of the nuclear spin of Ar^{39} by optical methods is continuing. To date it is still somewhat uncertain whether the value is $\frac{7}{2}$ or $\frac{9}{2}$.

The consequences of a possible electric hexadecapole (16-pole) moment for nuclei with spin $I\geqslant2$ have been investigated. It has been shown that for the case of ions in crystals the effects of a possible hexadecapole moment will be considerably amplified by antishielding effects of the same type as have been previously calculated for nuclear quadrupole moments. The hexadecapole antishielding factor was calculated for the cases of the Cu^+, Ag^+, and Hg^{++} ions, and was found to be very large.

SOLID STATE PHYSICS

Theory

Most of the theoretical work during the year has been on the production and properties of defects in crystals. Several calculations have reached the stage of giving important results.

Machine calculations of radiation damage events in a model that simulates metallic copper have been described in earlier BNL annual reports. This technique has been exploited further during the past year. These calculations substantiate many of the predictions of the cascade theories, which clearly demonstrates the existence of a threshold energy for displacement, the production of interstitials and vacancies, and the occurrence of many replacement collisions for each interstitial. Perhaps the most important amendment to the

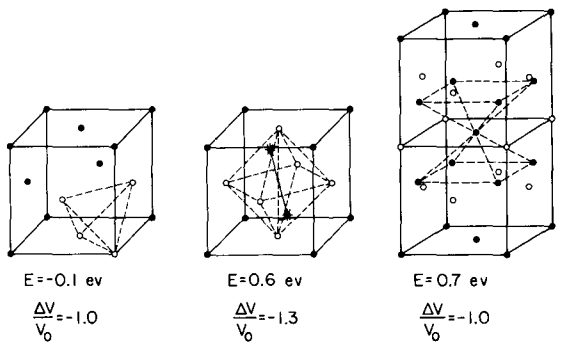


Figure 5. Schematic configurations of three tetravacancies calculated to be stable (or metastable) in copper. Vacated lattice sites are shown by open circles. Grossly relaxed atoms are shown by large dots. Relaxation of other atoms is not depicted. Binding energies, E, and volume changes, ΔV, are also listed.

cascade picture is in the distribution of interstitials and vacancies: because of the collision chains interstitials tend to be produced at a distance and are thus thinly distributed, while vacancies, having no modes of dynamic propagation, are left behind in rather compact arrays. The Brookhaven calculations do not lead to anything that one would naturally describe as an amorphous zone (possibly larger sets and higher energies would be required), but they do suggest the formation, in rich variety, of clusters of vacancies. Ideas on the nature of clusters of vacancies have developed rapidly in recent years. The same program was used to calculate the energies and configurations of vacancy clusters. The simplicity of the force law and neglect of the electron redistribution in the model appear to give energies that are a little lower than they should be. Thus the Frenkel pair has an energy of 2.7 ev, whereas previous calculations and some experimental evidence point to energies between 4 and 5 ev. Nevertheless, qualitative features of the calculations have considerable plausibility, and in particular the largest relaxations, which should occur in any reasonable model, are probably correct. In these calculations, besides the divacancy and two forms of trivacancy, three forms of stable tetravacancy and three forms of stable pentavacancy were found. The divacancy was bound with 0.06 ev (against separation into isolated single vacancies). The more stable form of trivacancy had the same configuration, but a lower binding energy (0.46 ev), as that found by Damask, Dienes, and Weizer. The configurations of the three tetravacancies are shown in Figure 5 and of the three pentavacancies in Figure 6. It is to be noted that the tetrahedral form of the tetravacancy is only metastable. The octahedral forms of the tetravacancy and the pentavacancy are especially noteworthy. The former has a pair of grossly relaxed atoms at its center, the latter a single one. In both cases the grossly relaxed atoms are in unsymmetrical positions, approximately as indicated in the figures. The large number of stable clusters and the high binding energy of all but one of them are thought to be significant for radiation damage and annealing theory. Undoubtedly, many more stable configurations of clusters of a small number of vacancies exist.

The simple clusters discussed above, as well as impurity-defect complexes, also play an important role in the annealing of point defects. An extensive theoretical study of annealing processes is in progress. The results to date may be summarized as follows:

1. For vacancy annealing with vacancy-impurity complex formation, the decay curve is exponential, and the decay constant is related to, but not equal to, the rate constant for vacancy migration.

2. The simultaneous annealing of mono- and divacancies is kinetically complex, but under certain circumstances simple quadratic decay and a quadratic plus linear decay are predicted theoretically. Both have been observed experimentally.

3. A complete analytic solution has been obtained for the kinetics of vacancy-interstitial annihilation with impurity-interstitial trapping. After an initial transient, the decay is a simple quadratic. No closed solution and no simple approximations were found when diinterstitial formation occurs.

The properties of interstitial atoms in the alkali halides are also of considerable current interest. A

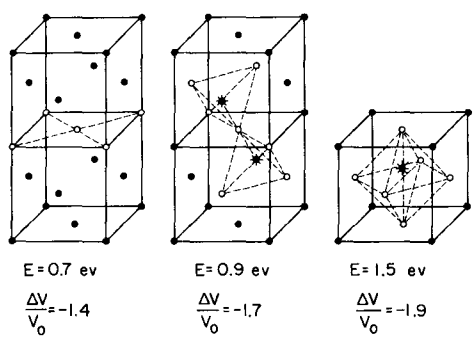


Figure 6. Schematic configurations of three pentavacancies calculated to be stable in copper. Conventions are the same as in Figure 5.

method has been developed for calculating the relaxation energy for an interstitial neutral defect in an alkali halide lattice by expanding the electrostatic, polarization, and dipole-dipole energy contributions to second order in terms of the displacements of the ions from their regular positions. The repulsive energy contributions involving the defect atom are treated exactly, whereas the repulsive contributions involving the regular ions themselves are also expanded to second order. This method has been applied to the case of an interstitial chlorine atom in NaCl for positions where the defect atom is at the center of a cube of ions and at the center of a square of ions; the difference when related to the same standard configuration gives an activation energy of $\approx$0.5 ev for the migration of a neutral interstitial chlorine atom in NaCl.

The work on the nature of the interaction potentials for various substances is continuing. The fields around the Thomas-Fermi atom corrected for exchange and inhomogeneity are being evaluated for all the elements. These fields will be applied to problems in radiation damage and atomic physics.

Radiation Effects

Radiation effects and other departures from perfect periodicity are under investigation with many diverse techniques. This is one of the major experimental research activities in solid state physics.

The study of solid state reactions controlled by diffusion and/or nucleation is continuing. It is now established that both parameters are affected by neutron irradiation. Diffusion effects have been isolated in the α-brass system, as discussed in previous reports, since the short-range-order changes being studied are not controlled by nucleation. Further work on enhanced diffusion is in progress with gamma-ray irradiations. In addition, the isolation and study of nucleation in alloys enhanced by radiation was begun. Iron containing 0.01 wt % carbon was irradiated in the BGRR at liquid nitrogen temperatures for various lengths of time, and the amount of carbon in solution was determined by internal friction measurements. Subsequent annealing of the specimens showed that the carbon disappeared from solution at a rate greater by $\approx$3 orders of magnitude than the thermal rate. The controlling activation energy for this accelerated reaction is that of the self-diffusion of carbon. The acceleration of the reaction is too large to be explained by an increased number of precipitation nuclei and is believed to arise from the trapping of the carbon atoms by point defects produced by radiation. However, when both the irradiation and subsequent annealing are carried out at 50°C, the reaction rate is increased by only one order of magnitude, and this effect saturates at low irradiation doses. This latter effect is probably true increased precipitation due to nucleation enhanced by radiation.

Additional measurements, utilizing color centers, of the number of defects induced in NaCl by reactor neutrons have been completed, and the previous results have been confirmed. Measurements have also been made which show that the 70° reactor irradiation temperature does not cause annealing of the negative ion cavancies. Annealing above 100°C, however, removes electrons from some, but not all, of the *F*-centers and destroys a small fraction of the vacancies. The total color removed and the number of vacancies removed increase as the annealing temperature increases. The results suggest that the removal of an electron from a negative ion vacancy in NaCl is a preliminary step to the annealing of the vacancy. This appears to be the case in three materials studied so far: fused silica, Al_2O_3, and NaCl.

Preliminary paramagnetic resonance studies (in cooperation with Picatinny Arsenal and the University of Connecticut) of irradiated crystals have shown much promise. Electron spin resonances, suitable for detailed study, have been found in a number of irradiated crystals (KN_3, Al_2O_3, TiO_2, $NaBrO_3$, and $NaClO_3$). A 5-line resonance system attributable to N_4^- has been observed in gamma-ray irradiated KN_3, and two other radiation-induced systems are formed at liquid nitrogen temperature. One of these is suggestive of N_2^- ions, and the other apparently involves only a single nitrogen atom. A single spin resonance appears in Al_2O_3. High sensitivity measurements possible with TiO_2 disclosed at least ten resonance systems at liquid nitrogen temperature.

The cooperative program with Brown University is concerned with the application of ultrasonic techniques to the study of irradiation-induced changes in solids. Several in-pile experiments have been carried out successfully. The ultrasonic attenuation and velocity changes in α-quartz during reactor irradiation have been measured. Velocity changes are very small, but the attenuation increases steadily after temperature equilibrium is reached, with two well-defined peaks superim-

posed on the curve, and a saturation value is reached after $\approx$1 wk in the BGRR.

Studies of the effect of radiation on the chemical activity of solids are continuing. The thermal decomposition of $NaBrO_3$ is under investigation by the technique previously used for $KBrO_3$. Gamma-ray irradiations cause a marked increase in decomposition rates. Neutron irradiations initially cause a large increase in decomposition rates, but upon prolonged irradiation the rate decreases. These observations, as well as those made previously on $KBrO_3$, are in accord with the conjecture that the increased decomposition rates are related to enhanced diffusion occurring in the irradiated materials.

An investigation of the effect of prior reactor irradiation on the gas adsorption properties of γ-Al_2O_3 has been in progress for some time. Extensive data are now at hand for hydrogen adsorption on this material. Hydrogen adsorption is decreased by irradiation of the solid, and the shapes of the isotherms are altered.

Structure of Solids

As in the past, the activities in x-ray and neutron diffraction have largely been confined to magnetism and ferroelectricity. The work in these areas has been strengthened by the acquisition of equipment for Mössbauer studies.

The properties of two-dimensional Fourier projections of typical neutron form factors have been studied in an attempt to determine whether anisotropies in the unpaired spin density in magnetic alloys can be observed directly. By varying the projected density maps as a function of the termination point of the Fourier series, certain gross features of the spin density symmetry become readily visible. Polarized neutron data for fcc cobalt and ordered Fe_3Al have been analyzed in this way, and the previous interpretation of the unpaired spin density made by comparison with calculated form factors has been confirmed.

The spatial distribution of the magnetic electrons on the manganese atoms in Mn_2Sb is being investigated. This material is of interest not only because the manganese atoms possess different magnetic moments, but also because of its layer-type structure. Data taken with the polarized beam spectrometer indicate definite differences between the manganese atoms, and gross departures from spherical symmetry are evident.

One of the important problems concerning the magnetic features of metallic iron is its intrinsic moment in the gamma or fcc phase. Although the high temperature magnetic susceptibility data indicate 6 μ_B for the iron atoms, the paramagnetic scattering data of Shull and Wilkinson are consistent with a value of 2.2 μ_B. Paramagnetic scattering for some face-centered iron alloys, namely $Fe_{0.88}Mn_{0.12}$ (Hadfield steel) and $Fe_{0.73}Ni_{0.11}Cr_{0.16}$ (stainless steel), indicates a temperature-independent magnetic moment of <0.5 μ_B on the iron atoms, which is consistent with the value 0.4 μ_B in an antiferromagnetic arrangement of the iron atoms, demonstrated by the low temperature data of Corliss, Hastings, and Weiss on Hadfield steel. For stainless steel no ordered antiferromagnetic structure has been observed, contrary to expectations based on the susceptibility data of Kondorskii.

Extensive studies have been carried out to determine the angular dependence of the magnetic scattering in ionic NiO by measuring the small magnetic peaks at the large scattering angles with high precision. The results indicate that the magnetic electrons associated with the Ni^{+2} atoms in this material possess e_g symmetry, as expected if the levels fill up according to Hund's rule, and that the magnetic electrons are more contracted than in the free atom.

The antiferromagnetic structures of $CrVO_4$, $FeSO_4$, $NiSO_4$, and $CoSO_4$ have been determined by neutron diffraction. Some of the magnetic interactions are rather unusual, since they must occur in linkages such as Fe—O—S—O—Fe. The magnetic structure of $CrVO_4$ consists of ferromagnetic sheets that stack antiferromagnetically in the c direction. The magnetic structures of $FeSO_4$ and $NiSO_4$ consist of antiferromagnetic sheets with ferromagnetic coupling between them. In $CoSO_4$ there is also antiferromagnetic ordering within each sheet, but the coupling between successive sheets does not lead to a collinear spin structure.

The tetragonal structure of ferroelectric $BaTiO_3$ has been re-examined by applying the completely general method of least-squares refinement in IBM 704 calculations. The results of this study illustrate very clearly the pitfalls, some of which have been ignored in the past, involved in the study of pseudosymmetric structures. Since all ferroelectric structures are pseudosymmetric, the accuracy of a number of such structures in the literature is open to some question.

The properties of gamma- and x-ray irradiated Rochelle salt have already been extensively studied, and several explanations have been offered for

the interesting effects on the dielectric properties. A basic feature common to most of the interpretations is that ferroelectric domain reversals are inhibited in the irradiated crystal, and that on continued irradiation the domains eventually become locked. An important new observation obtained by neutron diffraction is that odd ($0k0$) reflections decrease in intensity and may eventually disappear as the crystal is irradiated. Since these reflections provide direct evidence for structural changes in the transition between the paraelectric orthorhombic phases and the ferroelectric monoclinic phase, this observation suggests that in a region around each damage center the monoclinic symmetry is no longer stable.

Sodium nitrite undergoes a phase transition at 158°C, below which the crystal has the ordered ferroelectric structure described in an earlier report. Above the transition point the structure becomes disordered, and the crystal loses its ferroelectric properties. A single-crystal neutron analysis of this high temperature phase has now been completed by using ($0kl$) data at 185°C. Free rotation of the nitrite groups as the source of disorder was eliminated, and a refined analysis was carried out on a simple, spatially disordered model and on a hindered rotator. The best agreement with observed data resulted from the disordered model, although hindered rotation with a high potential barrier cannot be dismissed completely.

A refined analysis of the high temperature neutron diffraction data on β-brass is being carried out. Short-range-order parameters can be derived for some 20 shells from the data, but the reliability of the resulting values cannot be judged until the necessary refinements are completed.

A program has been initiated to determine some electric and magnetic properties of materials by using nuclear resonance fluorescence (the Mössbauer effect). Ferromagnetic Fe_4N has been studied by this technique. This material gives a Zeeman absorption pattern which can be interpreted to mean that the iron exists at two different sites with different magnetic and electronic properties. The relative intensities and the Zeeman splittings associated with these two sites tend to agree with the structure of Fe_4N obtained by neutron diffraction.

A theoretical and experimental program has been started on the study of defect modes of vibrations arising from substitutional impurity atoms in monatomic lattices. Preliminary calculations of the changes in the frequency spectrum have been made, and more refined calculations are in progress. Experimental results on the frequency of localized modes caused by nickel atoms in palladium have been obtained from inelastic cold neutron scattering measurements performed by the slow chopper group. The measured frequency of the localized mode is not in agreement with any of the simple theoretical models proposed.

High Energy Accelerators

On November 1, 1960, the Accelerator Department was formed by combining the staffs and facilities of the Cosmotron and the Alternating Gradient Synchrotron. Dr. G.K. Green was appointed Chairman, and Drs. J.P. Blewett and L.W. Smith were designated Deputy Chairmen.

ALTERNATING GRADIENT SYNCHROTRON

Preliminary testing of the Alternating Gradient Synchrotron (AGS) commenced on May 26, 1960, when a 50-Mev beam was injected and successfully spiraled around the ring $\simeq$100 times. On July 22, 1960, the injected beam was accelerated through transition energy to $\simeq$7 Bev. On July 29, 1960, acceleration to $>$30 Bev was finally achieved. The operation of the machine at this time depended on the accurate adjustment of many parameters in order to hold the beam to the end of the cycle. Beam intensity at 30 Bev was estimated to be $\simeq 2\times10^{9}$ protons/pulse. Immediately after these trials most of the staff's effort was de-

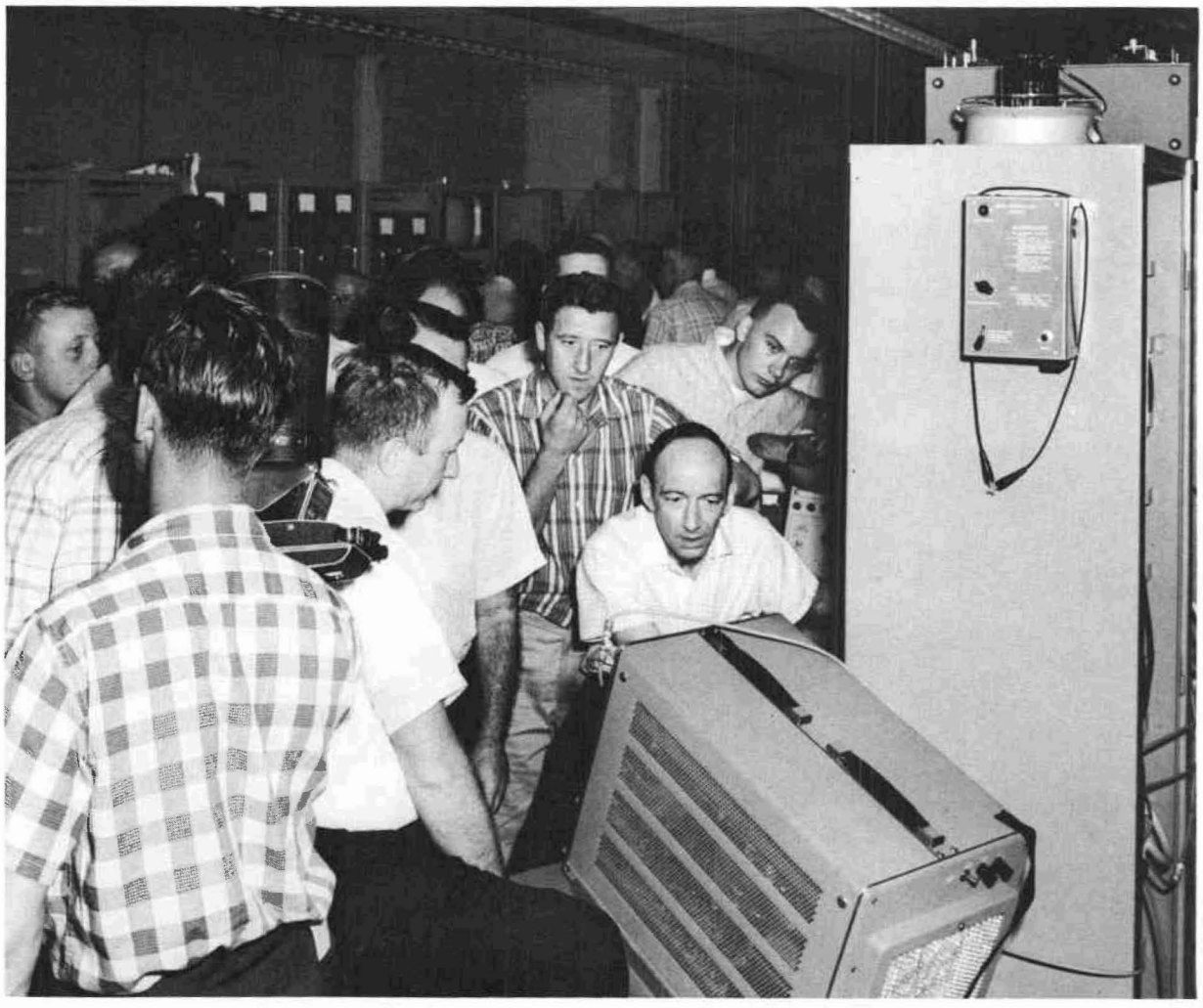


Figure 1. AGS control room, July 29, 1960.

voted to equipment modifications to increase operational reliability and beam intensity. Because of the longer operating experience and satisfactory performance of the linear accelerator (linac), initial efforts in this area were concentrated on injection optics studies. These investigations yielded procedures for rapid and accurate beam injection into the synchrotron. In addition, development was started of new ion sources and a beam buncher to give higher output currents from the linac.

During the early part of the fiscal year, $\approx$60 hr per month were devoted to machine operation. Approximately half of this time was used for experiments in high energy physics (principally beam surveys), and the remaining time was used for AGS studies. Consistent beam intensities of $\approx 5 \times 10^{10}$ particles/pulse were achieved. As operating experience was accumulated on the various machine components, additional improvements were made in the injected beam, capture processes, and acceleration. Beam intensities close to 1×10^{11} protons/pulse were recorded. This value represents an over-all acceleration efficiency from injection to end of cycle of $\approx$60%.

A technique of wrong frequency injection (first evolved at CERN) also helped to increase the yield of protons per pulse. In this method the beam is deliberately injected into an rf accelerating voltage at an incorrect frequency. The result, corroborated by work on the IBM 704 computer, is to bunch the beam and markedly increase the capture efficiency.

By mid-March 1961, machine operation was on the basis of two 8-hr shifts per day. Most of the available time was devoted to the program in high energy experimental physics (about three 8-hr shifts per week were used for machine work or studies). Beam intensities of $>1 \times 10^{11}$ were consistently achieved.

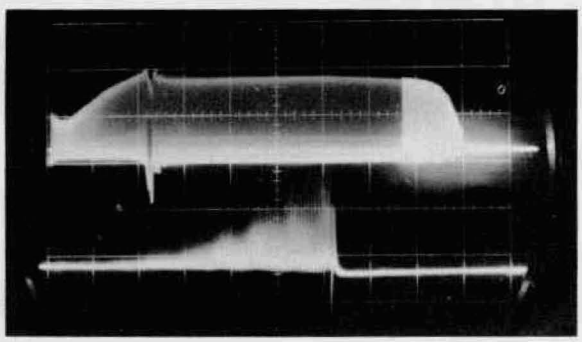


Figure 2. Upper trace: Pickup electrode display showing beam accelerated to 30 Bev. Lower trace: Particle spill from target (end of cycle).

Early in July the linac beam buncher cavity was installed; after completion of initial tests, an average of 2.5×10^{11} particles/pulse were carried out to the end of acceleration, with some peaks of 3×10^{11} particles/pulse being recorded.

The AGS has operated for extended running periods at these representative values:

Bev	Repetition period, sec
33	3.2
30	2.4
20	1.4
10	0.8

The greater part of the time assigned to high energy physics at the AGS since it began operation has been devoted to a rather complete survey program. Two target positions have been available, both located $\approx$15 in. from the beginning of the 10-ft field-free sections where the synchrotron magnets begin to open radially outward instead of radially inward. The *G* target, in the center of the *G* superperiod, is situated near the center of the Target Building (see Figure 3); the *F* target, at the center of the *F* superperiod, is upstream 30°, within the earth-covered tunnel, and provides small angle beams at the south end of the Target Building.

From the *F* target two beams were set up. One is a diffracted proton beam whose properties have been explored with nuclear emulsions; it has also been used for radiochemical experiments. The other is a secondary beam at a production angle of 4¾° that passes through a 72-in. analyzing magnet located in the tunnel and then is brought through ports in the shielding wall. Some preliminary survey work was carried out here with counters. Later, the Brookhaven 20-in. hydrogen bubble chamber was set up, and $\approx$100,000 pictures were taken as part of a moderately extensive exploratory program.

Secondary beams from the *G* target were brought through ports located at 4½°, 9°, 13°, 20°, 30°, and 90° on the outside, and at 30°, 37°, 45°, and 90° on the inside of the synchrotron ring. These beams have been used mainly for counter explorations. A search started (at the *G* target) for the Dirac magnetic monopole during the counter

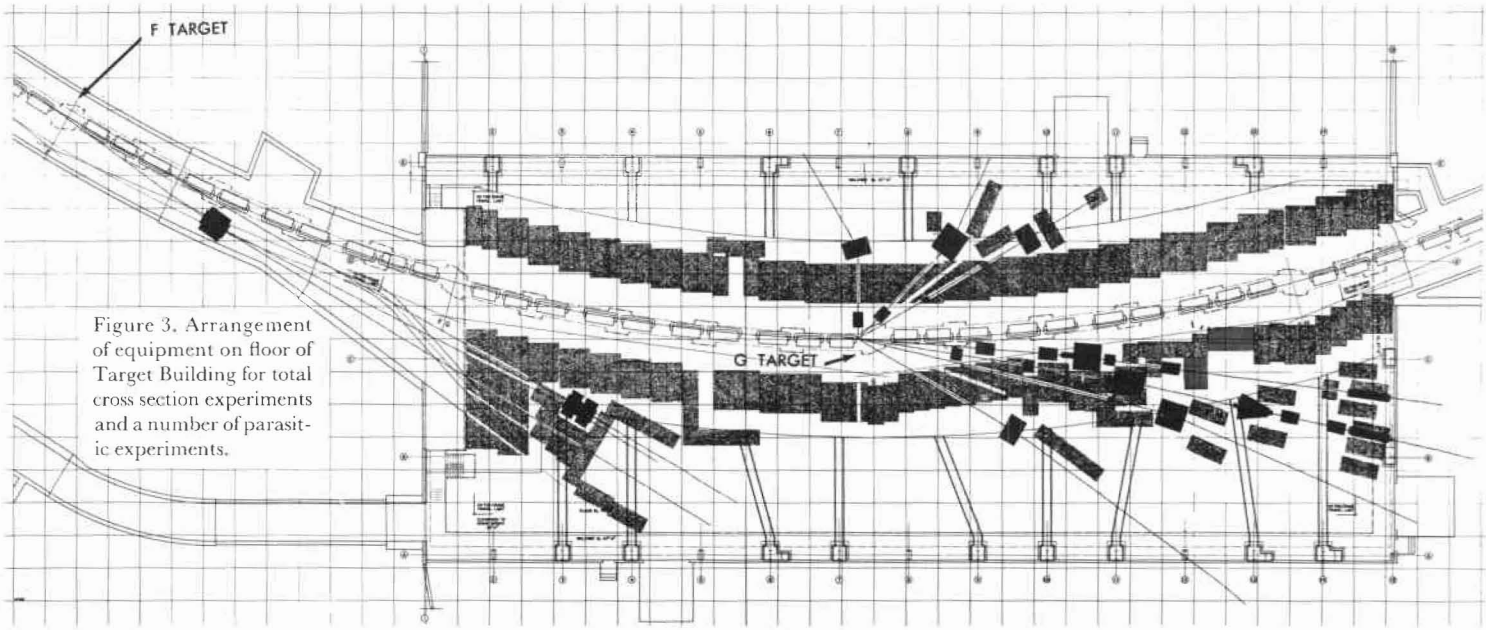


Figure 3. Arrangement of equipment on floor of Target Building for total cross section experiments and a number of parasitic experiments.

Figure 4. View of nearly completed new experimental area.

survey program is still in progress. In the past two months, the outside beams at 4½° and 9° have been modified through the addition of focusing magnets in the shielding wall (as shown in Figure 3) and external liquid hydrogen targets to permit the determination of K^+, K^-, p, and $\bar{p}-p$ total cross sections for momenta up to $\approx$20 Bev/c.

The first group of magnets and power supplies for beam transport systems are on hand and have been tested. Deflecting magnets include four 36-in.-long and five 72-in.-long units, each with 6×18-in. apertures, and three 72-in.-long units with 6×30-in. apertures. Quadrupoles include ten 24-in.-long and five 48-in.-long units of 8-in. diameter, and four 30-in.-long and six 60-in.-long units of 12-in. diameter, as well as six 36-in.-long rectangular quadrupoles with 6×24-in. apertures. Power supplies for these magnets are silicon diode rectifier units with magnetic amplifier control; they are available in three sizes. Sixteen units have a rated dc power output of 175 kw (75 v), eight have 300 kw (125 v), and six have 600 kw (125 v). The latter are also used to provide power for bubble chamber magnets.

Magnetic measurements show that in the deflecting magnets the integrated field (with respect to length) across 16 in. of the aperture does not vary by $>$0.1% at $\approx$14 kgauss and varies by $\approx$0.5% at 18 kgauss. Preliminary measurements on the circular quadrupoles indicate that the higher harmonics in the gradient of the magnetic field are $\leqslant$1% of the quadrupole component. More accurate measurements are in process. The rectangular quadrupoles have not yet been measured.

To control the magnetic fields with precision of the order of 0.1%, the Hall effect has been utilized. Small Hall plates, carefully controlled with respect to temperature, are placed in a suitable part of the magnetic field, and current flows through the plate. The induced voltage from the Hall plate is then fed to the current control amplifier circuit. Variations in the magnetic field can then be made to provide corrective action in the servo control circuits of the magnets' power supplies.

Six electromagnetic beam separators of conventional design are on order; the first prototype unit has been delivered and is being assembled in preparation for testing. High voltage power supplies for these separators have been ordered from two manufacturers, and delivery is scheduled for this summer.

During the fiscal year construction work was started on a 9600-ft² addition to the Service Building and a 58,000-ft² addition to the Target Building (East Experimental Area). The Service Building extension will provide much-needed laboratory space for the staff. Already the limited floor facilities in the Target Building have proved inadequate. The new experimental hall will house the complex beam transport systems for both primary and parasitic experiments scheduled in the high energy physics program and permit their efficient arrangement. Further, the expanded facilities will allow experimentalists to set up and test equipment just prior to their assigned running periods. The Target Building has been modified, and provision has been made in the East Experimental Area for the use of explosive gases.

The 80-in. hydrogen bubble chamber being constructed at Brookhaven will be permanently located in the structure to the north of the Linear Accelerator Building. Detailed plans have been completed for a suitable experimental area and beam channel from the AGS. Current schedule estimates indicate that the synchrotron will not be able to operate for about three months during which the major work of excavation, tunnel breakthrough, backfilling, and releveling of the main magnet will be done. This work will commence in the spring of 1962.

COSMOTRON

The energy region just above the threshold for production of associated strange particles continues to be a rich field for investigation of the properties of elementary particles. Experiments at the Cosmotron are increasingly designed to produce more precise, quantitative information; as a consequence, more complicated arrangements, more precise control of beam parameters, and longer periods of running time are required. Much use is made of the three external proton beams, and several secondary beams from internal targets are used simultaneously with them. During this year $\approx$60% of the Cosmotron's experimental time was used by outside research groups.

Experiments completed this year include several devoted to pion-proton scattering, strange particle production in pion-proton collisions, and pion production in pion-proton collisions. Two experiments designed to measure the magnetic moment

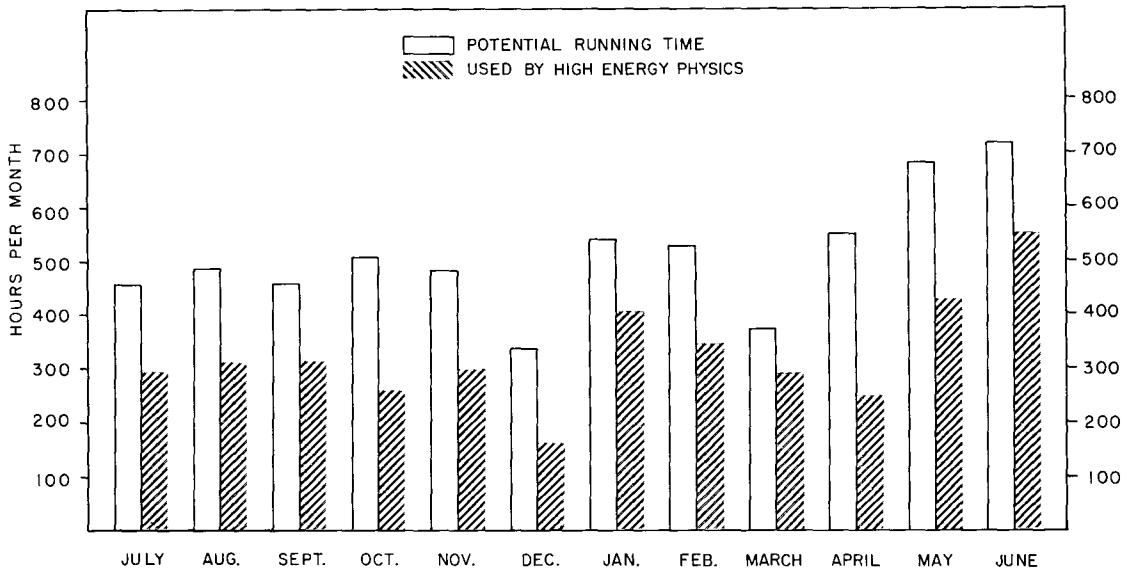


Figure 5. Use of the Cosmotron for experiments in high energy physics during fiscal 1961.

of the Λ^0 hyperon were completed. A measurement was made of the angular and energy distributions of positive kaons and positive and negative pions produced in proton-proton collisions. Formation and decay of the hyperon isobar, Y^*, was investigated, and the interaction and decay properties of the K_2^0-meson were studied. Two experiments on the decay properties of the $K_{\mu 3}$-meson and the K_{e3}-meson were carried out. Two experiments demonstrated the pion-pion resonance in an unambiguous manner. Studies of the formation of isobars of the proton in proton-proton collisions were carried out, and a survey of proton-proton interactions at 1.5 Bev was completed. A study of the neutral decay modes of hyperons and mesons was undertaken with use of a heavy element bubble chamber, and a search for a new neutral boson was started. In addition, a number of radiochemical experiments and some medical irradiations were completed.

During the last quarter of fiscal 1961 operation of the Cosmotron was increased from 15 to 21 shifts per week. An operations engineer, who is responsible for operation of the complete facility, is present during each shift. Machine intensity continued to be reliable at between 1×10^{11} and 2×10^{11} protons/pulse. The analyses of potential running time shown in Figures 5 and 6 do not include scheduled shutdowns for major maintenance or modifications. The availability of several external proton beams has resulted in greatly reducing the down time required to set up new experiments. The time used for machine experiments includes "on-line" time for the installation and checking of new devices and machine improvements as well as the investigation of details and optimization of operation. Routine maintenance is accomplished during $\approx$2 shifts per week plus 1 hr of down time each day. No major component failure occurred during the fiscal year.

Several improvements have been made in the Cosmotron. The corona gaps used to establish the correct voltage gradient down the accelerating column of the Van de Graaff generator were replaced with resistors. The resulting decrease in ozone production greatly increased belt life and reduced the amount of maintenance required. A newly developed method of measuring betatron oscillation frequencies at any time during the acceleration cycle clearly demonstrated the existence of the nonlinear $\nu_r=\frac{2}{3}$ resonance due to magnetic imbalance. New iron straight sections to remove this effect are being constructed. A number of improved detection and targeting devices for use in these sections are under construction. Investigations to establish the ultimate practical intensity of the Cosmotron included examination of several collective effects. Azimuthal space charge instabilities in agreement with MURA calculations have been observed, as well as some new effects

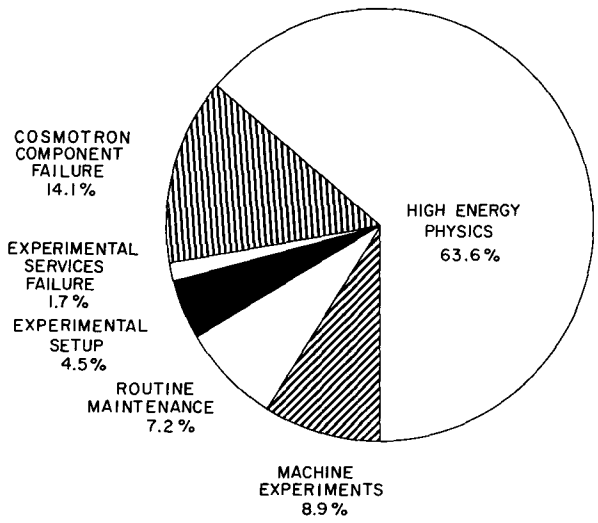


Figure 6. Cosmotron utilization during fiscal 1961.

not explained by the linear theory. Design studies were started for several long-range programs to improve the radio-frequency, vacuum, and water-cooling systems. Many other electronic, mechanical, and electrical devices to improve observation and operation were designed and installed.

Because of the greatly increased scope and complexity of the experimental program, the amount of research support given to the various experimental groups has increased considerably. At least one engineer is assigned to each experiment to oversee magnet positioning, shielding erection, etc., and to design and supervise the installation of the various mechanical and electrical services required. Many of the experiments utilize large quantities of explosive gases and liquids (e.g., liquid hydrogen), and in such cases special precautions must be taken in making the experimental arrangements. In order to operate all the experimental services and satisfy safety requirements, from 5 to 8 technician-operators are on duty on each shift in addition to the 4 or 5 technician-operators required to operate the Cosmotron itself.

During fiscal 1961 several new deflecting and focusing magnets were procured, additional dc power supplies totaling 3 Mw were ordered, an additional crossed-field particle separator was completed, and another high pressure helium compressor was placed in service. Considerable effort was expended in developing devices to monitor intensity and focal conditions of the external proton beams, and prototype models are now under test. The hydrogen liquefier facility produced 98,900 liters of liquid hydrogen for experimental use; in addition, 11,605 liters were purchased from an outside supplier to satisfy research demands while the liquefier was undergoing maintenance and repair. A number of special-purpose liquid hydrogen targets were designed and constructed, and a deuterium recovery system was placed in operation.

Instrumentation

During the past year the staff of the Instrumentation Division increased from 65 to 80 and on June 30th consisted of 18 engineers and physicists, 5 persons engaged in secretarial and administrative activities, 5 glassblowers, 3 draftsmen, and 49 electronic and mechanical technicians. Approximately half of the technicians are highly skilled and carry some engineering or supervisory responsibility. A room was added to the main instrumentation building to house a construction shop in which to build photomultiplier bases, coincidence circuits, and other special electronic circuits that are used extensively in high energy physics experiments. The construction staff numbered six at the year's end.

The study of semiconductor radiation detectors has continued in cooperation with the Bell Telephone Laboratories. This new type of detector is especially useful for measuring the energy of protons and other heavy particles. However, nonlinear response to very heavy particles such as fission fragments has frequently been observed. This has been shown to be related to the high density of charge produced by such particles in the detector. The concentrated charge substantially reduces the collecting field locally, so that some of the charge is not collected rapidly enough to prevent its being neutralized at recombination centers. Semiconductor detectors have been applied to several fields of research. Their response to minimum ionizing particles has been studied. Satisfactory operation was obtained within a cryostat at extremely low temperatures, and also inside the Brookhaven Graphite Research Reactor in an experiment to measure the energy distribution of fission fragments. Facilities have been installed for etching and introducing n-type material into p-type silicon in order to make experimental detectors.

Spark chambers have recently become of interest for determining the tracks of charged particles of high energy. A number of factors affecting their operation, such as the type of gas, the electrode materials, firing voltage, and recovery time, have been studied here. Work has also been done on modulator circuits to apply the high voltage pulses. A chamber consists of several parallel plates, the intervening space being filled with a suitable gas (e.g., neon) at atmospheric pressure. An external detector is used to signal that a particular type of charged particle has traversed the chamber. Then, as rapidly as possible, a high voltage (15 kv) is applied to alternate electrodes, and sparks are visible along the particle path where ions have been produced. Normally, considerable time must elapse before a chamber can be pulsed again. However, this dead time can be drastically reduced by making the electrodes of high resistivity materials, e.g., a transparent resistive coating on glass plates. It is important that the high voltage be applied promptly after a particle has traversed the chamber. An extensive study has been made of the spark formation time and discharge current as a function of pulse voltage, delay, and other factors. Most of the modulators built here are similar to those used elsewhere for this work. They make use of hydrogen thyratrons that have very high power gain but have a dead time of many microseconds. Pulsers using vacuum tubes have also been built; they have rapid recovery and permit wide adjustment of pulse shape.

The ultra-fast circuits for use with scintillation detectors at the large accelerators, described in last year's report, have been redesigned and re-engineered. A complete set of amplifiers, amplitude discriminators, coincidence circuit, and scaler or counter is now available for this type of experimentation. The present circuits operate with pulses of a few millimicroseconds' duration, and the counter circuit will operate at rates from zero to 200 Mc. Tunnel diodes and the fastest transistors available are the active elements. The designs have been frozen. Twenty of each type of circuit card have been built, and a stock will be built up to supply all current high energy counter experiments with a standardized set of fast electronic circuits.

High energy counter experiments often require a large number of radiation detectors. When an event of interest occurs it is important to know which detectors responded, and sometimes the pulse height or the delay between pulses in two

detectors is also significant. Events of interest occur at a high rate while the beam is "on." In the comparatively long period between pulses, the accumulated data may be processed. Two systems were built for recording this type of data. Both make use of a set of switching circuits which are normally inactive. When an event of interest occurs, these electronic switches are closed and all the detectors are connected to the recording system for a short period of time. In one system 50 signal lines, which are sampled simultaneously, are connected at intervals to a long delay line. Whatever signals were present emerge from the delay line in succession. They are then displayed on an oscilloscope and photographed. The location in time identifies the source, and amplitude information is preserved. The second recording system is digital. It will accept 96 separate "yes" or "no" signals in parallel. Each 96-bit event is stored in a magnetic core memory. As many as 32 such events may be accumulated in the memory during the accelerator beam pulse. In the interval between accelerator beam pulses the data are tranferred from the core memory to a magnetic tape, which may then be taken to a computer for analysis.

Several other data-handling projects have also been completed. These include a relay and diode system for recording data in a counting room in the Nuclear Engineering Department; systems for recording coordinates of bubble chamber tracks on punched cards and punched tape; a system to read punched tape and record the data on an X-Y plotter; and the development, in cooperation with the Bubble Chamber Group, of electronic circuits for use with a flying spot scanner to read bubble chamber track coordinates directly into an IBM 704 digital computer.

Three different systems were designed for monitoring accelerator beams. Two of these systems integrate the charge produced by each beam pulse in a thin ionization chamber or scintillation counter. During the interval between bursts the integrated potential is converted to a digital indication, and the integrators are reset. One system uses vacuum tube techniques, and the other is transistorized. The third monitor uses a matrix of ionization chambers. The charge produced in each element is stored on a corresponding capacitor. Between beam bursts the capacitors are sampled in succession by very high impedance diode switches. The successive readings are sampled sequentially and are amplified by a single electrometer amplifier to give a display on a cathode ray tube of the shape and intensity of the beam.

The following projects deserve mention: (1) a whole-body counting system for rats; (2) a plastic scintillator, well counter that will hold a rabbit; (3) a transistor double-delay-line amplifier for scintillation spectrometry; (4) a new design of a high current, low noise, regulated power supply for achieving low temperature by adiabatic demagnetization; (5) a precision high current regulator for focusing magnets used in experiments at the accelerators; (6) several high voltage power supplies for charging capacitors for flash photography; (7) a radio-frequency pulse generator for a plasma experiment; and (8) devices to count kernels of corn into cups and drops of liquid into test tubes.

About 15% of the Division's time is spent on repair and maintenance. Eight members of the Division are assigned full time to servicing, and others are assigned as needed. In addition, the service group often assists experimenters in setting up their apparatus or in determining the reason for malfunction of an experiment. The main service group has responded to more than 300 requests for assistance. The calibration group has calibrated and repaired $\approx$2200 portable health physics instruments and 600 ac-operated radiation monitors in the past 12 months.

METEOROLOGY

The permanent staff of the Meteorology Group has remained essentially constant during the past year despite efforts to recruit scientific personnel. The number of qualified individuals available in this particular field is exceedingly limited. To some extent this has been offset by the presence of three visitors from overseas, two of whom spent $\approx$6 months with the Meteorology Group, while one (from Japan) will remain for a full year.

Research Activities

Studies of airborne particulates have constituted the major portion of the Group's effort. The work has been devoted largely to refinement of the techniques of particulate generation and sampling and to collection of deposition data. In the summer and fall of 1960 a number of runs were conducted on the deposition sampling grid in which only the nonradioactive uranine tracer was used. The

actual low-level diffusion patterns thus defined indicate that it will be completely safe to use radioactive tracers and that there will be no interference with any other Laboratory activities. The diffusion data obtained in these uranine runs are unique, since they make possible a very low-level, three-dimensional evaluation of the concentration patterns which has heretofore been unavailable in any field studies known to members of the Group. Successful attempts have been made to reduce the size range of the Cu^{64} tracer spheres by more careful air and water elutriations.

The ragweed pollen studies in which the Group has become increasingly interested produced excellent data late in the summer and early in the fall of 1960. A vane-type sampler developed at the Laboratory was used in place of the standard Durham slide samplers, and concentration data were obtained in a series of concentric circles surrounding two fields of ragweed. One of the fields was brought to pollination in advance of the normal season by artificially shortening the periods of daylight. The second field was allowed to receive normal daylight and pollinated simultaneously with naturally occurring plants.

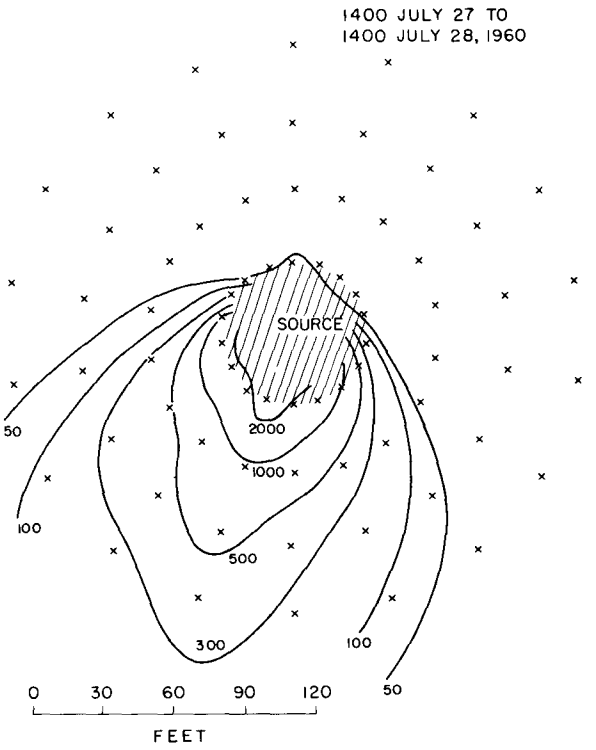


Figure 1. Typical dispersion pattern from a preseason ragweed field. Sampler locations are marked by X, and the isolines are pollen concentration in grains/m^3 of air.

The samples obtained during these tests have now been processed by the New York State Museum and Science Service and are ready for analysis. Figure 1 is a typical example of a 24-hr concentration distribution. First inspection shows the distribution curves to be exceedingly consistent in virtually all respects, and they also reveal some rather interesting aspects of the pollen distributions. The concentrations decrease much more rapidly with distance than simple diffusion estimates would suggest, which indicates rapid removal of the particles by deposition and impaction. The slopes of these curves are sufficiently reproducible to permit a quantitative estimate of the rate of deposition. It is also apparent that the decrease in pollen concentrations in the area of forest vegetation north of the test plots is more rapid than that in the open areas.

The long-range diffusion studies have continued with the completion of a large number of airborne runs in which the cooling air from the Brookhaven Graphite Research Reactor has been used as the tracer. These data are also under analysis, and indications are that they have provided valuable information on the plume dimensions and concentrations to a maximum distance of $\approx$50 miles.

The staff of the Meteorology Group has long been interested in the effect of vegetation on tracer concentration distributions in the atmosphere, and a very limited study of such effects was conducted in 1950 and 1951. A renewed attack on this problem was begun in January 1961 with interesting results. Previous analysis of oil-fog concentration data obtained early in the 1950's had revealed fairly consistent relationships between short-term peak concentrations and the longer-term means. However, while most of these data were obtained in relatively open areas, a limited number were taken in rather narrow fire lanes or roads surrounded by scrub oak and pine vegetation. These data have been analyzed separately, and it is clear that almost all concentration fluctuations having periods of $<$2 min are absent. This result is difficult to interpret, because the earlier oil-fog data were derived from an elevated source, and it is difficult to be certain of the path of a particular puff of oil fog from the source to the samplers. To obtain a proper evaluation, both the samplers and the source should probably be at ground level; such a study has been added to the program and

will be conducted directly south of the Meteorology Building in a large expanse of scrub oak and pine with a mean height of $\approx$30 ft.

Related Projects

The pollen study discussed above is conducted cooperatively with the New York State Museum and Science Service, whose activities are in this instance sponsored by the U.S. Public Health Service. The Meteorology Group devotes most of its attention to the problems of sampling the pollen and to the analysis of the concentration patterns, while the New York State personnel have devoted most of their attention to ragweed pollination, tagging of individual pollen grains, and processing of samples.

The Wind Profile Study, sponsored by the U.S. Army Signal Corps for several years, is to be terminated in September 1961. The major portion of the work has already been completed. During the past year most of the emphasis has been on the evaluation of the effect of horizontal displacement of a low-level reference wind instrument on the predictability of a tower wind profile at some distance from it.

Chemistry

The research program in the Chemistry Department embraces experimental and theoretical studies in nuclear chemistry, radiation chemistry, the chemistry of isotopes and the application of isotopes to the study of chemical reactions, and structural chemistry. These studies are made possible by the special facilities of the Laboratory and are carried out by the continuing scientific staff, postdoctoral research associates, and visiting scientists.

NUCLEAR CHEMISTRY

High Energy Nuclear Reactions

The interactions between complex nuclei and high energy particles continue to be investigated by a variety of techniques, including radiochemistry, mass spectrometry, and nuclear emulsion detection. Although the major fraction of this work in the past year was again performed with protons accelerated by the Cosmotron, some reactions induced at 28-Bev energy have been studied at the Alternating Gradient Synchrotron (AGS). To establish a generally useful beam monitor in this new energy range, the absolute cross section of the reaction $C^{12}(p,pn)C^{11}$ was determined in an external diffraction-scattered beam. The proton intensity was measured by means of nuclear emulsions, and the C^{11} activity induced in plastic scintillators was determined. The cross section was thus found to be $\approx$26 mb, practically the same value as that at 2 and 3 Bev for the same reaction. Quite surprisingly, the same result (cross sections at 28 Bev agreeing within $\approx$10% with those at 3 Bev) has been obtained for several other reactions, particularly the formation of a variety of spallation products from aluminum and copper. Work on targets of higher atomic number has only begun at the AGS.

The work at the Cosmotron has been concerned with both spallation and fission reactions. Although the general features of spallation processes are rather well understood in terms of the cascade–evaporation model, many details must still be clarified, particularly with a view to refining the model. A study was completed of uranium and thorium spallation products with mass >224. Calculations of these cross sections were made, based on published Monte Carlo calculations of the knock-on phase of the interaction, and combined with systematics of nuclear evaporation, including fission–evaporation competition. Even without fission competition the calculated yields are considerably lower than the experimental ones, which indicates failure of the model for the knock-on phase of the reaction to predict sufficient probability for simple processes with low deposition energy. The results of a similar experimental study of simple reactions of gallium isotopes were again compared with calculated cross sections. Here the agreement was rather good except for products removed only one or two mass numbers from the target, whereas in the uranium and thorium data the discrepancies extended appreciably farther. Particular interest continues to center on attempts to correlate cross sections for the very simple reactions (p,pn) and $(p,2p)$ with the energies and occupation numbers of various neutron and proton shells.

The general success of the cascade calculations completed some years ago, as well as their failure in some details, has prompted a new attempt to devise a computer program for Monte Carlo calculations of these processes. The new program initiated last year differs from the old in several major respects: (1) The nuclear density distribution assumed for nuclei will be a more realistic one, with a tapering edge. (2) The entire cascade will be followed in a proper time sequence rather than particle by particle. (3) The wealth of new information on elementary particle interactions will make it possible to treat pion production processes in the nucleus in much greater detail and to extend the calculations to higher energies.

Whereas at least a semiquantitative theory exists for spallation reactions, the details of fission processes at high bombarding energies are still very poorly understood. Considerable effort has therefore been directed toward fission studies. In particular, charge distributions (cross sections as a function of Z for a given A) have been investigated for uranium fission products in various mass regions. At $A=47$ to 49 and at $A=72$, the charge distribution appears to have a single peak centered approximately on the stability line. In the region of cesium ($A=125$ to 140) a double-peaked charge distribution has been established at energies above

$\approx$0.7 Bev, with the peak on the neutron-excess side of stability having the characteristics of the single peak observed at much lower energies (50 to 100 Mev). The peak on the neutron-deficient side is clearly characteristic of high energy processes, but no detailed explanation in terms of a mechanism is yet available.

Studies have continued on the interaction of high energy protons with the silver and bromine nuclei in insensitive emulsions. The large numbers of alpha particles and light fragments accompanying the fission fragments suggest that the fission of silver or bromine tends to be associated with a high deposition energy. The velocity distribution of the fission fragments was derived from the measured ranges. This distribution, along with other data, is consistent with the idea that most of the charged particles are emitted before the scission, that the fission is roughly symmetric, and that the fission products have mass numbers mainly in the region from 25 to 50. During the year a radiochemical study was begun of the products formed by the interaction of 3-Bev protons with silver. An attempt will be made to correlate the cross sections and ranges determined for specific products with the results of the emulsion study.

As finer details of high energy reaction cross sections have come under scrutiny, rather precise determination of the cross sections of the monitoring reactions $C^{12}(p,pn)C^{11}$ and $Al^{27}(p,3pn)Na^{24}$ has become important. Since good absolute determinations of the $C^{12}(p,pn)$ cross sections were carried out some years ago, a careful remeasurement of the ratio of the $Al^{27}(p,3pn)$ cross section to that of $C^{12}(p,pn)$ at various proton energies was undertaken. In the process an interesting effect, previously unobserved, was detected: Some of the C^{11} atoms formed in plastic foils ($\approx$15% in the case of 0.004-in. polyethylene, $\approx$3% for 0.003-in. polystyrene) are lost from the foils in gaseous form as a result of hot-atom reactions of the recoiling C^{11} atoms. This effect has, in the past, led to incorrect cross sections for the $Al^{27}(p,3pn)$ reaction and for many other high energy cross sections based on beam calibrations carried out by activation of plastic foils. Careful measurements of the gas loss have been made for various materials, and corrections for this effect can now be made.

Low Energy Nuclear Reactions

The study of nuclear reactions induced by low energy protons, deuterons, and alpha particles available at the 60-in. cyclotron has been continued. At these low bombarding energies ($<$40 Mev) it is commonly assumed that nuclear interactions can be described adequately by compound nucleus theory. However, it is clear from observations on spectra and angular distributions of emitted particles that even at these low energies other types of mechanisms such as stripping and direct interaction are important. The results expected for compound nucleus reactions can be predicted from a Monte Carlo calculation based on Weisskopf's evaporation model. This calculation was described in an earlier report and was shown to yield good agreement with experimental results both as to magnitude of cross sections and shapes of excitation functions for compound nuclei in the mass region $50<A<74$ at excitation energies up to $\approx$50 Mev. Furthermore, it is a necessary condition of compound nucleus theory that the decay properties of a compound state be independent of its mode of formation. Thus the production of a given compound nucleus by two or more reaction paths should yield the same distribution of reaction products. Comparison of experimental results on reaction cross sections with those predicted by statistical theory will be useful in determining the relative importance of the various mechanisms as a function of type and energy of the incident particle and target nucleus.

A study of the excitation functions of alpha-induced reactions on Cd^{106} is in progress, and results will be compared with those expected from statistical theory. This target was chosen because ten different radioactive products can be observed; thus it is possible to study the yields of a wide variety of simple nuclear reactions from a single target nucleus.

Deuteron-induced reactions on Ti^{47} were measured and compared with results obtained previously for the alpha-induced reactions on Sc^{45}. If the incident particles were totally absorbed, then both systems, $d+Ti^{47}$ and $\alpha+Sc^{45}$, would form the same compound nucleus, V^{49}. Because of deuteron stripping reactions, the compound nucleus contribution to the (d,n), $(d,2n)$, $(d,2p)$, and $(d,\alpha n)$ reactions has been found to be only $\approx$30 to 50% of that observed in the alpha-induced reactions. Stripping, followed by evaporation of a nucleon, was found to make a substantial contribution in the $(d,2n)$ and $(d,2p)$ reactions.

In a similar experiment the compound nucleus Cu^{63} was produced by three different reactions:

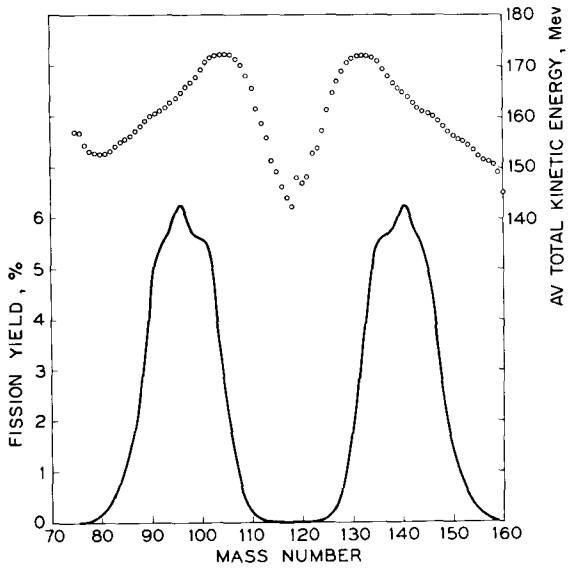


Figure 1. Fission yield and average total kinetic enery as a function of mass number.

$\alpha+Co^{59}$, $p+Ni^{62}$, and $C^{12}+V^{51}$. It was found that statistical theory adequately predicts the experimental results except for the yields of the $(p,2p)$ reactions on Ni^{62} and the $(\alpha,\alpha n)$ reaction on Co^{59} at high incident energies.

The mechanism of fission continues to be of interest to nuclear chemists in the study of both high energy and low energy reactions. An experimental program using solid-state detectors in conjunction with a two-dimensional pulse-height analyzer is in progress to measure the kinetic energy of the fragments produced in various fissioning systems. From the experimental data information can be derived about the yield of fission fragments as a function of their mass number and about the relationship between mass and total kinetic energy. Figure 1 shows the yield and average total kinetic energy as a function of mass for the system $U^{235}+n$. The peak-to-valley ratio for the mass–yield curve shown is 370:1. Figure 2 shows fine structure observed in the energy spectra of heavy fragments in coincidence with light fragments of energies greater than $\approx$100 Mev for the same system.

Atomic Electron Ejection in Polonium-210

During the past year additional work has been done on the problem of orbital electron ejection accompanying the alpha decay of Po^{210}. The discrepancy by a factor of $\approx$300 between experiment and theory for M electron ejection reported in 1959 has been confirmed by a new measurement, and must be attributed to a theoretical result that is much too small. The theory of Migdal includes, as possible final states for the ejected M electron, only the continuum states. It has now been extended to include ejection to unoccupied bound states ($n>5$), and also states ($n=4$ and 5) normally occupied in the lead atom. The latter may become available because of the ejection in the decay act of many of the N and O electrons. If states of $n=4$ and 5 become available in the decay act, the theoretical result is increased more than tenfold. In addition, the experimental result, which depends on the x-ray fluorescence yield, is substantially reduced because the N and O electrons become unavailable to take part in Auger processes, which decreases the ratio of radiationless to radiative transitions. However, even if these effects are assumed to occur, the experimental result remains about ten times greater than the corrected theory predicts.

Vibrational-Rotational Levels in Osmium-186

In cooperation with members of the Physics Department a study has been undertaken of the level scheme of Os^{186}, a nucleus that would be expected to show a vibrational-rotational level structure capable of providing detailed comparisons with that of other osmium isotopes and with the models for deformed nuclei proposed by the Danish and Russian schools. Measurements of the Os^{186} radiations, which are produced in the decay of 15-hr Ir^{186}, have been made thus far with the 50-cm radius, double-focusing beta-ray spectrometer, with a three-crystal gamma-ray spectrometer, and with gamma-gamma coincidence equipment. In the interval between $\approx$60 and 1800 kev, 200 internal conversion electron lines have been assigned to Os^{186}. These have been associated with 100 gamma-rays, whose energies are determined with accuracies varying from 1/5000 to 1/1000. Multipole orders have been established in many cases. Deduction of the level scheme from the information now available is in large part based on the comparison between sums of gamma-ray energies and energies of the individual radiations. The density of observed lines is so great that statistical analysis for accidental equalities is required to establish the degree of reliability of the levels found. Results of coincidence experiments are being used to support and guide the synthesis

of the level scheme. Fifteen previously unknown levels have been established, and a new gamma-vibrational-rotational band has been found. Relative transition probabilities from this band to levels of the ground-state band show that the properties of Os^{186} are intermediate between the predictions of the asymmetric rotor model and the strong coupling model.

Solar Neutrino Experiment

The sun produces energy by a series of nuclear reactions that occur in the deep interior and emit nutrinos that pass through the exterior without attenuation. If these particles could be detected, a direct means of studying the process of solar energy generation would be available. The present knowledge of these reactions is based upon extrapolation of nuclear reaction rates measured with particle accelerators to obtain rates corresponding to the thermal energies at the center of the sun. These measurements, coupled with a stellar model giving the temperature and density within the sun, permit selection, from a number of possible reactions, of the ones most likely to occur. The energy of the neutrinos and the flux at the earth's surface depend upon the particular set of reactions chosen. While reactions have been proposed that would emit very energetic neutrinos, the most recent calculation favors the series $p(p,e^+\nu)D(p,\gamma)He^3(He^4,\gamma)Be^7(e^-\nu)Li^7(p,\gamma)2He^4$, which would produce neutrinos with energies below 0.8 Mev and a flux at the earth of 3×10^{10} cm^{-2} sec^{-1}. A flux of neutrinos of this magnitude and energy cannot be detected by any existing apparatus. However, in view of the uncertainties in the calculations involved, it appeared reasonable to make a search for high energy neutrinos which, for example, would be produced in the sequence $He^3(p,\gamma)Li^4(e^+\nu)He^4$ with a detector developed at Brookhaven to test lepton conservation. This detector has the highest sensitivity of any operating device, but to realize its full capabilities measurements must be made in a deep mine to eliminate cosmic-ray background effects.

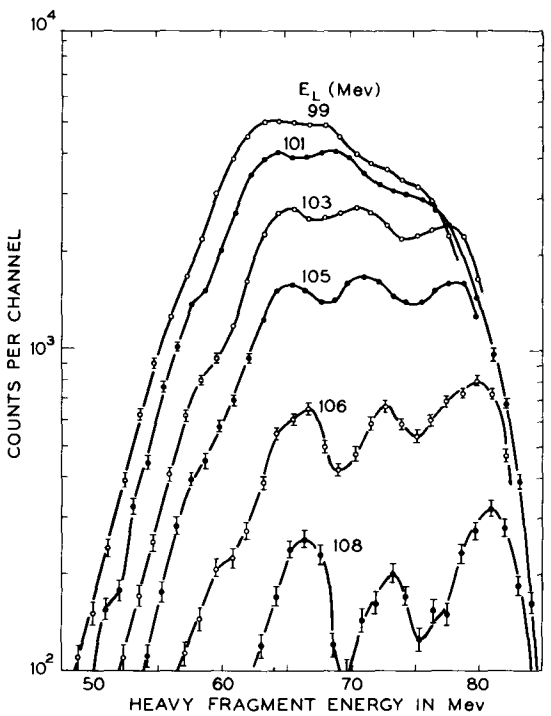


Figure 2. Spectra of heavy fission fragments in coincidence with given light fragment energies, E_L. The circles correspond to a heavy fragment into counter A and a light fragment into counter B; the dots correspond to the reverse.

The detection is based upon observing the $Cl^{37}(\nu,e^-)Ar^{37}$ reaction which has a threshold of 0.82 Mev. One thousand gallons of perchloroethylene is exposed, and the 35-day Ar^{37} is removed by sweeping the liquid with helium. The argon recovered is purified and counted in a very small low-level counter (0.3 cc volume).

The apparatus was installed in a mine 2300 ft deep, owned and operated by the Chemical Division (Columbia Southern) of the Pittsburgh Plate Glass Company at Barberton, Ohio. In the three experiments performed, the detector operated at nearly background level, which indicates that the neutrino capture rate is <10 per day in the 1000 gal of perchloroethylene. The capture cross section for neutrinos depends upon the neutrino energy, and the experiment sets a limit on the product of the neutrino flux and the capture cross section, that is, $(\phi,\sigma)_{av} \leqslant 5\times10^{-33}$ captures/sec-atom. This result is consistent with the present view that the sun emits predominantly low energy neutrinos. The experiment also serves to place an upper limit on the $(\phi,\sigma)_{av}$ product for neutrinos from the galaxy. If the energy generation cycle proceeded directly through the Li^4 reaction, as was recently proposed, a flux of 6×10^{10} neutrinos/cm^2 with an average energy of 10 Mev would be observed. These energetic neutrinos would have a cross section for capture of 1.7×10^{-43} cm^2 $atom^{-1}$. The experiment shows that the flux must be $<3\times10^{10}$

cm^2 of 10-Mev neutrinos, which indicates that $<50\%$ of the He^3 is transformed to Li^4 in the sun.

Induced Radioactivities in Satellite Materials

Observation of cosmic-ray-induced radioactivities in materials carried on satellites is of value in studying cosmic-ray phenomena and assists in the interpretation of radioactivities induced in meteorites. Studies have begun on two satellites: Discoverer XVII, launched November 12 during an intense solar flare and remaining in orbit for 50 hr, and Discoverer XVIII, launched December 7 and subjected to the normal cosmic-ray exposure for 75 hr. The Bi^{205} activity induced in a lead ballast sheet carried on Discoverer XVII was observed and the decay followed. The Ar^{37} activity induced in the stainless steel battery casing was measured in both satellites. The activity produced by the flare protons in the materials from Discoverer XVII was considerably higher than the activity observed in similar materials carried on Discoverer XVIII. The measurements can be interpreted quantitatively from the known cross sections for the products studied and the energy spectra of the flare protons and cosmic-ray particles. These experiments will be extended in the future as opportunity permits.

Exposure Ages of Iron Meteorites: Constancy of Cosmic Rays in Time

During its existence as a relatively small body in space, a meteorite is exposed to bombardment by cosmic-ray particles which produce radioactive and stable spallation products. The radioactive species are in equilibrium with the radiation at the time of capture by the earth, which means that the rate of their radioactive decay equals the rate of their production in space. The stable products never reach equilibrium and represent the total dosage received by the specimen during its exposure. Therefore a measurement of the activity of a radioactive nuclide such as Cl^{36} (half-life, 308,000 yr) and the mass spectrometric measurement of a stable nuclide such as Ar^{36} permit determination of the length of time between the production of a meteorite by collision in space and its capture by the earth. Earlier work on exposure ages has been extended to include a group of dated-fall iron meteorites, for which the decay of radioactive species that has taken place prior to laboratory examination can be readily computed. Table 1 shows the results of these measurements together with the corresponding exposure ages. The age distribution bears on the question of whether meteoric material has been produced continuously in time, or whether discrete meteor-producing events have occurred in the history of the solar system. Additional data of the type reported here may make it possible to distinguish between these alternatives.

Table 1

Exposure Ages of Iron Meteorites

Meteorite	Cl^{36}, dis/min-kg	Ar^{36}, cc (NTP)/g	Exposure age, millions of years
Aroos*	15.8±1.7	21.3	550±80
Norfork*	14.7±1.5	18.4	510±80
Grant	12.4±1.2	14.5	480±90
Norfolk	19.5±2.0	20.4	430±60
Sikhote Alin*	6.3±0.6	3.6	230±35
Treysa*	20.3±2.0	16.5	330±50
Estherville*	22.7±2.3	2.2	40± 6

*Dated falls.

Results obtained earlier at this Laboratory concerning the constancy of cosmic rays in time have been extended by measurement of Ar^{39}:Cl^{36} ratios in four dated-fall iron meteorites (Table 2). In addition, the Ar^{39}:Cl^{36} ratio has been measured in an iron target bombarded by 6.2-Bev protons at the Berkeley Bevatron. The target ratio can be directly compared with the iron meteorite results and is in good agreement. From this it is concluded that the average intensity of cosmic rays during the last million years was the same as the intensity during the last thousand years.

Analysis of Lead in Meteorites by Alpha Activation

Alpha particles from the Brookhaven 60-in. cyclotron have been used in activation analysis for lead isotopes in meteoritic material. If a thick target is exposed to an incident alpha energy of 30 Mev, essentially only an $(\alpha,2n)$ reaction is produced on lead isotopes. This method eliminates contamination problems when determining lead in rocks containing $<10^{-6}$ g/cm^3 lead and requires much less material for analysis.

The present abundance of lead isotopes in stone meteorites should be a combination of the lead

introduced at the time of the meteorite's formation and of increments due to the decay of uranium and thorium over the lifetime of the meteorite. In at least one case, that of the Norton County stone meteorite, the observed Pb^{208}:Pb^{206} ratio of 1.66 and the lead concentration of 0.5 ppm do not fit the parameters commonly used in the model. The lack of fit indicates a different history for this meteorite, and the parameters needed to bring the results into agreement with the model should reveal something about this history.

Applications to Geochemistry

Chlorine-36 and Deuterium in Great Basin Water. Chlorine recovered from the waters of Mono Lake, Pyramid Lake, and the lower Truckee River was purified and examined for Cl^{36} content by low-level counting techniques. No radioactivity could be detected in the samples of lake water, which indicates that the chlorine recovered from these closed basins had been exposed to cosmic-ray neutron irradiation for $<300{,}000$ years. However, a significant amount of Cl^{36} was found in the Truckee River. Since this fresh-water river drains into Pyramid Lake where the radioactive chlorine is greatly diluted by inactive salt, it is concluded that the activity found in the river is of recent origin, and has probably been produced by thermonuclear testing and distributed over the Great Basin by rainfall.

The chlorine of Great Salt Lake has previously been reported to contain no detectable radioactive component, and in this investigation a similar finding was made on surface chloride from three separate locations in the salt flats of Utah and Nevada.

The ratios of hydrogen to deuterium atoms were measured for the waters of Mono Lake, Pyramid Lake, Lake Tahoe, and their associated streams. From these measurements it was possible to deduce that all three lose water largely by evaporation. In the case of Lake Tahoe, which is not a closed basin, the ratio indicated a substantial residence time despite the constant overflow of water into the Truckee River. The measurements on Truckee River water itself indicated strong dilution by fresh rain runoff water between the times of exit from Lake Tahoe and entry to Pyramid Lake.

Age of Volcanic Rocks. Two volcanic regions, Marysvale, Utah, and Grants, New Mexico, which lie along the margins of the Colorado Plateau, contain a number of potassium-bearing materials suitable for potassium–argon age determinations. An investigation of these materials was undertaken for three reasons: to test the relative merits of the different substances for age determinations on geologically young rocks (1 to 30 million years); to relate nearby uranium mineralization to the volcanism; and to take initial steps in developing the broad chronological pattern of volcanism in the southwest.

From Marysvale, feldspar, biotite mica, muscovite mica, and volcanic glass were used successfully for age determinations. It was possible to distinguish four periods of activity (in millions of years): flows, 30; intrusives, 25; flows, 20; and finally mineralization, 13 (determined at Columbia University by the uranium-lead method on the uraninite ore and at Brookhaven on the associated mica mineralization by the potassium-argon method).

At Grants, both massive volcanic glass (obsidian) and porous, hydrous volcanic glass (perlite) were used successfully in establishing 3.3 million years as the age of the volcanic complex known as Grants Mesa.

RADIATION CHEMISTRY

Aqueous Solutions

A successful model of the radiation chemistry of water has been built around the postulate that water is simply decomposed into one-electron reducing and oxidizing radicals by the radiation. In

Table 2

Comparison of Ar^{36}:Cl^{36} Ratio in Iron Meteorites and 6.2-Bev Steel Target

Meteorite	Date of fall	Ar^{39}, specific activity	Cl^{36}, dis/min-kg	Ar^{39}:Cl^{36}
Aroos	1959	16.3±0.9	15.8±1.7	1.03
Norfork	1918	14.1±1.0	14.7±1.5	0.96
Sikhote Alin	1947	5.5±0.6	6.3±0.6	0.87
Sikhote Alin*	1947	6.7±0.3	6.9±0.3	0.97
Treysa	1916	22.1±1.5	20.3±2.0	1.09
			Av, meteorites	0.98±0.08
			Target ratio	0.96±0.05

*From earlier work.

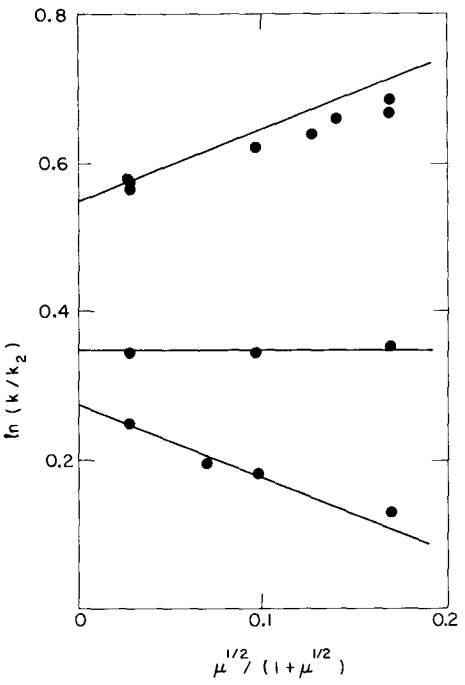


Figure 3. Ionic strength effects on reaction rate constant ratios for e_{aq} reacting with various solutes.
Upper curve, $k_{(e_{aq}+NO_2^-)}/k_{(e_{aq}+H_2O_2)}$;
Middle curve, $k_{(e_{aq}+O_2)}/k_{(e_{aq}+H_2O_2)}$;
Lower curve, $k_{(e_{aq}+H^+)}/k_{(e_{aq}+H_2O_2)}$.

the past these radicals have been called H and OH for lack of a better experimental description. Recent research in the Chemistry Department has been concerned with the adequacy of this model, the nature of these radicals, and the reactions they undergo.

It has been known for several years that there are two reactive species in aqueous solution that behave similarly to hydrogen atoms. The species produced in water by radiation reacts with O_2 and H_2O_2 at similar rates and with organic chlorides to form chloride ion. If this species reacts with acid it is converted to the second species, which does not react readily with H_2O_2 and which abstracts hydrogen from organic chlorides to form H_2. The second species seems to be the same as that produced in the reaction

$$OH+H_2 \rightarrow H_2O+H\,.$$

On the basis of these and similar chemical data it was suspected that the reducing entity formed by radiation is a form of solvated electron, e_{aq}, which may react with acid to form a hydrogen atom.

Solutions of H_2O_2 have been irradiated at various acid concentrations in order to learn something about these radicals. The data were in excellent agreement with a mechanism that includes the following reactions:

$$\begin{aligned} e_{aq}+O_2 &\rightarrow O_2^- & k_1\\ e_{aq}+H_2O_2 &\rightarrow OH+OH^- & k_2\\ e_{aq}+H_3O^+ &\rightarrow H+H_2O & k_3\\ H+O_2 &\rightarrow HO_2 & k_4 \end{aligned}$$

The HO_2 radicals (and O_2^-) react to give H_2O_2 and O_2, so that the first and fourth reactions lead to hydrogen peroxide formation, while the second leads to hydrogen peroxide destruction. It was found that $k_1/k_2=2.0$ and $k_3/k_2=2.0$. Strong evidence that the reducing species in the first three reactions is negatively charged has been found in a study of the effects of ionic strength on the rate constant ratios. Additional information can be obtained from the reaction

$$e_{aq}+NO_2^- \rightarrow NO_2^{=} \quad k_5$$

which can be studied in solutions of H_2O_2 and NO_2^-. Rate constants for reactions between oppositely charged species decrease with increasing ionic strength, whereas those for like-charged species increase with ionic strength. Hence k_3/k_2 should increase and k_5/k_2 should decrease with ionic strength, while k_1/k_2 should be independent of ionic strength. These predictions are well borne

Table 3

Major Products of Radiolysis of Solutions of Tetrachloroethylene (C_2Cl_4) in Pentane
Numbers are G values in molecules/100 ev

	Electron % C_2Cl_4 added			
Product	0	2.62	5.02	9.79
H_2	4.1	2.4	2.0	2
Decane	1.2	0.9	0.4	0.3
Pentene-1	0.53	0.3	0.1	0.1
Pentene-2	1.4	0.2	0.15	0.1
C_2Cl_4		−5.5	−6.0	−10
HCl		3.2	4.7	6.8
Trichloroheptene		2.8	4.2	6.1
Trichloroethylene		0.5	0.66	1.0
Tetrachloroethane		0.16	0.15	0.2
Pentachloroethane		0.7	0.6	0.8
Chloropentane-3		0.9	1.1	2.5
Chloropentane-2		2.0	2.3	1.4
Chloropentane-1		0.1	0.1	0.1

out, as is seen in Figure 3. The lines represent the theoretical slopes, assuming e_{aq} has unit negative charge. It is concluded that the reducing species formed when water is irradiated is negatively charged and is probably a solvated electron.

It has been suggested in the literature that excited water molecules are produced by the action of radiation on water and that they have a sufficiently long lifetime to react with solutes or radiolysis products. This proposal has been investigated by study of the steady-state behavior of hydrogen peroxide and oxygen produced in pure water irradiated at high intensity. The steady-state concentrations of the products have been found proportional to the square root of the intensity. Calculations have shown that any combination of second-order reactions, such as the four shown above, plus any number of second-order radical–radical combination reactions will lead to a square root intensity dependence, whereas any reaction that is not second order will destroy this relationship. Excited water molecules would undergo a first-order decay, in disagreement with the square root observation.

Organic Solutions and Compounds

The understanding of the radiation chemistry of hydrocarbons should in principle be simplified by the large reservoir of knowledge available on reaction rates of free radicals and various ions with hydrocarbons. In spite of this extensive background, very few firm statements can be made about the mechanism of the action of radiation on these systems. This is true partly because the reagents used to test the reaction mechanism are generally ambiguous in their behavior: compounds reactive to neutral free radicals also tend to react with ionic radicals and free electrons and to act as "sinks" for excitation energy as well.

A study has been made of the effect of tetrachloroethylene (C_2Cl_4) on the radiation chemistry of *n*-pentane. This reagent is known to be relatively unreactive toward organic free radicals, but it should react readily with free electrons. It was thought that C_2Cl_4 might be useful in distinguishing between free radical and ionic reactions.

The effect of adding several mole percent of C_2Cl_4 to liquid pentane is to lower the yields of the products arising from pentane, as is shown in Table 3. A number of new chlorinated products appear. HCl and trichloroheptene are the major new products.

It is reasonable to attribute the change in the hydrogen yield to the reaction of hydrogen atoms with C_2Cl_4. The formation of trichloroheptene would suggest an ionic reaction, since C_2Cl_4 is relatively inert to organic radicals. On the other hand, the yield of trichloroheptene is dependent on intensity. Thus, at a gamma-ray intensity of 10^8 rad/hr (obtained by using an electron beam), the yield of trichloroheptene is smaller and that of decane larger than the values given in Table 3, which refer to an intensity of 3.5×10^5 rad/hr. This intensity effect casts doubt on the ionic nature of the reactions and suggests a free radical mechanism in which combination of pentyl radicals competes with their reaction with C_2Cl_4.

The appearance of chloropentanes and the lower yield of pentene in the presence of C_2Cl_4 suggested a study of pentene–HCl solutions in pentane. A chain reaction between pentene-1 and HCl was found with yields as large as 50 molecules per 100 ev. The interesting feature of these results (Table 4) is that chloropentane-2 represents 90% of the chloropentane formed. This product results

Table 4

Major Products of Radiolysis of Mixtures of Pentene-1 and HCl in Pentane
Numbers are *G* values in molecules/100 ev

	Mole % of pentene-1 and HCl, respectively					
Product	0.76, 1.5	0.38, 1.5	0.38, 0.75	0.38, 0.39	0.19, 0.39	0.19, 0.19
H_2	3.2	4	3.7	3.4	4.3	4
Chloropentane-2	48	30	15.6	8	5.3	3.0
Chloropentane-1	5.8	3.6	2.0	1	0.5	0.25
Chloropentane-3	—	—	0.6	0.5	0.5	0.5
Pentene-1	−53	−33	−18.7	−9.8	−6.4	−5.3
Decane	—	—	1.2	1.2	1.4	1.2

from Markownikov addition, which is characteristic of ionic reactions. Free radical reactions tend to give primarily terminal halogen compounds. The indication of a relatively long ionic chain reaction in solution is surprising.

Acetamide exists in two crystalline forms. The stable form is rhombohedral and melts at 81°C. The metastable form is orthorhombic and melts at 69.4°C. The liquid phase supercools easily and below 69°C will crystallize in the metastable form. These two forms have been used in a study of the effect of crystal structure in radiation chemistry. The data obtained are also interesting in view of the resemblance of the bond structure in acetamide to the peptide linkage in proteins.

Marked differences were observed between radiolysis products of the two crystalline forms (Table 5). The yield of CH_4 increases slightly with temperature in both forms. The yield of H_2, however, increases in the stable form and decreases in the metastable form with increasing temperature. The yield of acetonitrile (CH_3CN) increases sharply with temperature in the metastable form but is almost independent of temperature in the stable form.

All yields show a discontinuity with change of phase. The G values of CH_4, H_2, and CO are 0.15, 0.26, and 0.008 for the stable crystal at 70°C, while they are 0.49, 0.32, and 0.26, respectively, in the supercooled liquid at the same temperature. The yield of CH_3CN, however, drops sharply in the liquid by a factor of 10. This behavior suggests that the reaction forming CH_3CN and water is independent of the reactions forming the other products. The yield of CH_3CN from the metastable crystalline form increases with the total dose given the sample. This suggests the presence of a precursor of CH_3CN, but it has not yet been detected.

The formation of a stable radical in irradiated acetamide has been reported. Additional work has been done to characterize the radical and to learn something about its yield. Electron spin resonance measurements were made at room temperature on irradiated samples of both acetamide and deuterated acetamide. CH_3CONH_2 and CH_3COND_2 gave triplet spectra with 24-gauss separation between the lines, whereas CD_3CONH_2 gave a 5-line spectrum. These results are consistent with the radical assignment, $\cdot CH_2CONH_2$. By comparison with known amounts of the free radical DPPH, the yield of this radical appeared to be

Table 5

Product Yields in the Irradiation of the Two Crystalline Forms of Acetamide at 25°C (Dose $=2.5\times10^7$ rad)

Numbers are G values in molecules/100 ev

Product	Rhombohedral (stable)	Orthorhombic (metastable)
CH_4	0.14	0.18
H_2	0.25	0.075
CO	0.005	0.007
NH_3	0.07	0.02
CH_3CN	1.10	0.74
H_2O	1.2	0.86
Acetone	0.02	0.05
Succinamide	0.05	0.03
Malonic amide	0.006	0.004

$\approx$0.2 radicals per 100 ev. The concentration of the radical does not increase linearly with dose, but appears to reach a steady state above 10^6 rad.

At present, only an empirical description of the system can be given. It has been shown that marked crystal structure effects exist, but there is insufficient information to warrant a discussion of mechanism.

CHEMISTRY OF ISOTOPES

Isotope Effects on Vapor Pressure

The development of a general theory of the effect of isotopic substitution on the partition function of condensed phases has been carried through the first quantum correction, i.e., to terms of order $(\hbar/kT)^2$. The theory explains a large number of phenomena previously observed in the vapor pressures of isotopic polyatomic molecules, such as the rule of the geometric mean, and, within the approximation considered, includes the effects of rotation, coupling of translation and rotation, perturbation of internal molecular vibrations, and coupling of lattice and molecular vibrations.

Experimental tests of the theory have been carried out through the study of the vapor pressures of $N^{14}N^{14}O^{16}$, $N^{14}N^{15}O^{16}$, $N^{15}N^{14}O^{16}$, and $N^{14}N^{14}O^{18}$. It is shown experimentally, in agreement with theoretical predictions, that the vapor pressures of the pair $N^{15}N^{14}O^{16}$ and $N^{14}N^{15}O^{16}$ differ by almost as much as those of the pair $N^{14}N^{14}O^{16}$ and $N^{14}N^{15}O^{16}$. The difference between the two N^{15} isomers is a consequence of

hindered rotation in the liquid. The relative effects of O^{18} and N^{15} substitution are quantitatively described in terms of the random structure of solid N_2O, which has been directly confirmed by neutron diffraction.

An even more subtle effect of molecular geometry, as manifested in the volatility of isomeric dideuteroethylenes, has been explained by the theory. Measurements of the vapor pressures of the *cis*, *gem.*, and *trans* compounds in the range 130° to 180°K indicate that the *trans* isomer is the most volatile by 0.05 and 0.1% at the upper and lower temperatures respectively. In addition, all the dideuteroethylenes are $\approx$1.0 to 1.5% more volatile than ethylene between 130° and 180°K. These observations are consistent with the known decrease in frequency of C—H stretching vibrations by van der Waals' forces. The molecular geometry effect is a consequence of the stiffening of planar and out-of-plane bending motions of the hydrogen atoms by the intermolecular forces.

Secondary Isotope Effects and Solvent Properties of D_2O

A review and evaluation of the experimental data and theory of secondary isotope effects in rate and equilibrium processes has been prepared. The differences in the solvent properties of D_2O and H_2O have been summarized. The review includes a discussion of the ionization of weak acids and acid-base catalysis in D_2O vs H_2O and in H_2O-D_2O mixtures.

Correlation of Tritium and Deuterium Isotope Effects

A theory has been developed that permits the correlation of tritium–protium and deuterium–protium isotope effects in both rate and equilibrium processes. The theory has been confirmed by experimental observations, which has made possible the extrapolation of a large body of experimental data on the chemistry of deuterium to that of tritium. This should lead to more quantitative applications of tritium in meteorology, geology, and geophysics. The study of relative tritium and deuterium isotope effects is a particularly useful diagnostic tool for the analysis of small isotope effects and tunneling in chemical reactions.

Ammonia-Tritium Exchange Equilibrium

The equilibrium constant K for the exchange reaction

$$NH_3(g)+HT(g)=NH_2T(g)+H_2(g)$$

was determined between 516° and 623°K by kinetic investigation and also by more standard methods. With this information, the zero point energy difference between NH_3 and NH_2T was calculated to be 919 ± 21 cm^{-1}. This number is in reasonable agreement with the value to be expected on the basis of the previously determined zero point energy difference of NH_3 and NH_2D.

Proton Transfer Reactions

Simple models were used to make calculations for transition states of proton transfer reactions, $A_1H + A_2 \rightarrow A_1 + HA_2$. For a Coulombic model the contribution of the transverse frequency to the hydrogen isotope effect is shown to be exactly canceled by the tunnel effect in the first quantum approximation. If the first quantum approximation is not sufficient, the tunnel effect will be the more important. These conclusions are found to apply to any reasonable model in which the proton moves between two independent centers of force.

Hydrogen-Chlorine Reaction

Previous study at this Laboratory of hydrogen isotope effects in the reaction

$$H_2 + Cl \rightarrow H + HCl \qquad (1)$$

has given insight into the vibrational frequencies of the H_2Cl transition state. During these studies it became necessary to estimate the ratio of the rate constant of the inverse reaction

$$H + HCl \rightarrow H_2 + Cl \qquad (2)$$

to the rate constant for the reaction

$$H + Cl_2 \rightarrow HCl + Cl\,. \qquad (3)$$

The ratio k_2/k_3 has now been determined by a technique involving the measurement of the appearance of isotopically substituted hydrogen in the photochemically induced reaction of protium with hydrogen chloride in the presence of isotopically labeled hydrogen chloride:

$$k_2/k_3=(0.143\pm0.033)\exp[-(1540\pm130)/RT]\,.$$

This rate constant ratio has led to the determination of the doubly degenerate bending frequency in the HCl_2 transition state which has been assumed linear : $\omega_\phi \approx 105$ cm^{-1}.

KINETICS OF OXIDATION-REDUCTION REACTIONS

The rate of the electron exchange reaction between thallium(I) and thallium(III) has been measured in 3 M $NaClO_4$-$HClO_4$ media at various acid concentrations. In contrast to earlier results at higher ionic strengths, the rate was found to decrease as the acidity is decreased. The rate law can be written as

$$R=k_0(Tl^{+})(Tl^{+3})+k_1(Tl^{+})(TlOH^{+2}),$$

with $k_0=0.253\pm0.005$ mole^{-1} hr^{-1} and $k_1=0.089\pm0.012$ mole^{-1} hr^{-1} at 25°C. No evidence was found for an exchange of Tl^{+} with $Tl(OH)_2^{+}$. The activation energy for k_0 is 17.2 kcal/mole.

The above measurements show that while the hydroxide group does not have the strongly catalytic effect on the thallous-thallic exchange that it has in some other electron exchange reactions, neither does it have the strongly inhibiting effect shown by chloride, bromide, or cyanide groups.

The rates of oxidation-reduction reactions between coordination complexes have been studied by using a rapid mixing and flow technique. The reactions between such positively charged complexes as $Fe(phen)_3^{+3}$ and $Os(dipy)_3^{+2}$ and between such oppositely charged complexes as $Fe(phen)_3^{+3}$ and $Fe(CN)_6^{-4}$ proceeded with rate constants which are $>10^8$ mole^{-1} sec^{-1} at 25°C. On the other hand the rates of oxidation of $Fe(CN)_6^{-4}$ ions by $IrCl_6^{-2}$, MnO_4^{-}, and $OsCl_6^{-2}$ ions are considerably slower and increase as the standard free energy changes become more negative.

The relative slowness of the reactions between negatively charged oxidizing and reducing agents may be a consequence of their smaller sizes and comparatively larger charge products. These factors will tend to increase the work required to bring the reactants together to form the activated complex. The relationship between the rates and standard free energy changes of these reactions is consistent with the view that part of the free energy of the reaction is available for overcoming the electrostatic repulsion between the reactants and reorganizing their coordination shells prior to electron transfer. In addition, the very rapid rates of the oxidation-reduction reactions involving the phenanthroline and dipyridine complexes suggest that the conjugated ring systems facilitate the transfer of electrons between the reactants. This conclusion is consistent with the observation that the second-order rate constants for the oxidation of ferrohemoglobin and ferrocytochrome c by ferricyanide ions in a phosphate buffer of pH 6.0 are $(7.0\pm0.5)\times10^4$ mole^{-1} sec^{-1} and $(1.6\pm0.1)\times10^7$ mole^{-1} sec^{-1}, respectively, at 25°C. In contrast to the iron atom in hemoglobin, the iron atom in cytochrome c is coordinated solely to conjugated groups.

CHEMICAL EFFECTS OF NUCLEAR TRANSFORMATIONS

Carbon-14 Recoil Chemistry

The recoil chemistry of the system methanol–ammonia has been studied in experiments in which liquid ammonia (serving as the nitrogen source) was dissolved in purified degassed methanol and irradiated in the conventional manner. Several simple alcohols were added as carriers, and their yields were determined:

Labeled product	% of Total activity produced
Methanol	1.0
Ethanol	5.5
n-Propanol	2.6

The high yield of propanol is noteworthy because it is a three-carbon product. The distribution of C^{14} activity in this product, as determined by degradation, is given below.

$$\underset{43\%}{CH_3}—\underset{55\%}{CH_2}—\underset{2\%}{CH_2}—OH$$

The fact that most of the activity is found in the 2- and 3-positions suggests that a two-carbon fragment is first formed and may then react with its surroundings. The data rule out stepwise scavenging of carbon by an energetic C^{14}, random recombinations of one- and two-carbon fragments in the recoil track, and labeling by replacement in radiolytically produced n-propanol.

Cobalt-60 and Ligand Recoil Effects in Complexes of Trivalent Cobalt

The amine complexes of cobalt(III) form an interesting and convenient group for hot-atom investigations, since they (1) are well-characterized crystalline substances, (2) are fairly stable in aqueous solution, (3) permit the study of recoil processes either in the central atom or in a ligand, (4) can be made in isomeric *cis* and *trans* or *d* and *l* forms, and (5) exhibit typical thermal and radiation-induced hot-atom annealing processes.

Studies with cobaltic hexammine salts (the nitrate was mentioned in the last report) are currently being extended to the bromide. It is found that the recoils of Co^{60}, Br^{80m}, and Br^{82} all lead to the ion $Co(NH_3)_5Br^{++}$, labeled with the appropriate recoil atom, and that this species disappears on annealing the crystal. The relative rates of disappearance of the three labeled forms are currently being measured.

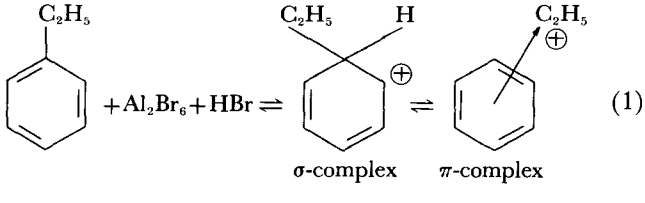
In similar fashion the relative rates of annealing of Cl^{38} and Co^{60} in irradiated *cis* and *trans*-dichlorobis(ethylenediamine)-Co(III) nitrate have been studied. The Co^{60} annealing rates are found to differ in the *cis* and *trans* crystals, and in each case differ from the Cl^{38} rates in the same crystal. However, the rates of Cl^{38} annealing are similar in the *cis* and *trans* compounds. It was previously found in this Laboratory that the configurations of *d* and *l*-tris(ethylenediamine)-Co(III) salts were preserved in both the hot-atom and the thermal-annealing reactions of Co^{60}. The same has been found to hold for both Co^{60} and Cl^{38} atoms in the irradiated *cis* and *trans*-dichlorobis(ethylenediamine)-Co(III) nitrate.

Attempts have been made to use these data to distinguish among several alternative mechanisms for the annealing process. For example, it has been possible to eliminate decisively one proposed mechanism based upon two annealing sites, each having a single energy of activation.

ORGANIC CHEMISTRY

Reaction Mechanisms

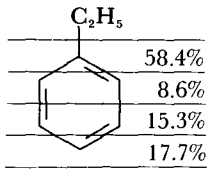
Disproportionation of Ethylbenzene. The mechanisms of isomerization and disproportionation (transalkylation) of the alkyl benzenes under the influence of strong acids have been the subject of much study. The enormous rate difference in the disproportionation of toluene as compared to that of ethylbenzene had been explained on the basis of a series of rapid prior equilibria involving a localized π-complex (Eq. 1).



(1)

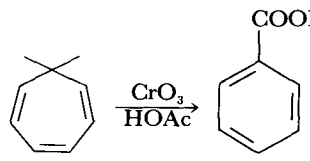
It had been suggested that the reaction velocity is proportional to the product of the alkylbenzene concentration and that of the π-complex. Theoretical considerations indicate that the π-complex of ethylbenzene is considerably more stable than that of toluene, which accounts for the difference in rate.

The disproportionation of ethylbenzene-1-C^{14} was carried out to test this hypothesis. Ethylbenzene-C^{14}, which had been undergoing reaction for $\approx$15 min, was isolated and degraded. The results are given in the following diagram.



If the localized π-complex were indeed involved, either a random distribution of activity or a site preference in the order one $>$*ortho*$>$*meta*$>$*para* would be expected. Since the bulk of the rearranged activity is in the *meta* and *para* positions, the results rule out the postulated prior equilibrium to a localized π-complex. An additional point brought out by the observed distribution of activity is that isomerization by a series of 1-2 shifts of the ethyl group is less rapid than transalkylation. Experiments in progress will determine the activity growth in the *meta* and *para* positions as a function of time and should give more information about the mechanism.

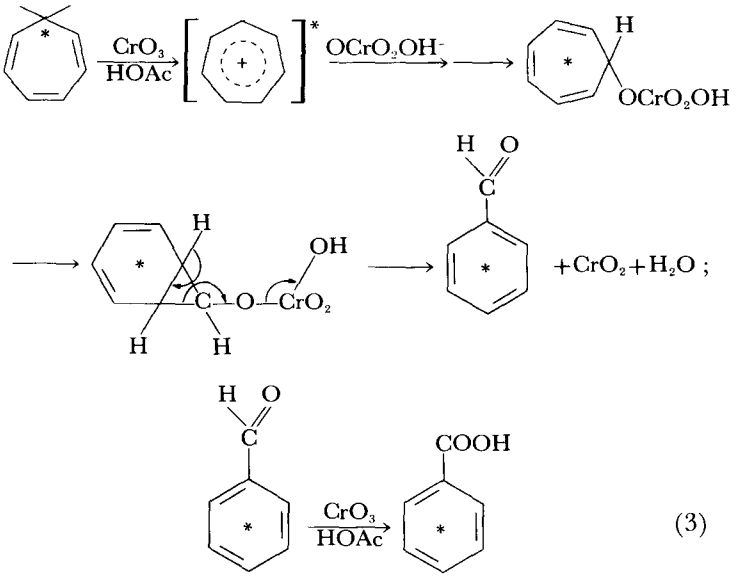
The Chromic Acid Oxidation of Cycloheptatriene. The base-catalyzed conversion of various cycloheptatriene (CHT) derivatives to fully aromatic systems is well known. The acid oxidation of CHT itself also results in the formation of a fully aromatic compound, benzoic acid (Eq. 2).



(2)

Specifically labeled CHT was prepared by photolysis of diazomethane-C^{14} in benzene. Benzoic acid isolated from the acid oxidation of the specifically labeled CHT was subjected to a Schmidt degradation. The carboxyl group (assayed as CO_2) contained one-seventh of the total activity, and the ring (assayed as acetamide) contained six-sevenths. Clearly a symmetrical intermediate, most probably the tropylium cation, is involved in this rearrangement. A mechanism

based on these data and on the work of Doering and Westheimer is suggested (Eq. 3).

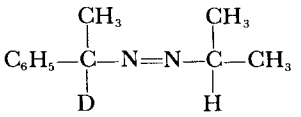


(3)

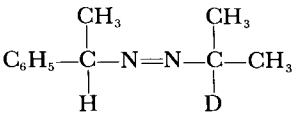
Secondary Isotope Effects

Various researchers have correlated observed secondary α-deuterium isotope effects with a change in geometry (planar or tetrahedral) at the α-carbon atom. If the simplified model for this effect is adopted as the isotope effect on the change in zero point energy between reactant and transition states, then the major contributor to this effect is the change in the bending force constant of the H—C-leaving group. Theoretical calculations were undertaken to determine the effect of geometry on the isotope effect. By using Wilson's F-G matrix method to calculate frequencies, it was found unlikely, in the case of the CH_3—C pseudomolecule, that the isotope effect can be used to distinguish between planar and tetrahedral transition states.

Previously, the secondary α-deuterium isotope effect in the radical decomposition of azobis-α-phenylethane-α,α′-d_2 had been found to indicate that both C—N bonds are simultaneously breaking in the transition state. In continuing work on this problem, the specifically deuterium-labeled compounds, α-phenylethyl-α-*d*-azoisopropane (I) and α-phenylethylazoisopropane-2-*d* (II) were



(I)



(II)

synthesized. Their rates of decomposition in diphenyl ether–benzoquinone solution were measured and compared to that for the natural compound. The isotope effects at 143°C are $k_H/k_I = 1.15$ and $k_H/k_{II} = 1.04$. These effects appear to indicate that in going from the reactant state to the transition state both bonds are stretching simultaneously but to different extents; the movement of the α-phenylethyl group away from the nitrogen is probably greater than the movement of the isopropyl group away from its neighboring nitrogen atom.

The secondary isotope effect in the ionization of fully deuterated triphenylmethyl chloride in liquid sulfur dioxide has been measured. The ratio of equilibrium constants is $K_D/K_H = 1.19$ and is to be contrasted with the reported ratio of equilibrium constants, $K_D/K_H = 1.02$, for ring-deuterated benzoic acid. The inverse effect in the case of the former appears to be related to the delocalization of positive charge into the phenyl groups of the carbonium ion and is qualitatively consistent with the known out-of-plane C—H bending frequencies.

Nicotine Biosynthesis

C^{14} tracer studies of the biosynthesis of nicotine by tobacco roots now indicate the incorporation into the pyridine ring of only one or two carbon atoms of various two to four-carbon precursors. Present efforts are directed toward using a specific carbon-by-carbon degradation of the pyridine ring of nicotinic acid (derived from the nicotine) to determine the location of label from specifically labeled precursors, with a view to elucidating their role in pyridine ring biosynthesis in the tobacco plant and probably in other higher plant and animal systems.

CHEMISTRY OF ENZYMES AT LOW TEMPERATURES

In studies relating enzyme chemistry at ordinary temperatures and at low temperatures, solvents containing considerable concentrations of water have been used. As an example, a solvent containing 25% water, 55% methanol, and 20% ethanol gave at liquid nitrogen temperature a clear glass suitable for absorption spectroscopy, softened at about −150°C, and flowed freely but with high viscosity at −120°C. At this temperature the solvent has a dielectric constant higher than that of water at room temperature and has been found to dissolve salts, acids, and bases such as are usually

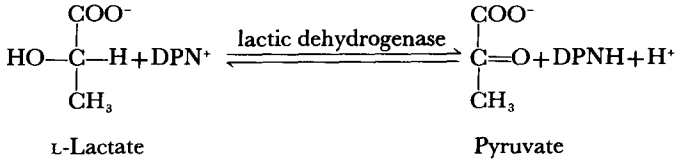
employed in enzyme chemistry. It was possible to obtain concentrations of the enzymes chymotrypsin and trypsin in this solvent adequate for study; in fact, higher concentrations than at ordinary temperatures were achieved by the inhibition of the crystallization process. After removing the solvent from the enzymes, usually by pumping at low temperatures, the enzyme activities were found intact.

An attempt was made to detect the presence of the enzyme–substrate complex of α-chymotrypsin and a specific substrate, arginine tyrosine ethyl ester (ATEE), by measuring the decrease in the characteristic phosphorescence of the substrate caused by the transfer of its excitation energy to the enzyme upon compound formation in very dilute solutions. The existence of a compound between enzyme and substrate was established, and a rough equilibrium constant was determined.

Similar compound formation between trypsin and ATEE was also observed, perhaps because of the similarity in amino acid composition of the active sites in these two enzymes.

It became evident that in the work of others at room temperature with α-chymotrypsin in 10% and 30% methanol, a reaction had occurred between enzyme and solvent which led to an uncoupling in the resonance energy transfer processes. It now appears that this reaction can be inhibited if the enzyme in water is mixed with the methanol solution at 0° C to arrive at the same concentrations, and that under these conditions the spectrum of the enzyme is virtually the same as in pure water. Furthermore, the spectrum of the hydrated enzyme is preserved on addition of mixed alcohols to the methanol solutions at −80° C, even when the total alcohol concentration is 75%.

Lactic dehydrogenase is one of the important oxidation-reduction enzymes utilizing diphosphopyridine nucleotide (DPN) as coenzyme. The overall enzymatic reaction can be represented by the following equation:



L-Lactate Pyruvate

Earlier investigators have established that the enzyme forms a triple complex with the DPN and substrate, which subsequently falls apart to yield the corresponding products. An investigation was undertaken to resolve the over-all enzymatic reaction of lactic dehydrogenase into individual reaction steps and if possible to isolate the intermediates by the use of reactions at low temperatures.

In preliminary studies alcohol–water solutions were used to maintain the enzyme in the liquid phase at low temperatures. Lactic dehydrogenase has been found to dissolve in solutions of high alcohol content (up to 95% by volume) without undergoing any observable damage if the reaction is carried out at −80° C. Complex formation has been observed between the reduced and oxidized forms of the DPN and lactic dehydrogenase; formation was so rapid at −80° C that it could not be measured by conventional techniques.

A systematic investigation of the total enzymatic reaction (assay), in which L-lactate was converted to pyruvate, indicated that a small amount of alcohol generally enhanced the enzymatic activity. As the concentration of alcohol was increased, the activity stayed constant for a limited alcohol concentration range; it then dropped rapidly and approached zero activity. At room temperature the assay decreased to zero activity in the presence of 35% ethanol by volume, but at 8° C the system showed an activity of 62.5%, and at 1° C it showed an activity of 30%, all relative to the activity of purely aqueous systems at room temperature.

STRUCTURAL CHEMISTRY

Antiferromagnetic Structure of Chromium

Single-crystal neutron diffraction studies on chromium, initially undertaken to check the earlier powder results of Shull and Wilkinson, have shown a complex antiferromagnetic structure with a Néel temperature of 310° K. The basic magnetic structure proposed on the basis of the powder results shows further long-range modulation, which may be described either in terms of a helical or an antiphase domain model with a period of ≈28 unit cells. All attempts at finding the higher harmonics implied by the antiphase domain model have failed. However, an additional transition has been found at ≈110° K which is described most simply in terms of the antiphase domain model. The low temperature transition seems to involve a switching of the chromium moments from a direction perpendicular to the modulation axis to one parallel to it. A simple helical model that can explain this transition has not been found.

Hydrogen Bonding

The investigation of polycrystalline chromous acid, mentioned briefly in last year's report, has been completed. The interest in this compound stems from the fact that a very short O . . . H . . . O hydrogen bond is present, and the neutron diffraction investigation was undertaken to determine whether or not the hydrogen atom is located symmetrically with respect to the two oxygen atoms. The data for $DCrO_2$ can be unambiguously interpreted in terms of a model that does not have a centrally located deuterium atom but is disordered, the deuterium atom being attached to either of the two oxygen atoms at random with a more normal bond length of $\simeq$1.0 A. The data for $HCrO_2$, however, seem to indicate that the hydrogen atom does lie at the center of the bond. The difference in the two compounds is compatible with the infrared spectra and can be interpreted in terms of a double-minimum potential well, with the first vibrational state of the deuterium atom lying below the central maximum, while that of the hydrogen atom lies above.

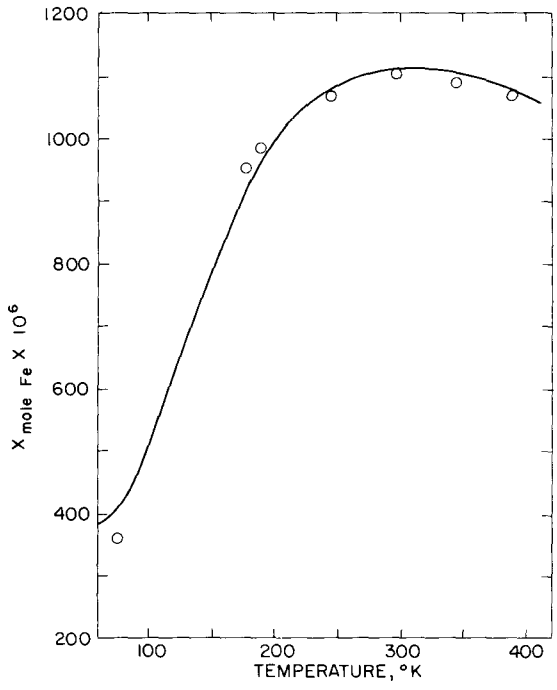


Figure 4. Magnetic susceptibility of ferric orthophenanthroline.

Rotational and Orientation Disorder

Several studies have been directed toward establishing the existence of rotational or orientation disorder of molecules and ionic groups in crystals.

Potassium cyanide has the sodium chloride structure at room temperature. This can be accounted for by randomly orienting the CN groups along the body-diagonal directions of the unit cell or by allowing them to rotate freely in the lattice.

X-ray diffraction data have not distinguished between these models because of the low scattering power for x-rays of carbon and nitrogen. A neutron diffraction investigation was therefore carried out. In this situation the scattering powers of potassium, carbon, and nitrogen are comparable, and the model with rotating cyanide groups was found to give good agreement with the experimentally observed diffraction pattern. The randomly oriented cyanide model, however, was in disagreement and was definitely excluded.

It was also found possible in this work to obtain a more accurate value of the C—N bond length (1.16$\pm$0.01 A), in good agreement with the bond length 1.1575 A observed in HCN.

In connection with work reported earlier in the Chemistry section, the structure of polycrystalline nitrous oxide has been studied at low temperature. The interpretation of patterns taken at 77°K supports the hypothesis, previously based on thermodynamic evidence alone, that disorder exists in crystalline N_2O, such that the average structure is the same as that of CO_2. At a given crystallographic site the molecules are sometimes oriented N—N—O and sometimes O—N—N.

Paramagnetism of Ferric Orthophenanthroline

The magnetic susceptibility of tetraphenanthroline dihydroxyl diferric chloride has been measured over the temperature range 76° to 391°K. The susceptibility of this salt as a function of temperature is similar to that of copper acetate. The data suggest that two ferric ions are closely coupled in the lattice, probably through hydroxyl bridges, which gives rise to a singlet ground state and an excited triplet state.

By use of this model and the data shown in Figure 4 it was found possible to obtain a reasonable Landé g factor (g=2.22) and a singlet-triplet splitting (W=344 cm^{-1} or 490°K). The magnetic susceptibility is then given by the equation

$$\chi_{\text{mole Fe}} = \frac{0.60}{T}\left[1+\frac{1}{3}\exp\frac{490^\circ}{T}\right]^{-1}+360\times10^{-6},$$

the last term representing the temperature-independent susceptibility.

Molecular Dynamics

The first-order adiabatic energy derivative for a diatomic molecule can be developed in a spherical harmonic expansion. It has been shown that in most cases the force on a particular nucleus may be computed as if the nucleus lay completely outside the electronic charge distribution. The theoretical basis of empirical force constant expressions has been examined, and a justification for Badger's rule and similar relationships has been found.

Nuclear Engineering

During the past year the work on the Liquid Metal Fuel Reactor was brought to a close with the successful operation of the in-pile radiation test loop. Upon metallographic examination of this loop after 3000 hr of operation in the Brookhaven Graphite Research Reactor (BGRR) with fully enriched U-Bi fuel, no evidence was found of any adverse effect of the gamma, neutron, and fission fragment radiation on the corrosion rates of the materials of the loop. This eliminates the principal remaining uncertainty as to the feasibility of using these U-Bi systems as reactor fuel.

The present program of the Department falls into several categories. The first, and by far the largest in terms of man-years of effort, is basic research, which includes fundamental studies in physics, chemistry, and metallurgy. The reactor physics program, which is a notable one, is the greatest single effort in this field. Also included are work on liquid metals and reactor materials at high temperatures and liquid metal heat transfer, and studies of diffusion of fission product solids. The Department has taken over the work on cross section compilation from the Physics Department and combined it with the work on reactor cross section evaluation to form an expanded Sigma Center. Since much of the information and evaluation is common to both groups, more efficient and effective operation should result.

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 nonrigid fuel elements, high temperature volatility and fluidized bed processing schemes, radiation engineering methods, and waste processing devices such as the rotary calciner.

The engineering and evaluation studies in the third category are focused on practical application of the work in the preceding categories. Studies were made during the year on settled particulate bed fueled systems for high temperature, high performance reactors, breeder reactors, and chemonuclear reactors. Through this program assistance is also provided to the Atomic Energy Commission in reactor evaluation. Dr. Chad Raseman spent the year in Washington working for the AEC in this connection.

The development and design of the Brookhaven High Flux Beam Research Reactor (HFBR) and the High Intensity Radiation Development Laboratory (HIRDL) also involved appreciable effort. The preliminary design report of the HFBR was transmitted to the AEC in September 1960, and the site report prepared by the HFBR Project Staff was submitted to the AEC and approved. The reactor will be located on Rutherford Hill, southeast of the BGRR's cooling tower. In December 1960 the AEC requested Brookhaven to assign the contract for its construction to them, and they immediately instructed the Lummus Company to begin detail design, which is $\approx$50% complete as of June 30, 1961. The HFBR Project Staff has been working very closely with the AEC in handling the technical approval of the designs submitted by the architect-engineer firms, the Lummus Company and Combustion Engineering, Inc. A preliminary summary hazards report has been prepared by the HFBR Project Staff and submitted to the AEC; it will be reviewed at a meeting of the Advisory Committee on Reactor Safety in July 1961.

Although weather conditions have retarded the progress of construction of the HIRDL, most of the foundation work, the canal, and the concrete foundations for the cells are completed. The bulk of the steel shell of the building has been erected, and the building is now in the process of being closed in. Contracts for most of the specialized cell and auxiliary equipment have been let.

Because of the increased emphasis on fundamental work in the Department, the ratio of scientific and professional personnel to technicians has increased, and is now $\approx$1:1.

The Department also has designed and supervised construction of a number of gamma irradiators for exhibits (staffed by BNL personnel) in Cairo, Buenos Aires, and Rio de Janeiro and for a food irradiation program at MIT and the Universities of Washington and California.

The Department has made notable progress in the modernization of its research facilities this year. Phase I of the Nuclear Engineering Building

has been completed and is now occupied by members of the Chemistry and Chemical Engineering Division. Ground has been broken for additions to the Critical Assembly Facility and the Metallurgy Laboratory. These additions will be completed during fiscal 1962 and will add considerably to the effectiveness of the work of the two groups.

REACTOR PHYSICS

Theoretical Reactor Physics

Work in reactor physics theory and computations during the past year continued to be the primary responsibility of the Theoretical Reactor Physics Group. Physics evaluation of reactor proposals for the AEC was carried out cooperatively between members of this group and the Reactor Evaluation Group. The results of an evaluation of large power reactor systems utilizing settled bed fuels have indicated that such fuels have sufficient economic and breeding potential to justify further experimental and theoretical investigation of this novel fuel system.

Investigations in theoretical reactor physics have included such subjects as chemical binding effects in the thermalization of neutrons, collision probabilities and resonance integrals for lattices, the measurement of reactivity, the resonance capture of neutrons in nonheavy absorbers, the breeding ratio in U^{233} and Pu^{239}-fueled reactors, nonlinear, space-dependent kinetics, the effect of temperature on xenon instability, spatially dependent neutron spectra, thermal neutron flux distribution in space and energy, the effect of diffusion upon the initial phases of the thermalization of neutrons, a new analytical formula for Dancoff correction for cylindrical lattices, the equal charge displacement rule in fission product poisoning, and the fast effect in uranium and beryllium systems.

Further work on the analysis of water-lattice experiments was completed during the year. Results of calculations of the criticality of enriched uranium and uranium oxide lattices show that accurate theoretical calculations based only on known cross sections yield excellent agreement with the large number of experimental results obtained at BNL and Westinghouse (Bettis). Some discrepancies in cadmium ratios of U^{238} captures to U^{235} fissions remain, and these anomalous cases are being investigated. The theoretical calculations are also being extended to heavy water moderated critical experiments. Theoretical analyses of experiments on massive blocks of uranium (Snell experiments) and of beryllium moderated critical experiments have also been carried out to verify cross section data for inelastic scattering of U^{238} and to determine the magnitude of the $(n,2n)$ reaction in beryllium. The anisotropy of neutron migration in water moderated, 3% enriched uranium rod lattices, indicated by recent BNL experiments, has been confirmed by theoretical calculations.

Further studies have been carried out on Pu-Bi fast breeders and on high conversion ratio, plutonium-fueled, thermal reactor concepts, and more rigorous calculations of temperature coefficients in reactor lattices have been made. Studies of radiation effects in chemical systems have been carried out in cooperation with members of the Chemical Technology Group. Calculations in support of the HFBR Project were continued.

Experimental Reactor Physics

Plate Lattices. Disadvantage factors and fast fission factors have been measured in the miniature plate lattices (uranium metal slabs ⅛ in. thick, enriched to 1.3 wt % U^{235}, water moderated) with nominal water/metal volume ratios of 1, 1.5, 2, 3, and 4 to 1. Measurements of δ_{25} and δ_{28} were completed for all lattices. Measurements of resonance escape probability are being developed and correlated with those previously obtained for the miniature 0.387-in. metal rod lattices in an attempt to check the methods used. Measurements of buckling and reflector savings have been completed for the 4:1 H_2O/U volume ratio and are currently being measured for the other volume ratios. Anisotropy effects in the bucklings and reflector savings are being investigated.

The critical facility has been supplied with instrumentation and equipped for critical experiments with the slightly enriched, light-water moderated, uranium slab lattices. The hazards summary report has been approved, with slight modifications, and experiments will commence shortly.

Uranium Oxide Lattices. Exponential experiments on 3% UO_2 lattices have been performed, and material bucklings, reflector savings, and anisotropy factors have been obtained for five different volume ratios. Fuel rods are 3% enriched UO_2, 6 ft long, clad in 304 stainless steel jackets of 0.500-in. o.d. and 0.028-in. wall thickness. The data have been analyzed in terms of an anisotropy in the bucklings and migration area and with a

variation of reflector savings with radius. Critical masses have been observed during the initial loadings to nearly critical condition and have been compared with critical masses computed from exponential experiments.

Measurements of the migration areas by the boron poison method are under way.

Total Neutron and Activation Cross Sections of Dysprosium-164. Measurements of the total neutron and activation cross sections of Dy^{164} have been completed, and a set of resonance parameters has been derived. A trial-and-error fit was made to the total cross section data for the resonance parameters in the Breit-Wigner single-level resonance formula.

Neutron Diffusion Length in Water. Measurements of neutron diffusion length in pure water and in aqueous boric acid solutions are under way and should be completed in a few days. These data are useful from a safety aspect in the exponential experiments involving boron poison addition; they also yield accurate values of the diffusion parameters in water, including the diffusion length and diffusion cooling parameter.

Pulsed Neutron Source. Pulsed neutron measurements were carried out on graphite stacks and on graphite-bismuth stacks. The graphite stacks include GBF and AA grades of graphite. Preliminary data on the mean neutron energy as a function of time in the pulsed experiments indicate a complete thermalization time of $\approx$3 msec, which has a marked effect on the computed value of the diffusion cooling constant. In the light of this information, the pulsed neutron data are being reviewed and will be used in recomputing the diffusion parameters. Comparison of the transport mean free path as measured by the copper poison technique and by the pulsed neutron technique is also expected to be affected.

Improvements in the ion source and the addition of a deuteron beam deflector have increased the signal-to-background ratio of the Van de Graaff generator from its original value of 400 to $\approx 10^6$. The improved quality of the deuteron beam and subsequent neutron pulses has made possible the re-evaluation of earlier pulsed neutron data.

High Temperature Critical Facility. The Critical Assembly Facility at BNL is being enlarged to include two additional assembly rooms with associated laboratories and offices. An engineering study was performed by Burns and Roe, Inc., in cooperation with BNL to establish the feasibility and estimated cost of a high temperature, high pressure, water moderated critical experiment. This experiment will be made with the slightly enriched UO_2 fuel rods currently being used in the exponential experiments at room temperature.

Minimum Reflection Critical Experiments. A hazards summary report on the minimum reflection critical experiments has been prepared and submitted for approval. Critical experiments with bare assemblies of graphite-U^{235} and beryllium-U^{235} are contemplated. Nuclear instrumentation, movable carriages, and associated equipment have been installed in a steel shell Butler building in an isolated area $\approx$600 ft from the control building. Critical experiments will commence shortly after approval of the hazards summary report.

High Flux Beam Research Reactor. Critical experiments were performed on a mock-up of the HFBR, which consists of aluminum-U^{235} fuel plates, moderated and reflected by heavy water. Measurements to establish the power distribution, neutron characteristics of the beam tubes, control rod effectiveness, and gamma heating were made with the reactor in a cylindrical tank. Late in fiscal 1961 this tank was replaced by a spherical tank that accurately reproduces the geometry of the proposed HFBR reactor vessel.

A portable reactivity meter has been designed, tested, and installed in the operating console. It will replace the Pace computer in some of the reactivity measurements.

A study has been made of reactor transients which result from various step and ramp inputs of reactivity. In addition, a study has been made of transients that result from depressurization of the reactor vessel and the resulting boiling processes in the core. These studies have been carried out on both analogue and digital computers.

Total Neutron Cross Section of Europium-151. The total neutron cross section of Eu^{151} has been measured in the energy interval from 0.08 ev to 1.00 ev by using samples of high isotopic purity. The double resonance that occurs at 0.321 and 0.460 ev has been analyzed by fitting the experimental values to the sum of two one-level Breit-Wigner expressions, after the usual corrections.

Sigma Center

Neutron Cross Section Compilation Group. The primary function of this group is the collection of cross section data and their presentation in compi-

lations such as BNL 325, *Neutron Cross Sections,* and BNL 400, *Neutron Cross Sections – Angular Distributions.* Most of the year was spent in reorganizing the cross section files, making literature searches, and answering inquiries about available cross section measurements. New editions of BNL 325 and BNL 400 are contemplated, and work has begun on organizing the data. Principal users of and contributors to these compilations were solicited for comments and suggestions as to the contents and format of the reports.

Reactor Cross Section Evaluation Group. Four *Newsletters* were issued, covering recently received data on various cross sections.

A survey and evaluation of all experimental neutron cross sections in zirconium was issued. Values of total, elastic scattering, nonelastic, capture, (n,p) (n,α), and $(n,2n)$ cross sections are given over the energy range 0.02 ev to $\approx$20 Mev. The results are generally given as "best" values.

A critical evaluation of η of U^{233} in the epithermal energy range was begun.

A general program for calculating fast neutron cross sections on the IBM 704 computer was developed and tested. The optical (or cloudy crystal ball) model, with spin-orbit interaction, is used in determining total and elastic scattering cross sections. A wide variety of well shapes, encompassing most of those suggested in recent years, is available. The transmission coefficients obtained from these scattering calculations are then used to calculate inelastic (and compound elastic) scattering by means of the theory of Hauser and Feshbach. Provision also exists for evaluating various integrals of optical model wave functions useful in calculating direct interaction processes such as (n,γ), (γ,n), and (n,p). The first applications will be to U^{238} and zirconium.

A measurement of the thermal capture cross section and resonance capture integral in Mo^{98} is under way. The literature gives discrepant values for both these quantities. Preliminary results indicate that the thermal capture cross section is $\approx$0.15 barns and the resonance capture integral is $\approx$5 barns.

Evaluation and Advanced Design Studies

At the time of the previous annual report three reactor concepts were at various stages of investigation. Since then the group has concentrated on the settled bed fuel concept, which includes the former laminar fluidized bed reactor. Common to both concepts is a fuel in particulate form which is in a settled or quiescent state during operation and is fluidized when it is to be mixed, removed from, or added to the system. The following reactors incorporating this principle were evaluated: a UO_2-Na thermal reactor, a Li^7-BeO thermal breeder reactor, and indirectly and directly cooled fast reactor systems. At present efforts are concentrated on the conceptual design of the fast reactor types.

Work on the evaluation of chemonuclear systems was completed during the year.

In the area of direct conversion, work is progressing on the pulsed fission plasma device and also on electrochemonuclear systems. Since these two approaches offer the potential of direct conversion of fission energy to electrical energy, they are being studied in preference to thermoelectric and thermionic systems, in which, as far as is known, fission energy must first be degraded to thermal energy.

During the year a considerable number of evaluation studies and special projects were undertaken for the AEC in Washington and for the New York Operations Office.

METALLURGY

Reactor and General Metallurgy

The reactor metallurgy program is concerned with the problems of containment of liquid metal coolants for nuclear reactors, the production of controlled composition alloys for research, the constitution of encapsulated nonrigid (slurry) fuels, and general consultation on materials throughout the Laboratory.

Materials for Containing Boiling Liquid Metals. Boiling liquid metals, especially Hg and Na, are currently of interest as working fluids in high-performance nuclear reactor–turbine systems for space applications. Three all-liquid Hg and six boiling Hg loops are being run to determine the effectiveness of Ti and Zr as inhibitors of Hg corrosion in systems fabricated of ferrous alloys. Radiography of the carbon steel loops used for all-liquid Hg after 6000 hr of operation at 1000° to 600°F indicates that both inhibitors are effective.

Radiography of two steel loops used for boiling Hg with Ti and Zr as inhibitors has shown slight deposition near the condenser liquid-vapor interface of both loops, and corrosion above the liquid level in the condenser of one loop. The boiling

loops are operating at 1000° to 1100°F boiler and 1125° to 1300°F superheater temperatures. A large boiling Hg loop capable of 100-ft/sec vapor velocity and 2 to 3-ft/sec liquid velocity (by thermal convection) has been placed in operation.

Materials for Containing Pb-Bi Eutectic. Carbon steel thermal convection loops containing Pb-Bi eutectic inhibited with Ti or Zr and operating at a temperature differential (ΔT) of 150°C (650° to 500°C) have not shown any corrosion or mass transfer after $\approx$5000 hr of operation. A 1¼ Cr – ½ Mo steel loop containing uninhibited Pb-Bi eutectic has operated for 9886 hr (as of May 15, 1961) at a ΔT of 200°C (400° to 200°C) without any sign of corrosion or mass transfer.

General Metallurgical Studies. Iron melts of high purity, containing $<$10 ppm each of carbon and oxygen, are being made routinely in a furnace of the "molecular still" type by keeping the temperature close to the melting point and the vacuum chamber continuously cold-trapped.

Nonrigid Fuels. The proposed fuel element would consist of a partly, or completely, molten metal alloy sealed in an impervious graphite container. Fuel alloys would be composed of fissile metals (U, Pu), fertile metals (Th, U), and low cross section, low melting metals (Bi, Pb, Sn).

Stability under temperature differentials: Capsule experiments were carried out in which alloys containing 5% Th+5% U, or 10% U, in Bi were held in stationary, horizontal, 9-in.-long graphite tubes under a ΔT of 530°C (800° to 270°C). Under these conditions, the alloys consisted of solid $ThBi_2$ or UBi_2 platelets dispersed in molten Bi solution. The Th and U were observed to migrate rapidly toward the cooler end of the container. This rapid migration was caused by dissolution mass transfer rather than mass transport of the solids, was accelerated by thermal convection currents in the liquid phase, and could be compartmentized by interposition of porous barriers. The rapid migration could be prevented by increasing the volume concentration of solids in the alloy to the point at which high viscosity minimized flow by thermal convection currents. Migration by diffusion could probably be compartmentized only by impervious barriers.

Behavior of inert fission product gases: Attempts were made to measure the rate of escape of Xe^{133} from the solid phase of irradiated liquid-plus-solid U alloys as a function of alloy composition and temperature. Sealed capsule measurements of the change in radioactivity from Xe^{133} in a void space above the alloy, made with a single-channel pulse-height analyzer, were unsuccessful because of insensitivity of the method to Xe^{133}.

Measurements made by periodic withdrawal of samples from the irradiated alloys during heat treatment were more successful. The rate of Xe^{133} release was measured at 800°C from 100-μ UBi_2 particles in alloys of $\approx$11.4% natural U in Bi irradiated to an integrated flux of 7200 and 14,400 neutrons/cm^2. In all cases, $>$90% of the Xe in the UBi_2 was released within 30 hr, probably because of isothermal particle growth which destroyed most of the solid particles present at the beginning of heat treatment. This effect was minimized by cooling a saturated U-Bi solution and then separating the solids from the excess liquid by filtration. Since platelets thus produced are single crystals $\approx$100 μ thick by 1 cm in diameter, having the (001) plane parallel to the plane of the platelet, it may be assumed that the measured Xe^{133} release occurs by diffusion in the [001] direction.

Results of experiments carried out at 800° and 700°C on specimens irradiated to an integrated flux of 7200 neutrons/cm^2 indicated a rapid release of Xe^{133} at both temperatures over a period of 24 to 50 hr, followed by release at much lower rates. The slower release yielded relatively constant diffusion coefficients of $(2.15 \pm 0.05) \times 10^{-12}$ cm^2/sec at 800°C and $(7.92 \pm 0.01) \times 10^{-13}$ cm^2/sec at 700°C, which indicates an activation energy for the slower release of 20,720 cal/mole. The initial rapid release of Xe^{133} may be caused by radiation damage and terminated by annealing out the damage during heat treatment. The more rapid rates, yielding diffusion coefficients higher by a factor of $\approx$20, may therefore be closer to those to be expected during irradiation.

High Flux Beam Research Reactor Metallurgy. The first of three prototype fuel elements for the HFBR has been irradiated to 40 to 50% burn-up in the ETR and is now cooling, prior to detailed examination. No marked changes were observed. This element contained 30 wt % U^{235} in Al+3% Si, clad with x-8001 Al, and was externally identical with the ETR element. It remained in the ETR for 5 cycles. The second and third elements, containing 35 and 40 wt % U^{235}, respectively, are currently being irradiated. Hot cell examination of all three elements will be performed by the Phillips Petroleum Company under the supervision of BNL personnel.

Examination of a Partially Melted Fuel Element. In January, a ruptured element from the BGRR was examined, and punchings were taken near the melted area. These revealed that an area of U segregation may have existed at the point of melting. The core-to-clad bond was satisfactory.

Alloy Theory and Nature of Solids

The general objective of this program is to study the structure of liquid and solid alloys and their interactions. In addition, the effects of fission fragment bombardment on metals are being investigated.

Structure of Liquid and Solid Alloys. Evaluation of the heats of solution of many solute metals in liquid Bi or Pb-Bi alloy suggests that the published relationship between the heat of solution and the ratio of the atomic radii of the solvent to solute metals is not valid. However, with a given solvent and within certain families of solute metals for which the electronic contribution would be expected to be similar, a consistent behavior has been observed, namely,

$$\frac{d(\Delta\bar{H})}{d(b/a)} = \approx 200 \text{ kcal},$$

where $\Delta\bar{H}$ is the partial molal heat of solution in kcal/g-atom of the solute metal; a is the Pauling radius (coordination number 12) of the solute metal; and b is ½ the nearest spacing of liquid Bi and Pb-Bi alloys, as determined by x-ray and neutron diffraction. Systems that apparently obey this relationship include Sr and Ba in Bi; Y, La, Th, and many rare earth metals in Bi; Fe and Ru in Bi; and Fe in Pb-Bi alloys.

Work has been started on a statistical approach to the theory of liquid alloys based upon the theory of significant structures in liquids. Experiments to test the validity of this approach are being performed. A quantum-chemical calculation of the bond strength in metals has also been initiated. Preliminary calculations of the bond strength in H_2^+ have yielded energies much closer to those measured than those obtained by more conventional approaches.

Liquid Metal Corrosion Fundamentals. Measurements of the Fe–liquid Bi thermocouple have shown that the emf generated between two pure Fe electrodes by the temperature differential in the Bi is extremely sensitive to the concentration of Fe in the Bi.

Reproducible ($\pm 25\%$) formation of ZrN-ZrC deposits on steel surfaces (that inhibit corrosion by liquid metals) can be achieved by restriction of the liquid Zr-Bi alloy to a narrow passage between two mechanically polished coupons. However, the number of experiments required to detect small differences in film formation properties is still large. The high concentration of Zr frequently found on steel surfaces in pitted areas has been shown by electron diffraction of stripped specimens to be ZrN and ZrC.

Observation of Fission Fragment Tracks in Thin Films. A fission event in a thin, vapor-deposited film produces distinct tracks, which are observable by electron microscopy. The tracks vary from light lines where the energy transfer is sufficient to vaporize the matrix metal atoms to dark lines where local melting is assumed to have occurred and rendered the film more dense in the region of the track. The phenomenon observed is a function of the film thickness and the atomic number of the metal in the film. Tracks in Pt films occasionally show an unexpected transition from one type to the other as the fission fragment energy is reduced. This is seen in Figure 1 as a contrast reversal from light to dark. Discontinuous deposition of U^{235} oxide on a thin Pt film permits more careful observation of the track of a single fission product. The "void" regions are seen in Figure 2 to be periodic, with an average center-to-center spacing of 200 A.

Radiation Effects

This program encompasses the study of the effects of neutron and fission fragment irradiation on corrosion by liquid alloy fuels and the mechanical properties of metals and alloys.

In-Pile Loop. The in-pile loop was constructed for use in studying the effects of fission recoils on mass transfer and corrosion of materials by inhibited U-Bi liquid alloy fuel. The loop was run with a ΔT of 75°C (500° to 425°C) for 3048 hr in the BGRR and was heated primarily by fission heat.

No visual evidence of corrosion of the many types of steel, graphite, Mo, and Ta samples was found. The loop piping was not completely wetted. Metallographic examination of the specimens is partially complete; to date, no definite evidence of corrosion has been found in any sample or weld.

Effects of Neutron Irradiation on the Properties of Body-Centered Cubic Metals. The effects of material and neutron variables on the mechanical properties of bcc metals and of pure iron, in par-

Figure 1. Micrograph showing a contrast reversal along tracks in platinum films >150 A thick.

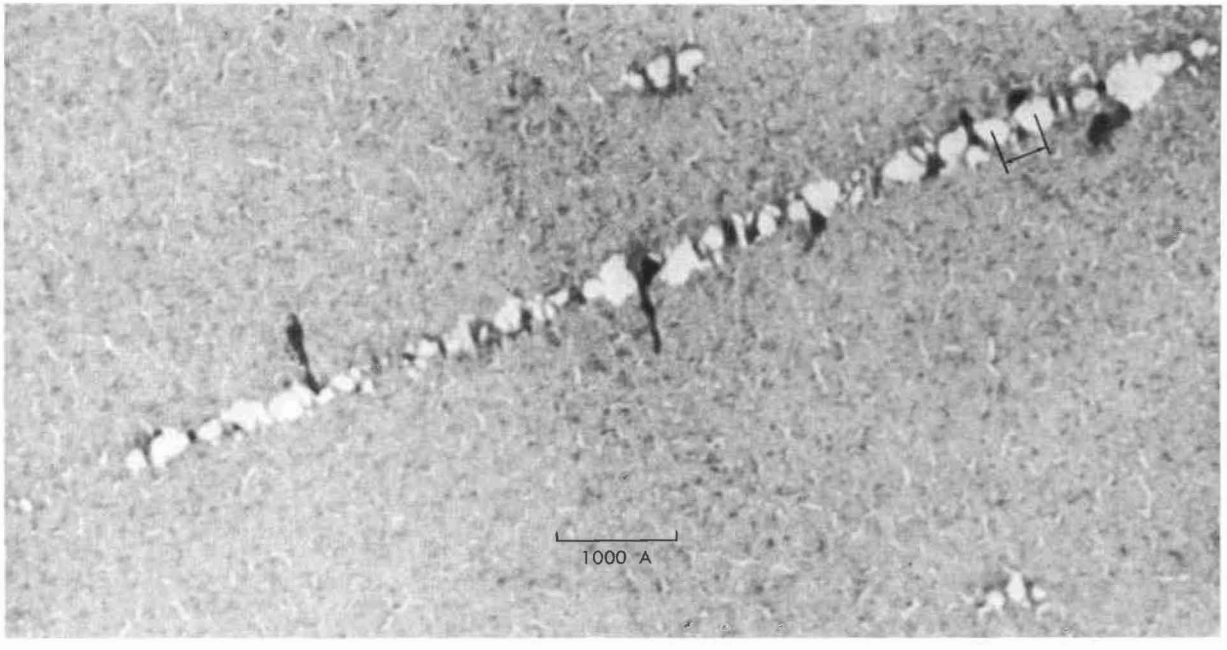


Figure 2. Micrograph illustrating the periodicity of damage sites along the fission fragment track in a platinum matrix. The two-headed arrow indicates an average spacing of 200 A.

ticular, are being studied by mechanical, metallographic, and electron-microscopic techniques at ambient to liquid He temperatures. With this information a mechanism for radiation-produced changes will be sought.

Results on cold-swaged and recrystallized Ferrovac "E" iron have shown that dosage up to 3×10^{18} nvt of fast (>1 Mev) neutrons has raised the transition temperature by $\approx$50°C, increased the yield strength, and lowered the strain hardening coefficient.

The increase in yield strength was found to be constant over a wide range of temperatures. The data indicate that essentially all the increase caused by irradiation is due to lattice hardening or frictional resistance to movement of dislocations. No irradiation-induced contribution to the source locking stresses was found.

Graphite and Ceramic Studies

The BNL graphite program includes studies of radiation and annealing-induced changes in the moderator structure of the BGRR, changes in the thermal conductivity and stored energy of several graphites with irradiation and annealing, and the parameters affecting oxidation and burning. The Brunauer-Emmett-Teller surface area, helium density, and porosimetry measurements are used to support these studies and others designed to determine mechanisms of graphite bonding under different high temperature conditions. A new program is under way to study the electrical and thermal changes in graphite irradiated at temperatures >800°C.

The present ceramic program includes studies on the diffusion of fission products in uranium carbides and uranium nitride.

BGRR Studies. The revised graphite annealing procedure for the BGRR which was initiated in May 1959 has consistently produced dimensional recoveries of >100% of the graphite growth between anneals. Increased frequency of annealing and longer "soak times" are thought to be responsible for this improvement.

Graphite Oxidation. Oxidation rates for AGOT cylinders (¼ in. diam ×2 in. long) machined from stock used in construction of the BGRR have been measured. The rates established at 400°C and 1-atm oxygen pressure vary from 1.2×10^{-9} to 2.8×10^{-9} g/cm²-sec.

Base oxidation rates (no treatment) and rates after water treatment are influenced by the position of the graphite sample in the original 4×4×24-in. block.

Graphite Burning Studies. The "burning" studies in channels have been completed, and the results are being published.

Ceramic Studies. Experiments to measure the diffusion of Xe^{133} from slightly irradiated uranium carbide powders are in progress. Results from a coarse powder (100 to 140 mesh) yield an activation energy for the process of $\approx$32 kcal/mole in the temperature range 680° to 1150°C. From a measured surface area of 0.25 m²/g for the powder, approximate diffusion coefficients can be estimated, ranging from 8×10^{-22} cm²/sec at 680°C to 2.5×10^{-19} cm²/sec at 1150°C. These coefficients are considerably lower than those obtained in earlier work on fission gas release from UC, and are also lower than most results for UO_2.

CHEMISTRY AND CHEMICAL TECHNOLOGY

Reactor Chemistry

Thermodynamics of High Temperature Systems. The determination of thermodynamic quantities by measurements of the emf of galvanic cells has continued and has been supplemented by a vapor pressure method. The system sodium-bismuth has been investigated by both methods, which give results in good agreement. In the vapor pressure experiments the procedure was to determine the boiling points of mixtures of varying composition,

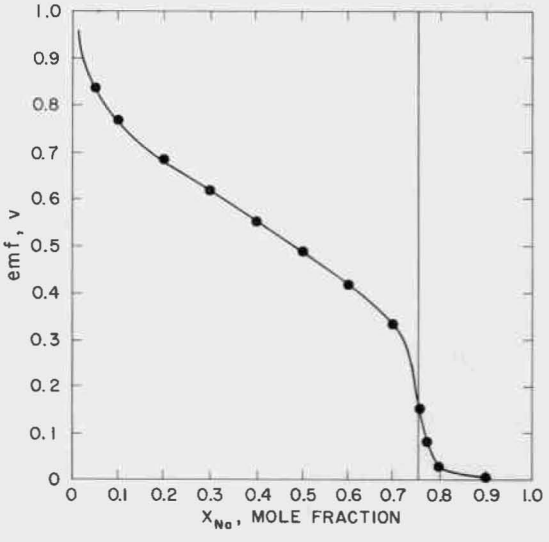


Figure 3. Emf of Na vs Na-Bi electrode concentration cells.

each at a number of different external pressures. Provided that sodium is the only constituent of the vapor phase and is almost entirely in the monatomic form, the equilibrium vapor pressure is proportional to its thermodynamic activity in the liquid. Figure 3 illustrates the results of both the previously reported cell measurements and the vapor pressure experiments. In this graph the ordinates are the emf's of electrode concentration cells with electrodes of pure sodium and of the alloys whose compositions are given by the abscissa. They are directly proportional to the partial molar free energies, $\bar{F}_{Na}$, of sodium in the alloys, the relation being

$$\bar{F}_{Na}=23{,}050\,E\,,$$

where $\bar{F}_{Na}$ is in standard calories and E is in volts. The points up to and including $X_{Na}=0.7$ were obtained directly from cells: for those above, the ordinate values are calculated from the vapor pressure results. The inflection at $X_{Na}=0.75$ is to be expected from the known existence of the stable intermediate phase Na_3Bi.

The thermodynamic properties of solid phases are also susceptible to the galvanic cell approach. In the past year a wide variety of cells containing thorium and thorium carbide electrodes have been made and tested, and one was finally found that appears to give an emf that is reproducible and is due to the desired cell reaction,

$$Th+2C\rightarrow ThC_2\,.$$

This is the cell

$$Th,\ ThF_4|CaF_2|ThF_4,\ ThC_2,\ C\,.$$

From it, the following values were obtained for the reaction at 800°C: $\Delta F=-29.6$ kcal/mole, $\Delta H=-37.35$ kcal/mole, and $\Delta S=-7.22$ cal/mole-°C.

Fluorocarbon Program. One of the main considerations in the important field of radiation chemistry is that of obtaining materials for study. Useful amounts of perfluorobenzene, perfluorobiphenyl, and perfluoronaphthalene, together with their alicyclic precursors, were obtained commercially from England after a long search. No source of supply was found for the perfluoroterphenyls, and a program to prepare them here is now under way.

In this synthetic work effort has been concentrated on fluorination of aromatic hydrocarbons by using the fluidized bed technique. Both CoF_3 beds and inert beds of alumina into which elemental fluorine is introduced have been used. The latter have been the more useful.

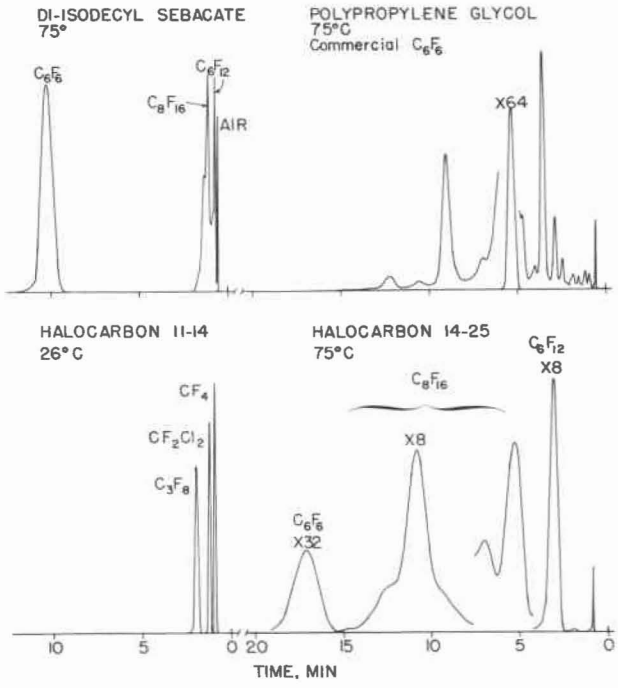


Figure 4. Gas-liquid chromatography of fluorocarbons: Some chromatograms of typical alicyclic and aromatic fluorocarbons showing effect of different column stationary phases on retention times. The alicyclic compounds have very short retention times with almost all stationary phases except halocarbon-type oils or waxes.

Radiation studies have been carried out on perfluorobenzene by using Co^{60} gamma-rays, Van de Graaff electrons, and the BGRR. G values for polymer and gas formation were somewhat higher than those obtained by Wall at the National Bureau of Standards, probably because of small amounts of impurities in the starting material. Methods have been worked out for purification of the three commericial perfluoroaromatics by using gas–liquid chromatography on a preparative scale.

Gas–liquid chromatography has been an indispensable tool in all the work involved in this program. A relatively large fraction of the total effort has gone into the development of chromatographic methods, and much more is required, particularly for high temperature applications. Figure 4 illustrates some of the results obtained at normal temperatures. Other techniques requiring development for analytical work include infrared spectrophotometry, mass spectrometry, elemental analysis, and molecular weight determination.

Radiochemical Analysis Development

Research and development work in the area of radiochemical analysis includes the following items of note.

Studies have continued on the synergistic effect of tri-*n*-octylamine (TOA) on the extraction of thorium by thenoyltrifluoroacetone (TTA) and have shown an effect apparently due to the thorium concentration which is inconsistent with the type of reactions postulated. Thus far, it has been shown that one molecule of the Th-TTA complex must be reacting to form two product molecules of equal concentration, but further work is required before the exact mechanism can be determined.

The molten eutectic of Li_2SO_4-K_2SO_4 was found to be a useful medium for electrochemical studies. Titration of Cl^-, released when the sulfate was passed through the Cl^- form of Dowex-1, readily gave accurate assays of the eutectic. Studies made with this medium have included coulometric versus direct potentiometric titrations, applicability of chronopotentiometry as an analytical tool in this medium, and the measurements of the standard potentials of four electrode systems relative to the Ag^+-Ag electrode.

The low-melting $LiNO_3$-KNO_3 eutectic as a medium for electrochemical studies offers the possibility of using mercury electrodes, and controlled-potential coulometry using a Ag-AgCl reference electrode is feasible in principle. However, in practice the combination nitrate-mercury melt sometimes gave rise to difficulties in the form of continuous current consumption due possibly to impurity-catalyzed oxidation of the amalgam, particularly when Cd^{++} is being determined. Polarography of copper in this eutectic using solid platinum needle electrodes rather than mercury electrodes established that the stable species is Cu^{++} in the absence of Cl^- but Cu^+ in the presence of Cl^-.

With the LiCl-KCl eutectic as a medium and a molten bismuth pool electrode, diffusion coefficients of zinc and lithium in bismuth and of Zn^{++} in the salt were determined. The controlled-potential coulometric stripping of 900 ppm U from molten U-Bi in this fused chloride eutectic was found to be accurate to within 2%.

Contact autoradiography of radioactive silver electrodes shows nonuniform rates of electrodeposition among different sites on an otherwise apparently uniform plane platinum electrode, which indicates that the rate of electrodeposition varied appreciably from one site to the next. Further investigation of this phenomenon may lead to a revision of the theory of electrode kinetics.

Preliminary studies of the adsorption of tellurium on alumina indicate that the mechanism probably proceeds via chemisorption rather than ion exchange.

Because visual observation of the end point is difficult in the conventional fluoride determination with thorium used as titrant and alizarin red S as indicator, a photometric method of end-point detection has been developed.

Radiation Chemistry Research

Solid State Polymerization. Considerations involving crystal geometry indicate that polymer molecules grow in a randomly oriented manner at an early stage of the polymerization. This implies that the polymer nucleates as a second phase at very low conversions. X-ray studies tend to bear this out (see Figure 5).

Electron spin resonance studies on acrylamide-propionamide solid solutions indicate that a radical or energy transfer mechanism may be operating in this system.

Graft Copolymer Studies. Studies were made on the radiation-initiated grafting of styrene to Mylar. This system was chosen because the Mylar could be hydrolyzed and the size of the grafted polystyrene chains determined. The grafting was

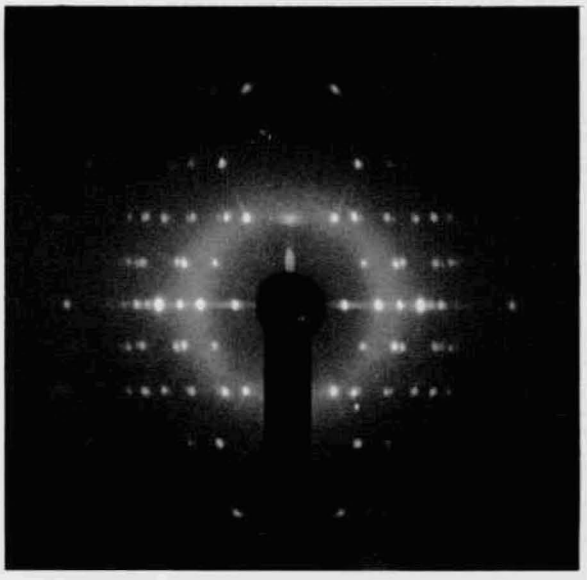


Figure 5. X-ray rotation diagram of a partially polymerized acrylamide crystal. The diffuse ring shows the polymer diffraction.

done by the vacuum preirradiation technique. Hydrolysis left a polystyrene residue with a number average molecular weight of 300,000.

Nylon Irradiation. The study of nylon irradiation by electron spin resonance techniques has been completed. At least two kinds of radicals can be detected. Kinetic measurements have been made on the radical decay. The results can be explained in terms of a free radical capable of migrating along the polymer chain by a hydrogen transfer mechanism.

Ionic Polymerization Studies. It has been found that the radiation-induced polymerization of α-methylstyrene is very sensitive to the presence of moisture. There seems to be an optimum water concentration which gives the maximum conversion of monomer per unit absorbed dose. Molecular weight determinations show that the polymer chains are of the order of 10 to 20 monomer units.

Radiolysis of Aromatics. The gas formed on toluene radiolysis is 90% hydrogen. The remainder appears to be methane. Among the radiolysis products diphenylmethane, dibenzyl, benzene, methylcyclohexane, and *n*-heptane have been identified.

Radioisotopes Development

The following partial list of accomplishments in the work of making available potentially useful isotopes illustrates the direction of the effort and some of the progress made.

Yttrium-90. Several improvements reducing the cost were made in the Y^{90} generator. The *p*H of 5.5 now being used was found to be the optimum for the Dowex-50 ion exchange separation of yttrium from strontium.

Calcium-47. The cross section for the $Ca^{48}(n,2n)Ca^{47}$ reaction was found to be $\approx$2 b for 14-Mev neutrons or about five times higher than calculated. A preliminary value for the cross section for 14-Mev neutrons for the $Ti^{50}(n,\alpha)Ca^{47}$ reaction was determined to be $\approx$22 mb. Attempts to effect a Szilard-Chalmers reaction for the preparation of Ca^{47} were abandoned after investigation of a number of possible targets failed to disclose a suitable one; no solvent could be found for calcium phthalocyanine, otherwise the most promising.

Iodine-124. The preparation of tens of millicuries of I^{124} via the $Sb^{121}(\alpha,n)I^{124}$ reaction can now be accomplished with little difficulty; the yields are good, and the radioisotopic purity is satisfactorily high. However, the product fails to iodinate protein for reasons that are still being sought.

Gallium-68. A very satisfactory procedure was developed for milking the 68-min positron-emitting Ga^{68} from its long-lived Ge^{68} parent. The method, which is rapid and simple, involves eluting the gallium as the EDTA complex from Ge^{68} adsorbed on alumina. Yields are reproducibly good ($\approx$67%), and product purity was well over 99.7% throughout the equivalent of 1000 milkings.

Magnesium-28. Highly enriched Mg^{26} was found to be superior to natural magnesium for the production of Mg^{28}. The use of Mg^{26} is economical, notwithstanding the high price of $3000 per gram, because of the small amount required for a unit (50 μC) of Mg^{28}. The enriched material increases the specific activity of the product more than 30-fold, which makes possible a simpler process and results in a product of considerably higher value to the user.

Scandium-48. A hitherto unreported gamma-ray of $\approx$160 kev has been found in the decay of Sc^{48}.

Lithium-6 Deuteride. A study of the fast neutron flux produced by reactor irradiation of Li^6D and comparison with fast neutron fluxes produced by similar irradiation of U^{235} and by Van de Graaff deuteron irradiation of ZrT_3 indicate that each of the three methods has features to recommend it.

Europium-155. Because of the high cross section (14,000 b) of Eu^{155}, this element must be continuously removed from the BGRR during its production by neutron irradiation of samarium. A method being developed for this purpose will involve controlled-potential coulometric reduction and precipitation as $EuSO_4$.

Plutonium-Beryllium Source. Preliminary experiments with a Pu-Be neutron source indicate that neutron attenuation by hydrogen-containing materials can be useful in the identification of organic compounds because it permits determination of their hydrogen contents to within at least 0.2%.

Processed Isotope Production. During the year the first off-site shipment of 6-hr Tc^{99m} was made, and 21-hr I^{133} was shipped abroad (to Stockholm) for the first time. Y^{90} (65-hr) generators were made available to customers, and two were shipped to Japan. Shipments of 21-hr Mg^{28} to France and 2.3-hr I^{132} to Australia were also made. In addition, the isotopes supplied domestically increased in quantity and variety. Demand

for Mg^{28} increased markedly during the latter half of the fiscal year, possibly as a result of the greatly improved product brought about by the use of enriched Mg^{26}. However, in the first half of the year a combination of circumstances beyond our control forced cancellation of a number of shipments, which resulted in a net decrease in sales of this isotope. Prices of all processed isotopes in routine production were reviewed and adjusted in order to make this service self-supporting. A catalogue describing these isotopes has now been published.

Chemonuclear Processes Research

The following systems are under investigation.

1. The production of carbon monoxide from carbon dioxide is of interest in connection with fission fragment processes either for chemical production or for power conversion cycles using fuel cells. The experimental work in a gamma field has indicated small decreases in G value for carbon monoxide formation at increasing pressures and large decreases with increasing temperatures when nitrogen dioxide is used as a catalyst or inhibitor. G_{CO} values of around 5, which is half the value reported when fission fragment radiation is used, have been obtained.

2. The kinetics of ethylene is being studied. An induction period has been found. At 3700 psig, 40°C, and 13,100 rad/hr, an over-all G value for polymer formation of 2400 and a maximum differential G value of 3000 have been obtained. Attempts are being made to characterize and evaluate the product, which is a white powder.

3. The formation of hydrazine from aqueous and anhydrous ammonia is being studied. Irradiation in glass-lined vessels indicates increasing G values with ammonia concentration. Hydroxylamine and a third unidentified component have been detected. The quantity of decomposed ammonia is being determined.

4. The formation of nitrate from ammonia and oxygen in a radiation field is being studied in line with the use of cobalt-60 gamma radiation as a catalyst. Ammonium nitrate has been formed with a G value of up to 3.

5. The formation of uranium carbide from reduced uranium and hydrocarbons is under investigation. The G values increase with increasing temperature.

Studies of partial oxidation, polymerization, and metal deposition will be pursued in the future in the radiation processing program.

In the chemonuclear experimental program, an in-pile loop is being designed for installation in the BGRR for study of fission fragment chemistry, fuel element efficiency, and contamination problems.

High Temperature Technology

High Temperature Physical Property Measurements. This program is concerned with the measurement of the physical properties of refractory nuclear fuel materials at temperatures >1000°C. The General Electric XRD-5 diffractometer, together with the high temperature x-ray diffraction camera obtained from the Materials Research Corporation, has been assembled and installed. Modifications to improve the electronic, thermal, and vacuum stability of the equipment were made. X-ray measurements have been made on platinum and thoria in air up to a temperature of 1500°C. From the measured lattice parameters the thermal expansion coefficient was calculated over this temperature range for platinum and was found to agree accurately with literature values. The coefficient of expansion for ThO_2 is in the process of being computed; no phase or anomalous behavior is indicated. The tantalum heating element used in the high temperature x-ray camera was improved and successfulyy tested in vacuum up to a temperature of 2200°C.

Release of Fission Products From Fuel Elements. The diffusion of iodine through 2S aluminum was studied, with emphasis on the effect of temperatures analogous to those occurring during a reactor temperature excursion. Iodine does not diffuse through 0.035-in. aluminum in the temperature range 300° to 500°C. Results indicate that iodine may penetrate aluminum by what is essentially a corrosion mechanism if sufficient quantities are present to sustain the chemical reaction.

Preliminary experiments indicate that tellurium diffuses through aluminum.

The release of fission products from an irradiated U-Mo fuel was investigated in the temperature range 1100° to 1450°C for melt times up to 30 min. Released iodine and uranium were found in the cold zones adjacent to the melted fuel, but no definite I/U ratio was found to exist. The percentage of iodine released is strongly temperature dependent. Experimental evidence indicates that Te^{131} and I^{131} are released independently, i.e., I^{131} does not result from the decay after release of its precursor, Te^{131}; the same is true of Ba^{140} and La^{140}.

Sorption and Diffusion of Fission Products in High Temperature Materials. The quantities of xenon taken up by type R-4 high density graphite in contact with xenon gas at 750° and 1000°C have been measured, and the results have been published in a BNL report.

A beginning has been made on the study of the sorption and diffusion of iodine through graphite. The technique is to equilibrate a graphite sample with iodine vapor and subsequently measure the concentrations of iodine in the graphite. Initial experiments indicate that at 1000°C and 22.3 mm Hg pressure the type R-4 graphite will take up 100 to 300 μg iodine per g graphite in a 6-hr equilibration.

A tracer technique utilizing I^{131} has been developed whereby the concentrations of iodine in the graphite can be measured directly by means of a scintillation probe. A series of six isobars from a single sample has been obtained in the pressure range from 1 mm Hg to 40 mm Hg and in the temperature range from 475° to 725°K.

Fuel Reprocessing

Reprocessing Reactor Fuels by Volatilization Through the Use of Inert Fluidized Beds. One of the major problems in the development of methods for reprocessing spent reactor fuels by volatilization is the high rate of heat production in the exothermic reaction between the gases and the solid fuel elements. An investigation of the use of fluidized beds of inert material primarily as heat conducting media for carrying out these reactions has been under way at BNL for about three years.

During the past year the major effort has been centered on obtaining high recovery of uranium from U-Zr submarine-type fuel. The experimental procedure consists of hydrochlorination (350° to 450°C) of a sample coupon obtained from an unirradiated fuel element in a fluidized bed of granular Al_2O_3, followed by fluorination of the bed at $\approx$450°C and recovery of the evolved UF_6. Although optimum conditions for uranium recovery have not yet been established, acceptable uranium recoveries (98.4%) have been obtained by using the same bed for a number of cycles.

In addition, a program has been initiated to investigate the reaction between stainless steel and chlorine gas, with a view to developing a method for decladding stainless steel-clad fuel elements. Results have shown that a temperature of $\approx$600°C is necessary before the reaction will proceed at practical rates. At this temperature chlorine presents a serious corrosion problem. However, although a fluidized bed is a good heat conductor, the same bed in the settled state is a good heat insulator, and it should be possible to establish an appreciable temperature gradient between the reaction zone located in the central region of a settled bed and the container vessel walls. Several experiments have shown that such a system is possible and that temperature differentials of 150°C can be established between the reactor wall and the central portion of the bed in a 1½-in.-diameter vessel. Chlorinations of stainless steel coupons have been carried out under these conditions with no apparent damage to the nickel vessel and with reaction rates up to 2000 mg/cm²-hr.

Nitrofluor Volatility Process. The Nitrofluor process for treating spent reactor fuels is based on fuel dissolution in hydrogen fluoride solutions containing dinitrogen tetroxide, and final recovery of the uranium and plutonium as their volatile hexafluorides. Laboratory-scale studies have shown that this new solvent system is capable of dissolving nearly all current reactor fuel materials, the notable exceptions being thorium metal and thorium oxide ceramic fuel.

The process is being developed for both enriched U-Zr alloy fuel (Naval fuel) and uranium dioxide power reactor fuel. Small parallel-plate assemblies of the alloy fuel were dissolved in a readily controlled manner, and it is estimated that a full-scale fuel element will dissolve in $\approx$1 hr. The factors affecting uranium recovery are being studied, and high recovery was obtained in some experiments.

Uranium dioxide fuel with stainless steel cladding was dissolved in $\approx$6 hr. High plutonium recovery was obtained in microgram-scale experiments with a synthetic U-Pu alloy. The reduced recovery experienced in the case of zirconium-clad fuel requires further study.

Fission product behavior during fuel dissolution was examined by using a prepared uranium alloy containing nine representative fission product elements. It was found that 50% of the fission product activity could be expected to precipitate during the dissolution of uranium dioxide fuel and that up to 90% could precipitate in the case of enriched U-Zr alloy fuel. In each case the remaining activity accumulated in an evaporator vessel and was combined with the above solid waste.

Monel metal was found to be a satisfactory material of construction for some of the process steps;

however, a more resistant material will probably be required for operations involving solution evaporation, salt decomposition, and vapor condensation. Several promising means of reducing corrosion to tolerable amounts are being investigated.

A preliminary economic evaluation of the Nitrofluor process showed that it is in the competitive range, largely because equipment sizes and waste volumes are smaller. Another advantage is that the process is suitable for treating several types of fuel.

Phosfluor Process. This new process is based upon the use of monofluorophosphoric acid as a solvent for treating thorium oxide and beryllium oxide ceramic fuels. After fuel dissolution, one of several alternative methods of recovering uranium is used prior to recovering thorium by a solvent extraction step. Fuel dissolution rates in this new solvent were $\approx$10 times as great as those obtainable in present processes. Monofluorophosphoric acid also dissolved thorium, uranium, uranium carbide, zirconium, and stainless steel. Much more experimental work is required to develop the best intermediate process steps.

Preparation of Tetravalent Solutions. A method of preparing uranous nitrate solutions has been developed, based on precipitation of uranyl sulfide by reaction of uranyl nitrate with ammonium sulfide, decomposition of the uranyl sulfide to UO_2 and sulfur by digestion at 40°C, filtration, dissolution of the UO_2 in 4 to 6 *M* HNO_3 at 60°C, and filtration. The decomposition requires 1 hr, and a 1-hr dissolution yields a solution 0.5 *M* in total uranium, 71% tetravalent.

Radiation Engineering

Cobalt-60 Low-Level Dose Distribution Studies. A FORTRAN program was written for the IBM 704 which will compute dose due to uncollided flux from disc sources in an infinite homogeneous target at any point in the target. These calculations are being used to compute experimental build-up factors for systems of similar geometry.

Experimental dose distributions from Co^{60} in water targets have been measured and plotted. An anthracene scintillation dosimeter and a condenser-type ionization chamber in conjunction with a precision X-Y-Z positioner and water tank were used to obtain this information (Figure 6).

Heterogeneous Target. Heterogeneous targets have been designed and assembled to study the effect of discontinuities on dose distribution. The targets consist of arrays of cylinders and spheres of various sizes.

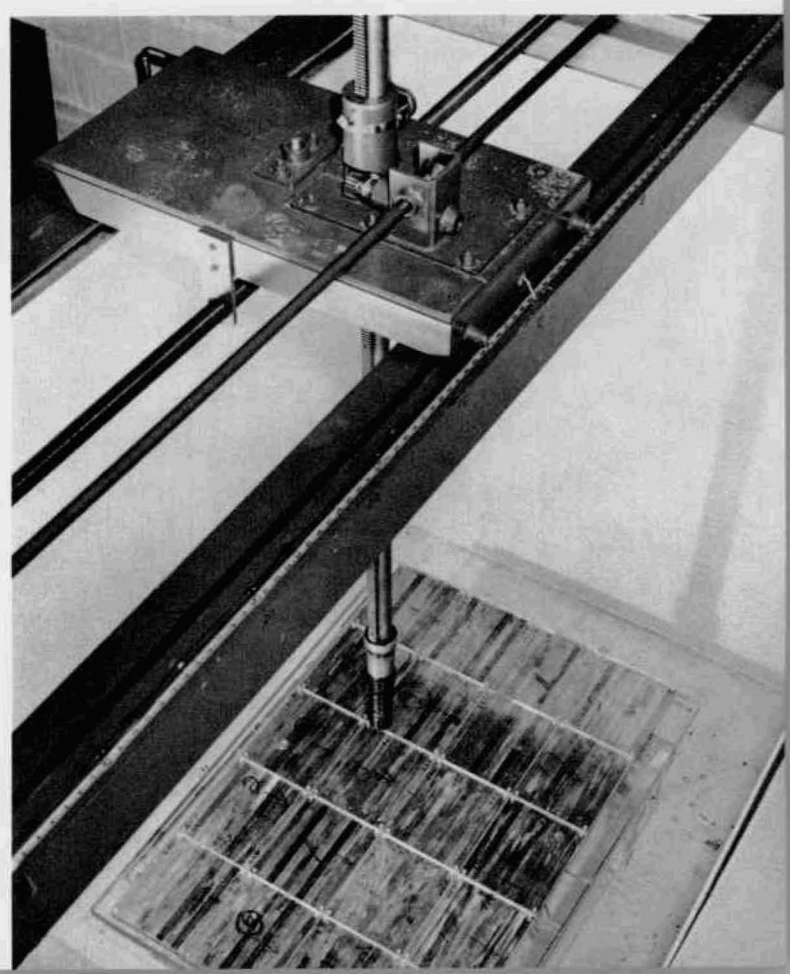
Source Element Geometry. Dose patterns and flux from sources of various shapes (cylinders, rods, rectangular strips) are being studied. The relative merits of these source elements are being compared with regard to efficiency, safety, and cost with a view to the possibility of making one or two shapes standard for routine use.

Conceptual Design Studies. At the request of the Office of Isotopes Development of the AEC, a study was made of conceptual irradiator designs for use in pasteurization of food.

Heat Transfer Studies. Approximately 550,000 curies of Co^{60} have been received from the ETR. These sources will eventually be used in the High Intensity Radiation Development Laboratory. In the interim they will be used at the gamma irradiation laboratory for experiments on heat transfer and radiation corrosion.

Several *in situ* experiments have been run to investigate the removal of gamma heat from a 7-ton Co^{60} shipping container used to ship sources from ETR to BNL. A loading of $\approx$83,000 curies was employed; sufficient temperature instrumentation was included to determine the safety of the con-

Figure 6. X-Y-Z positioner.



tainer under various shipping conditions and to characterize the important factors governing heat removal.

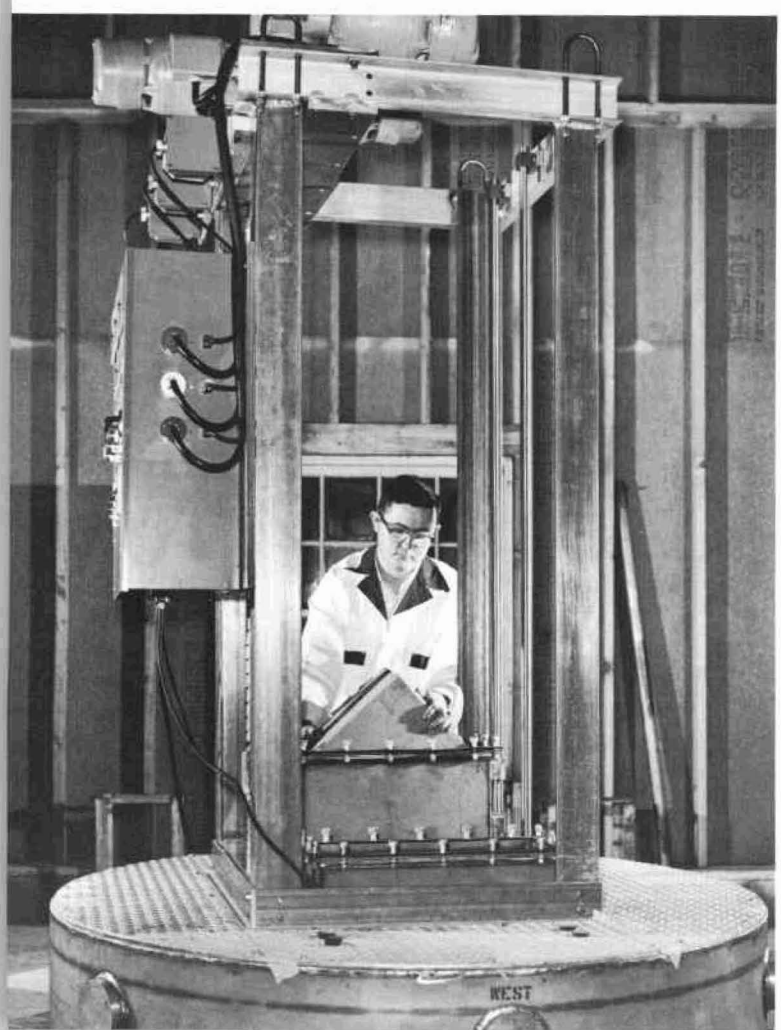
Research Irradiator Project. A research irradiator (Figure 7) has been built and tested at BNL and installed at MIT in the Department of Food Technology. Contracts have been let for the fabrication of two similar units. One will be installed at the University of California College of Agriculture in Davis, and the other at the University of Washington College of Fisheries in Seattle. The Co^{60} source material for these units is currently being encapsulated at Oak Ridge, Tenn.

Liquid Metal Heat Transfer Research

Nearly all the heat transfer research at BNL in recent years has dealt with liquid metal media, and most of the experimental work has involved the flow of mercury through rod bundles to simulate shell-side conditions in shell-and-tube heat exchangers.

Late in the fall of 1960, an improved mercury heat transfer loop was placed in operation. The test bundle in this loop contains 13 rods, the central one being the only one on which data have yet been taken. It is especially constructed for this purpose and from a heat transfer standpoint is considered to be representative of a tube in the interior of a tube bank of commercial size.

Figure 7. Co^{60} research food irradiator.



To date, four different test elements have been tested, and the results are shown in Figure 8. Test rods Nos. 1 and 2 were chromium plated and therefore unwetted, while test rods Nos. 3 and 3A were copper-nickel plated and therefore wetted. At the lower Peclet numbers all the results are seen to be in substantial agreement, but at the higher numbers the spread in the curves is significant. On the other hand, the agreement with theory is better at the higher Peclet numbers, which seems to be generally true of liquid metal heat transfer results. As mercury data go, the duplicability of these results is fairly satisfactory. They represent the best data available for design purposes. The meanings of the symbols in Figure 8 are as follows:

Nusselt number $= hD_e/k$
h = heat transfer coefficient
D = outside diameter of rods
D_e = equivalent diameter of bundle
k = conductivity of liquid metal
Peclet number $= D_e v \rho C_p/k$
v = average linear velocity
L = axial length through bundle
ρ = density of liquid metal
P = distance between rod centers
C_p = heat capacity

Heater 3, being wetted, suffered attack by the mercury. Its surface was ground down slightly, new nickel and copper platings were added, and it was thereafter known as 3A. Why the results for heater 3A fell slightly above those for heater 3 is not definitely known, but presumably it was due to reworking.

On the basis of considerable evidence collected at BNL, forced-convection, single-phase heat transfer coefficients for wetted and unwetted surfaces are not significantly different, as long as there is no entrained or occluded gas and the system is clean.

During the year, a loop was built for the purpose of measuring heat transfer rates to alkali metals flowing through rod bundles. This information is pertinent to the design of heat transfer equipment and of reactors that are cooled with liquid metals. The loop will be operated with both sodium and NaK at temperatures approaching 1000°F. The first data will probably be taken on this equipment in September.

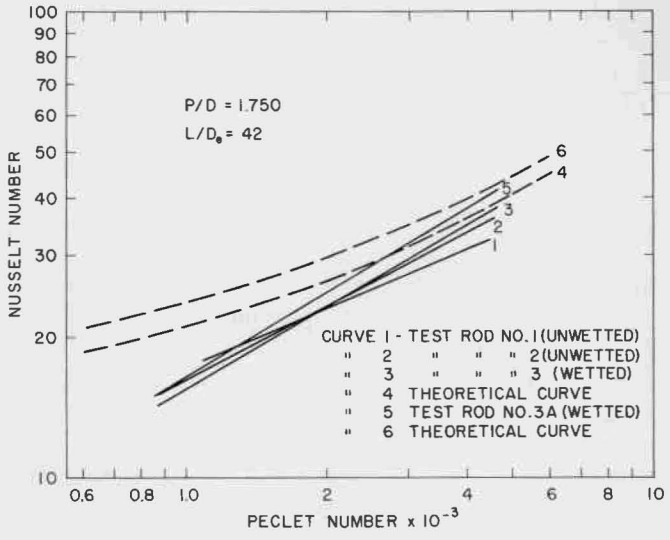


Figure 8. Heat transfer rates to parallel and turbulent flow of mercury through unbaffled rod bundles. Curve 4 from Dwyer and Tu, *Chem. Eng. Progr. Symposium Ser.* **56**, No. 30, 183-93 (1960); curve 6 from Friedland and Bonilla, *A.I.Ch.E. Journal* **7**, 107-12 (1961).

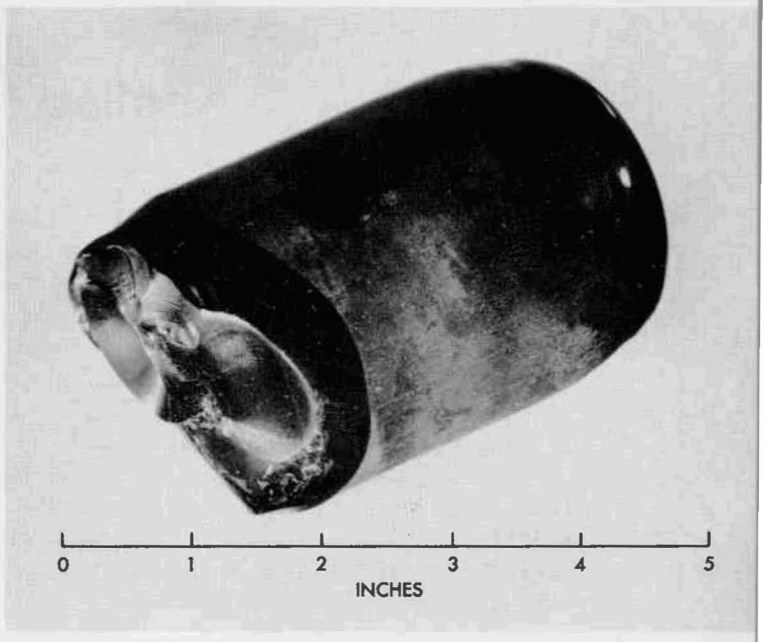


Figure 9. Phosphate glass cylinder made from simulated Purex waste.

Another loop has been designed and will be built to obtain fundamental heat transfer information for the design of boilers and condensers for auxiliary power plants for space vehicles using alkali metals as working fluids. This loop will be operated with potassium at temperatures up to 1800°F.

Ultimate Waste Disposal

The development of a process for the incorporation of fission products into phosphate glasses was initiated at BNL during the past year and promises to result in a simple and effective method of disposing of high level radioactive wastes. Of primary interest are the advantages to be gained from carrying out the entire conversion from the raw aqueous wastes to the final stable glass product, up to the point of cooling, in an all-liquid system. In particular, this method of disposal lends itself readily to the development of a continuous process in which the liquid media would be transferred by gravity flow from one temperature step to another (two temperature zones may be sufficient). The use of an all-liquid system and separate temperature stages would minimize problems associated with heat input, removal of decomposition gases, and handling or manipulation of the process materials, and no mechanical devices or moving parts would be required. Two alternative schemes are indicated at present, i.e., a semicontinuous process in which the molten glass would be formed directly in individual final storage containers, and a fully continuous process in which the glass would be formed in a central crucible and fed to storage containers.

The types of wastes that appear to be most suitable for incorporation into phosphate glasses are those of relatively low salt content such as Purex and Darex. Studies to date have been centered on the processing of Purex-type solutions with varying concentrations of iron, aluminum, and sodium. A cylinder of phosphate glass recently made on a semicontinuous basis from simulated Purex waste is shown in Figure 9.

Phosphate glasses made from simulated Purex waste (Hanford 1WW) and spiked with Sr^{90} and Ce^{144} were ground to a particle size of $\approx$0.42 mm and subjected to leaching in HNO_3 (pH 4) and in distilled H_2O. The leaching values compare favorably with results obtained from studies on other glasses and are of the order of one part of strontium or cesium leached per week per million parts contained in the glass. This quantity may be interpreted as a penetration rate which would decrease proportionately as the radius of the sample increased.

Corrosion tests have indicated that high density alumina shows considerable promise as a material of construction for the furnace crucible.

Applied Mathematics

The Applied Mathematics Division, of relatively recent origin at Brookhaven National Laboratory, has been reorganized during the past year and is undergoing rapid expansion. The Division has a twofold but integrated responsibility: to initiate and develop research in areas of mathematics consistent with the over-all program of the Laboratory, and to provide assistance in the mathematical aspects of the work in the natural and life sciences. The Division is primarily, although not exclusively, oriented toward those areas of research in which large-scale digital computers serve as a basic research instrument.

PROGRAMMING RESEARCH AND PREPARATION

An IBM 7090 computer is to be installed on site toward the end of the calendar year as part of a program to meet the Laboratory's increasing need for computational services. Since this computer differs radically from the IBM 704 in several respects, programs for all the problems currently being run on the IBM 704 at the New York University–Atomic Energy Commission Computing Facility must be rewritten. Since January the members of the Division have been actively engaged in this work and also in advising computer users outside the Division on the problems involved in working with a different computer. Attention has been directed in a number of cases toward improving the mathematical methods used with a view to achieving greater accuracy and shorter running time.

Much effort has also been devoted to the assembly of a library of new programs and subroutines. Here other AEC Laboratories with previous experience on the IBM 7090 have been most helpful. In addition, use has been made of SHARE (IBM users' organization), and one member of the staff, as a representative in SHARE, is actively concerned with advising IBM on the rewriting of the 7090 FORTRAN program. Considerable effort also has gone into the preparation of a 7090 monitor system suitable for the varied computational problems encountered at the Laboratory.

RESEARCH ACTIVITIES

In the area of mathematics, a calculational method was devised for the determination of a set of nonlinear parameters of a class of functions from a given data function involving a single variable. The method consists of obtaining a sequence of functions of several variables for each of the parameters, which converge to the solution value of the parameters. The data functions at predetermined values of the arguments appear as variables of the sequence of functions. However, since these functions depend only on the form of the original function involving the parameters and not on the data function used, the parameters may be calculated for new data without a recalculation of the sequence of functions. The method will be used for the analysis of x-ray diffraction data.

Work on the Monte Carlo calculation of high energy nuclear reactions mentioned in last year's report is still in progress. A sampling technique was devised which not only facilitates the calculation but also makes possible the introduction of more realistic nuclear models than those used in older calculations. A computer program is being prepared for the Brookhaven IBM 7090.

Work was also initiated to determine the feasibility of performing a complete Feynman diagram calculation in quantum electrodynamics by use of digital computers. The ultimate purpose of this work is to prepare a computer program that accepts a minimal set of input, such as specification of the external lines and the maximum order of the graphs to be considered, and produces as output the cross sections or amplitudes related to these graphs. A method of enumerating a restricted class of graphs has been found, and work is in progress to discover a more general procedure.

Theoretical work on internal symmetries of strong interactions was also carried out. It was found that the four-dimensional symmetry first discussed by Gell-Mann and Pais, which introduces selection rules stronger than those implied by interaction invariant in the isotopic spin space, may be broken to give rise to reaction amplitudes not in disagreement with experiment.

LIFE SCIENCES

Biology

The activities of the Biology Department center on the special facilities of the Laboratory and include studies of the biological effects of radiation and the use of isotopes for the elucidation of basic problems in biology. In general, problems are being investigated by the methods of molecular biology. The growth of the Department has been increasingly in the direction of this approach to biology and has involved studies on protein structure, enzyme kinetics, the molecular structure and function of antibodies, the molecular structure of chromosomes and its relation to the mutation process, etc. These concepts and techniques have found immediate application in such pressing problems as the nature of radiation-induced mutations, the intimate nature of the mechanism of radiation damage in plants and animals, and the details of the basic reactions involved in photosynthesis.

Each year the Department sponsors a symposium on a topic of current interest in biology. This year the symposium, entitled *Fundamental Aspects of Radiosensitivity,* was attended by 103 scientists in addition to members of the Brookhaven laboratory staff, and will be published as the 14th volume in the Brookhaven Symposia series.

This report briefly indicates major areas of research and some findings made during the year.

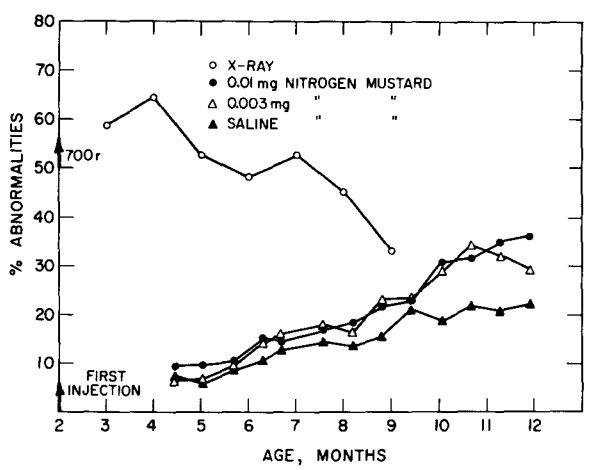


Figure 1. Abnormalities in regenerating liver cells as a function of age for normal mice, for mice receiving large doses of nitrogen mustard three times a week, and for mice receiving a single dose of x-rays. These curves show that chromosome abnormalities may play an important part in the mechanism of both natural and radiation-induced aging, and that the role of nitrogen mustard in aging is not significant.

MAMMALIAN PHYSIOLOGY

Radiation-Induced Aging

Radiation-induced aging, the decrease in life expectancy of animals caused by radiation, resembles natural aging. Both kinds of aging are being studied in order to establish the mechanisms involved and to determine the relationship between the two processes. It has been postulated that aging results from accumulative effects of nonspecific stresses. Tests of this possibility in mice subjected to a wide variety of stresses other than radiation have indicated that stress *per se* does not decrease life expectancy. Thus, radiation appears to differ from other stresses in that it uniquely shortens life. It has been suggested that aging results from the accumulation of viable mutations in the somatic cells of the body. Since radiation is a mutagenic agent, the phenomenon of radiation-induced aging supports this hypothesis. However, nitrogen mustard, a chemical mutagen, was found not to shorten the life span, which argues against the mutation hypothesis. Direct test of these arguments has now been made for liver based on the assumption that chromosome aberrations are proportional to somatic mutations. Results indicate that the number of chromosome abnormalities increases linearly as the animal grows older. The increase is only slightly greater in animals given periodic doses of nitrogen mustard than in controls. In contrast, following a single dose of x-rays a high proportion of cells show chromosome abnormalities, which decline $<50\%$ over a six-month period. Insofar as such abnormalities in liver cells are indicative of somatic mutations, it appears that mutations do play a significant but not necessarily decisive role in natural and radiation-induced aging.

The decrease in the ability of an organ to repair itself following injury as the animal grows older

may be taken as a measure of the physiological age of the animal. Based on this principle the hypertrophy of one kidney after removal of the other is being evaluated in mice as a function of age and irradiation. Results to date are not conclusive, but indications are that radiation interferes with kidney hyperplasia to some extent in mice of all ages even though the radiation was administered while the mice were very young.

Effects on the Central Nervous System of Localized Irradiation

Unavoidable exposure of the human central nervous system to irradiation for therapeutic reasons, e.g., the treatment of spinal and brain tumors, is associated with considerable hazard. After an unpredictable latent period of months or years, clinical signs and symptoms of radiation injury may appear, followed by paralysis and death. Further understanding of the nature of the injury is being sought through study of experimental animals subjected to localized x-irradiation of the central nervous system. Findings are as follows: In rats and monkeys exposure of selected portions of the spinal cord to 3500 rad gave rise, after a latent period of 5 to 9 months, to incontinence, weakness of the hind legs, and posterior paralysis. The findings are comparable to those observed in man. The pathologic basis for the clinical picture is a severe softening of the white matter of the spinal cord in the irradiated area. It is not clear whether the lesion represents a direct effect of radiation on white matter or is secondary to capillary damage and consequent lack of oxygen and nutrient. In a series of young monkeys, irradiation over a portion of a cerebral hemisphere resulted, after a latent period of some three months, in noteworthy changes in the electroencephalogram. One animal had epileptic seizures; another had visual disturbances on the side irradiated; and all exhibited motor weakness on the opposite side. These animals have been sacrificed, and the nervous tissue is being examined by a variety of techniques to define the areas of injury and the nature of the pathologic damage.

Cell Population Kinetics

Evolution of radiation effects within a dynamic cell system is determined to a marked extent by the kinetics of the system, i.e., the rates of proliferation, maturation, and decay of cells, or, in more general terms, the rates of transition of cells from one state to another. Thus, to define radiation effects a reasonably precise description of normal kinetics is required. Such information has been obtained for fast-growing cell systems: intestinal epithelium, growing hair follicles, and the vagina in estrus. In all these systems the duration of DNA synthesis was about the same, although other parameters differed. To determine whether deoxyribonucleic acid (DNA) synthesis time is a constant, a slow-growing system, the epidermis of the ear, was examined. In this system synthesis took about four times as long as in the others; thus the time required for DNA synthesis in organized systems is not invariant.

In the isolated rat femur perfused with blood treated in various ways, the release of leucocytes from the femur was found to be proportional to the rate of blood flow and dependent upon the number of leucocytes in the perfusing blood. Blood flow through the femur was specifically increased by a leucocytosis-promoting factor.

Deoxyribonucleic Acid Synthesis

Irradiation with small doses (100 rad or less) reduces incorporation of radioactive precursors into the DNA of proliferating cells. The effect represents a complex, one major component of which involves cells in the process of DNA synthesis. It is striking that the effect is found in all tissues studied in the intact animal treated with small to moderate doses of radiation, but is found in bacteria and cell cultures only with much higher doses. The reduced incorporation of precursors into DNA could be due to a number of mechanisms including reduced efficiency of transport of administered labeled precursors, flooding of the metabolic pool by precursors, increased breakdown of precursors, or reduced rate of DNA synthesis. To test for the nature of the phenomenon the effect has been studied under a wide range of conditions – various kinds and doses of labeled precursors, singly and in competition with unlabeled precursors, given at various times after a range of levels of radiation. It appears now almost certain that a true reduction in the rate of DNA synthesis occurs. If further work supports this, it will be pertinent to determine why the effect occurs in organized cell systems but not in isolated cells and whether there are correlations between this metabolic effect of radiation and cytogenetic effects.

Hormonal Control of Glucose Metabolism

Work in this area concerns the regulation of blood sugar level and particularly the mechanism of insulin action. The question of whether insulin directly causes the liver to reduce the amount of glucose it puts into the circulating blood is important because of the implications of the answer with regard to (1) the sensing mechanism of blood glucose concentration, and (2) the action of insulin at the molecular level.

Administration of phloridzin is known to cause leakage of glucose from blood into urine and simultaneous breakdown of liver glycogen. In early stages of phloridzin poisoning these events take place with no noticeable change in blood glucose concentration; hence at first glance it is not clear that breakdown of liver glycogen to furnish more glucose results from glucose loss by way of the kidney. However, if the kidneys are removed from the circulation or glucose lost from the blood through the kidneys is replaced, breakdown of liver glycogen does not occur. In the phloridzinized animal studied with the aid of C^{14}-glucose, the amount of glucose produced by liver clearly increases during the period of glycogen breakdown. It would seem that the increased glucose production results from operation of a sensing device for glucose concentration so sensitive that it reacts to a fall in blood glucose level not observable by chemical analysis. Intravenous infusion of insulin at this time results, as usual, in a decline in blood glucose concentration, but the C^{14}-glucose method reveals that the insulin infusion abruptly *stops* the extra production of glucose by liver induced by the phloridzin. This inhibiting action of insulin on glucose output by liver is similar to that seen in the control animal in which the demand for extra glucose output brought on by hypoglycemia is partly suppressed until insulin infusion is stopped. There are two alternative hypothetical explanations for the action of insulin on glucose output by liver. Insulin may act directly in the hepatic cell to inhibit glucose production, or it may stop the glucose-sensing mechanism from sending messages to the liver to increase glucose production.

One action of insulin that approaches the molecular level is now well established: insulin facilitates transport of glucose across the membranes of the cells of a number of tissues. If the sensing element for blood glucose concentration is inside a membrane whose glucose-transporting ability is similarly increased by insulin, then obviously exogenous insulin would cause the sensing element to overestimate the glucose at any given blood sugar level and, in the case of the phloridzin-treated animal, to estimate a normal blood sugar level instead of the slightly lowered level actually present. According to this hypothesis, the sensing element would therefore stop sending messages to the liver calling for more glucose.

The other alternative, i.e., that insulin acts directly on the hepatic cell to decrease its glucose output, has been partially tested with the C^{14}-glucose technique by intravenous infusion of both insulin and glucagon. Results are still inconclusive.

Other lines of evidence being developed point to actions of insulin in the cell independent of effect on glucose transport. If such actions are established, it may be that a single primary action causes both the increased transport of glucose through the cell membrane in peripheral tissue cells and a decreased production of glucose by hepatic cells under certain conditions.

Antibody Specificity

The fundamental problem involved in antibody specificity is whether the specificity (the ability of each antibody to react only with its particular antigen) reflects different three-dimensional arrangements of antibody protein, different sequences of amino acids, or both. Since only 10 to 20 of the 1600 amino acids making up antibody protein appear to be involved in the immune reaction, differences between antibodies due to specificity are too small for detection by standard methods of protein analysis. However, by suitable treatment with unlabeled iodine in the presence of hapten to limit inactivation and with labeled iodine after subsequent removal of hapten and photooxidation, the iodine-reacting amino acid at the active site of antibody directed against the negatively charged hapten, phenylarsonic acid, has been identified as tyrosine. As indicated by equilibrium dialysis, the iodine-reacting group not only reduces the rate of hapten binding to antibody but also decreases the number of binding sites.

The iodination procedure not only defines the active site of the antibody directed against the negatively charged phenylarsonic acid but also serves to distinguish this antibody from another directed against a contrasting hapten, the positively charged trimethylammonium group. Iodination of the latter antibody decreases immuno-

logical activity by 29% under conditions in which 87% of the antiphenylarsonic acid antibody activity is destroyed. Further, prior addition of hapten does not prevent the 29% loss in activity. Clearly the active sites of the two antibodies contain different chemical groups. Further comparison of the iodinated antibodies, one labeled at the active site and the other not, should determine whether the differences in specificity are due to variation in amino acid sequence or the three-dimensional structure of antibody protein.

Spontaneous Disease in Laboratory Animals

Animals for experimental use ideally should be obtained and kept free of disease, especially when maintenance for appreciable periods of time is required. In addition to the controlled environment and nutrition provided for all animals, the ideal is being approached through breeding. Mice are being bred from animals initially obtained under aseptic conditions by Cesarian section and fostered on germ-free females. However, even with this type of breeding, the animals require continuing examination for the presence of disease, particularly of forms that may be exaggerated by experimental procedures or confused with results of such procedures. The following are examples of diseases found in such animals that have been studied in some detail and are of considerable intrinsic interest.

Figure 2. Pituitary gland tumor in an irradiated rat. A transverse slice through the skull with the brain inside is shown. The tumor was 7 mm in diameter and is visible as a large dark mass. Animals with such tumors may exhibit circling, head tilting, and paralysis of the lower body. The same type of tumor occurs spontaneously in certain strains of rats.

Acute sialodacryoadenitis is apparently a new disease, which appeared in the rat colony. The animals exhibited a mumplike swelling of the neck under the jaw attributable to acute inflammation of the submaxillary salivary gland. The condition was complicated by infection of the Harderian glands. Pathological findings suggest that the condition arises from infection, possibly by a virus. The animals were not grossly ill and did not die acutely. The disease differs from another fairly common one that involves the salivary and lachrymal glands and is characterized by the presence of inclusion bodies in cells, but not inflammation.

Tumors of the central nervous system were found in rats. During studies on effects of irradiation on the nervous system, a clinical picture of paralysis little or no different from that seen in irradiated animals was observed in a number of control rats. The paralysis was attributable to tumors in the brain or spinal cord. Although tumors of the pituitary gland are fairly common in old rats of certain strains, central nervous system tumors are reported to be rare.

Cerebral encephalitozoönosis, a disease affecting the brain and caused by a parasite (*Encephalitozoön cuniculi*) was found, with a high incidence, in a mouse colony initiated from presumably disease-free animals. Clinical signs of paralysis were absent, and mortality was not obviously changed. Recognition of this disease is of particular importance, since the clinically silent brain lesions might be interpreted as arising from experimental procedures, e.g., irradiation. Also, in work involving transmission of infective material by brain inoculation, dual infections might be continuously transferred unless the condition is recognized.

GENETICS

Chemical Mutagenesis in Higher Plants – Use of Tritium-Labeled Compounds

An important advance in chemical mutagenesis is the theory, based on research with microorganisms, that analogues of purine and pyrimidine bases or nucleosides can become incorporated into DNA and bring about altered sequence in the normal bases, which is considered to be a fundamental cause of mutation. As a preliminary step in studies on base analogue-induced mutations in higher plants, investigations were carried out to

determine if these compounds do, in fact, become incorporated in nucleic acids of the root tip cells of *Vicia faba*. Tritiated 5-iododeoxyuridine, a thymidine analogue, and 2-aminopurine, a purine analogue, were used.

Autoradiographic localization of the tritium indicates that 5-iododeoxyuridine, like thymidine, is incorporated selectively into the chromosomes and specifically into the pyrimidine component of DNA. The cesium chloride density gradient technique provided evidence that the iodinated, rather than the normal 5-methyl form, is present in the DNA.

The results with tritiated 2-aminopurine were different, as expected, since this compound is an analogue of the adenine and guanine common to both DNA and RNA (ribonucleic acid). The label was found in nuclei and cytoplasm, and followed the pattern of distribution characteristic of incorporated cytidine.

Tracer studies, in which the plant *Arabidopsis thaliana* was grown on culture media containing tritiated thymidine, showed that this nucleoside (and by inference analogue nucleosides) can be taken up through the roots, transported, and incorporated into stem meristem cells undergoing division. The next step will be to study mutagenesis induced by incorporated DNA analogues and the possible potentiation of radiation effects on the chromosomes of the plant.

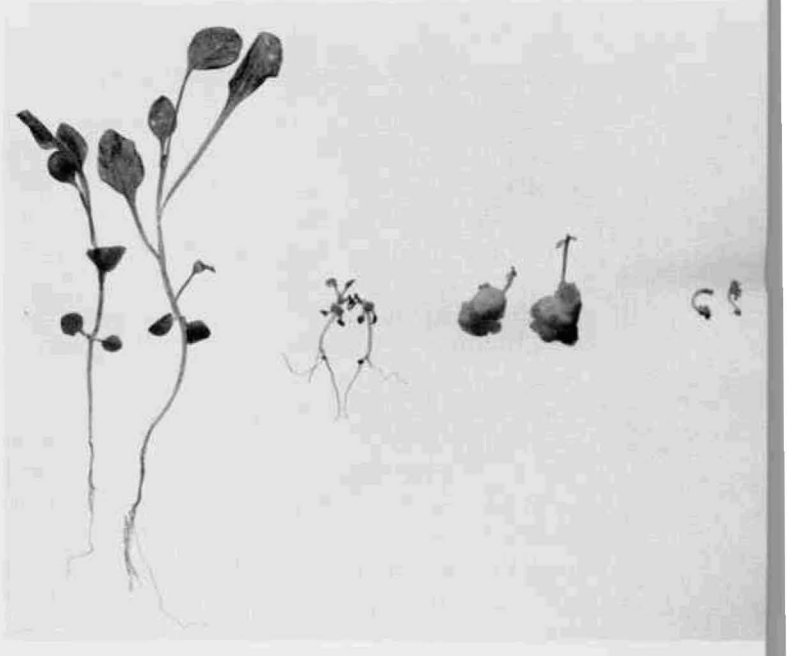
Physiological Studies on Genetically Controlled Plant Tumors

Spontaneous formation of tumors in interspecific hybrids of *Nicotiana* are controlled by genetic factors exhibiting typical properties of segregation, linkage, and mutation. Tumor formation usually occurs late in plant development, which suggests dependence on an accumulative process initiated by a DNA aberrancy originating from combination in hybrids of genes from widely divergent species. Present efforts are directed toward identifying and controlling key physiological or biochemical processes that take place in tissues of genotypes predisposed to tumor formation. Based on theoretical considerations, a major emphasis in the work on plant tumor formation is being placed on the determination of differences in the metabolism of nucleic acids for tumorous and nontumorous cell types by use of labeled purines and pyrimidines. Emphasis is also being placed on the control of differentiated vs undifferentiated growth through the regulation of stresses during growth, such as high oxygen levels, which would be expected to enhance accumulation of certain metabolic products. The interplay between rapid rate of aeration (a probable stress condition) and auxin in affecting tumor expression is illustrated in Figure 3.

Action of Mutator in *Salmonella*

Mutator genes have been observed in several higher organisms. The main characteristic is a greatly increased spontaneous mutation frequency either for a specific locus or all loci tested. The mutator gene (*mut*) in strain LT7 of *Salmonella typhimurium* is similar to those in higher organisms which affect all loci tested. Recent studies of spontaneous mutants from the LT *mut* strain show that practically all (98%) are of one type, namely, the type believed to be induced in genetic material by analogues of purines or pyrimidines. Thus these studies suggest that the mutator gene acts by stim-

Figure 3. Seedlings of a genetic tumor-forming hybrid of *Nicotiana* showing effect of different physiological conditions. Left to right: (1) Grown without auxin or high rate of aeration; no tumors found. (2) Grown without auxin but under stress conditions of high aeration rate (probable O_2 effect); small tumors found on stem near cotyledons. (3)High auxin level, low rate of aeration; mass of undifferentiated growth in root region. (4) High auxin level and rate of aeration; poor over-all growth, undifferentiated in both root and stem region.



ulating within a cell the production of some purine or pyrimidine base.

To test this suggestion *Salmonella* strains LT7 *mut* and LT2 not having the mutator gene were cultured under conditions causing excretion of purine and pyrimidine ribotides into the medium. From the media of these cultures, extracts were prepared for tests of mutagenicity and composition.

The LT7 *mut* extracts were mutagenic when assayed by the spot technique using histidine auxotrophs derived from either the LT2 or LT7 *mut* strain. A twofold increase in the mutation rate was observed. The LT2 extracts exhibited little or no mutagenic effect. Chromatograms from the LT7 *mut* strain showed the presence of ultraviolet-absorbing material in addition to the four substances normally found in the nonmutagenic LT2 extracts. This material moved slightly behind adenine in chromatograms made with a butanol-ammonia-water solvent. The absorption spectra indicate that the material is some type of purine. This supports the assumption that the mutator gene acts through the formation of some purine which is mutagenic.

Preliminary results obtained by using the transduction method suggest that the mutator gene is located on the chromosome very close to four known genes controlling the synthesis of purines. Further studies are being made to determine the chemical structure of the compound and the genetic relationship of the mutator gene to the neighboring purine genes.

Induced Changes Within a Bacterial Gene

Genetic studies of genes of *Salmonella typhimurium* have shown them to be complex in structure, each composed of a large number of linearly arranged "sites" at which changes responsible for mutant forms may occur. A spontaneous mutation may involve either a single site or several adjacent sites. The multisite mutations, since their phenotypes exhibit properties characteristic of the deletion mutants observed in higher organisms, are assumed to originate through deletion of a segment of the gene string. In general, the frequency of occurrence of deletions is low compared with that of single-site mutations. The one exception detected is the cystine-controlling region *cysC*, in which almost 40% of the spontaneous mutations are deletions. Therefore this region was selected for a comparative study of induction of single-site mutations and deletions by ultraviolet rays, x-rays, neutrons, 2-aminopurine, and sodium nitrite.

If a mutagen acts directly on the DNA molecule, as postulated for 2-aminopurine and sodium nitrite, all the genetic changes induced should be single-site mutations. This proved to be true for 2-aminopurine. Sodium nitrite, however, as well as all the other mutagens tested, induced deletions in addition to single-site mutations. It seems evident that two mechanisms operate in the induction of these mutations: one affects DNA directly, to produce single-site changes, and the other acts indirectly to bring about deletions.

More than 200 single-site mutations and 90 deletions have been identified. Mapping of the single-site mutations showed them uniformly distributed among five linearly arranged complementation units (*a*, *b*, *c*, *d*, *e*). Analysis of the deletions revealed that 80 are alike, their left ends falling between the *b* and *c* complementation units, and their right ends in a section beyond the right limit of the *cysC* region. Transduction experiments involving markers located in units *b* and *c* indicate a very high recombination frequency in the section

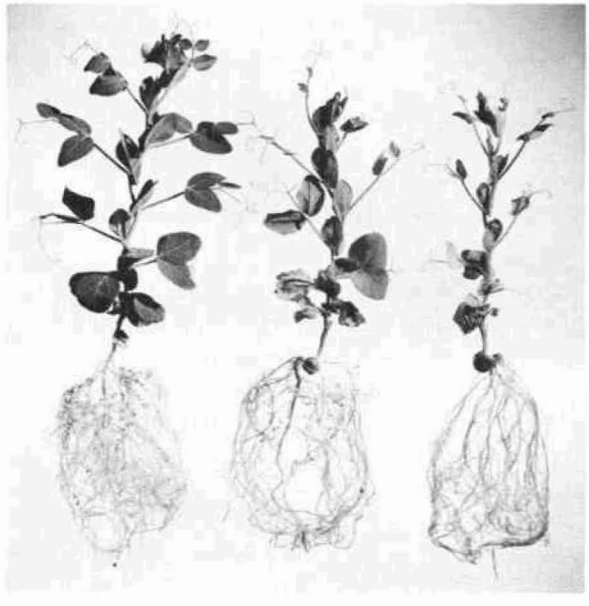


Figure 4. Extension of host range by mutation in *Rhizobium*. The pea plant at the left was inoculated with pea bacteria, *R. leguminosarum*, and the one in the center was inoculated with a mutant strain of clover bacteria, *R. trifolii*. The plant on the right was not inoculated. Although the mutant strain gave rise to root nodules, nitrogen fixation was negligible, as indicated by relative growth vigor of the plants.

including the left ends of the deletions. Assuming that frequency of recombination is a function of the distance between markers, this section should be about twice as long as all the rest of *cysC*. The section is "genetically silent," however, in the sense that none of the 200 single-site mutations is located within it. The most apposite explanation is that the silent section is a duplication of the material present in the section containing the right ends of the deletions, and that the deletions are produced by a frequent formation of loops in the DNA string (because of attraction between the duplicated sections) and omission of the material within the loops during replication of the DNA. Analysis of the remaining 10 deletions showed that they too are nonrandomly distributed within the *cysC* region. The majority have one end located either in the silent section or in the section containing the right ends of the 80 deletions.

The results suggest that most deletions have a common origin, namely, the formation of loops resulting from the attraction of homologous material, and that the frequency of occurrence of a certain type of deletion depends on the length of the duplicated section. Since the section analyzed is genetically silent, it is probably composed of noncoded DNA, which may correspond to the heterochromatin found in chromosomes of higher organisms.

Induced Variation in Symbiotic Nitrogen-Fixing Bacteria

The objective of this work is to determine the feasibility of altering the host range and nitrogen-fixing efficiency of rhizobial bacteria by means of experimental genetics. Nodule mutants, i.e., rhizobia with an increased nodulation or host range, have been induced in two genetically marked strains of the clover-nodulation group of bacteria by x-ray, fast neutron, and ultraviolet light treatment. These mutant strains of "clover bacteria" form nodules on pea plants but do not fix a detectable amount of nitrogen in these plants. Such mutants are also slightly less efficient than the nonmutant or "parental" strains in nitrogen fixation on their natural host, the clover plant. The net result, therefore, is increase in host range without gain in nitrogen-fixing ability. Thus, while the mutation approach offers promise as a means of extending the nodulation range, other genetic procedures may be required for concomitant increase in nitrogen fixation ranges.

In tests for potentially transducing phage, three lysogenic strains of the pea-nodulation group have been identified. At least one may prove to be a multiple lysogenic strain. All these strains yield temperate phage which can lyse one clover rhizobial strain, which makes possible initial transduction experiments in the same "direction" as the mutation experiments, i.e., from the ability to nodulate clover toward the capacity to nodulate peas.

Interstrain inhibitions (plus a form of self-inhibition) have been encountered in lysogenicity screening experiments. These phenomena do not involve demonstrable bacteriophage and appear to be produced by antibiotic agents. Present indications are that bacteriocins may be involved in a few strains, although the antagonistic agent in most cases appears to be a labile antibiotic substance of lower molecular weight. Several rhizobial strains have a wide range of antagonistic action; conversely, another strain is generally sensitive to other rhizobia.

The Lysogenic Interaction Between Bacteriophage and Bacterium

A remarkable feature of lysogeny is the apparent repression of production of infectious phage particles either from prophage or from the DNA of related phages introduced into lysogenic cells by superinfection. Synthesis of specific cytoplasmic immunity substances, under the control of prophage, has been postulated to explain this repression. Some lysogenics can be induced to form phage on a massive scale following treatment with ultraviolet light and agents that inhibit bacterial DNA syntheses.

Escherichia coli cells lysogenic for the prophage and *Salmonella typhimurium* cells carrying the prophage of phage P22 can be protected against induction of phage production by pretreatment with chloramphenicol (an inhibitor of protein synthesis) before exposure to inducing agents. The results suggest the build-up of material, in the presumed absence of protein synthesis, that represses phage formation. The material appears to resemble RNA in that repression of phage production is found following the addition of 5-fluorodeoxyuridine (an inhibitor of DNA synthesis) to the chloramphenicol pretreatment, but not after simultaneous exposure to 6-azauracil (an inhibitor of RNA synthesis) and chloramphenicol. The results suggest that the lysogenic immunity substance may be a form of RNA.

Cooperative Radiation Mutation Program

The Cooperative Radiation Mutation Program was established to assess the usefulness of radiation in producing mutations that represent an improvement in existing crop plants. Whole plants, seeds, and cuttings are irradiated with x-rays, γ-rays, or thermal neutrons at Brookhaven and are then studied and evaluated by scientists in the United States and other countries.

A new variety of oats has been produced and released to farmers by a group at the University of Florida. The new variety, named *Florad*, resulted from a thermal neutron-induced mutation and confers a high degree of resistance to crown rust, the most important disease of oats in Florida. This new variety is also superior to its parent (*Floriland*) in grain quality and stiffness of straw. The Florida group has estimated that it usually takes 10 to 12 generations to incorporate genes for disease resistance into commercial oats by conventional methods of breeding from new strains, whereas the radiation-induced resistance in *Florad* oats was accomplished in only three years.

CELL PHYSIOLOGY

Radiation Sensitivity of Plants

The marked species variation in tolerance to ionizing radiation is well known, but knowledge of its causes has been too limited to allow prediction of sensitivity for particular species. Systematic study of the factors affecting the radiosensitivity of different taxa promises to make this possible. The most important variables appear to be characteristics of the nuclei. Some of the characteristics associated with high radiosensitivity are listed below.

1. Large nucleus (high DNA)
2. Long chromosome arms (large chromosomes)
3. Acrocentric chromosomes
4. Normal centromere
5. Low chromosome number
6. Diploid
7. Much heterochromatin
8. Uninucleate
9. Large nuclear/nucleolar volume ratio
10. Sexual reproduction
11. Slow rate of cell division (long intermitotic time)
12. Long dormant period
13. Meiotic stages present at dormancy
14. Slow meiosis and premeiosis
15. Low concentration of protective chemical constituents, e.g., ascorbic acid.

The opposite characteristics (e.g., small nucleus and low DNA) are associated with low radiosensitivity.

All these factors almost certainly contribute to interspecific differences in sensitivity to prolonged exposure to radiation, but it is doubtful that Nos. 10 to 14 would be of much significance for acute exposure. Some quantitative expressions of the effects of nuclear variables examined in detail are as follows: (1) In eight species doubling the chromosome number by polyploidy increased resistance by a factor of 1.67. (2) Nuclear volumes ranging from $\approx$100 to 2500 μ^3 in five species correspond to a roughly twofold variation in chromosome breakage measured as frequency of micronuclei per r per μ^3 of nucleus (the frequency per nucleus per r is proportional to total nuclear volume). (3) Nuclear volume and DNA content are highly correlated in six species, and the DNA content per chromosome is inversely proportional to the daily dose of radiation required for severe growth inhibition. (4) A useful statistic, the nuclear volume at interphase per chromosome, which varies in different species from 0.5 to $>$100 μ^3, is directly correlated with sensitivity. (5) If differences in sensitivity attributable to chromosome form and number are ignored, it appears that a fairly constant amount of energy is required to produce a particular effect, such as severe growth

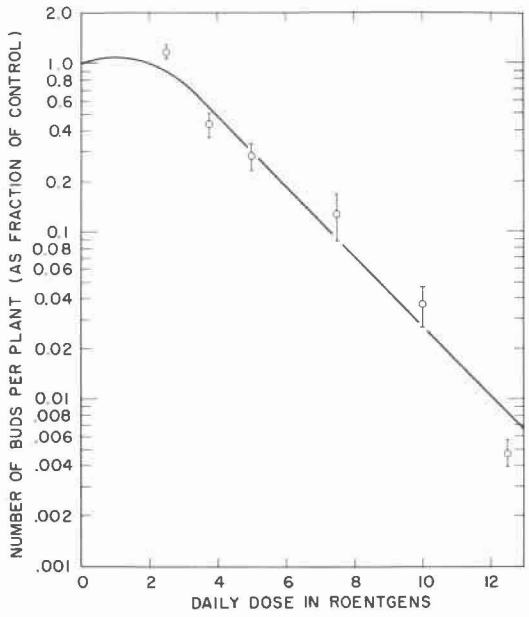


Figure 5. Effect of irradiation on bud formation in *Taxus* (yews). At dose rates of $\approx$7 r/day for a six-month period, reduction of bud formation is very severe.

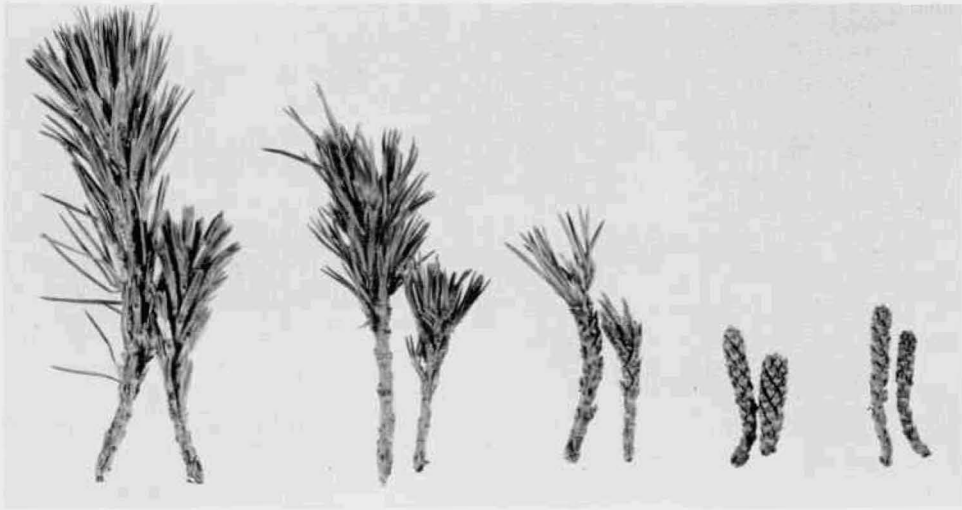


Figure 6. Effect of irradiation on dormant seedlings of *Pinus strobus*. A single dose of 300 r approaches the 100% lethal level. Left to right: Control; 150 r; 300 r; 600 r; 1200 r. These plants, like *Taxus*, are at least as sensitive to ionizing radiation as many animals.

inhibition under specified conditions; in 23 species studied, $\approx 67{,}000 \pm 10\%$ ionizations per day per nucleus are required for severe growth inhibition.

X-Irradiation and Root Growth

Visible light and x-rays inhibit development of the root primordia present in the bark of the stem of the Lombardy poplar. However, each seems to act through a different mechanism. Whereas no means have been found to permit roots to develop under light of appropriate wavelength, the plant hormone, indole acetic acid, overcomes the x-ray inhibition to a substantial degree. The hormone is somewhat more effective when used before x-irradiation than afterwards. The inhibitory action of light is most pronounced at one particular stage of root development, before and after which it becomes progressively less so. The x-ray-induced inhibition does not show the same stage sensitivity. Despite these obvious differences in mode of action, when light and x-rays are applied together, the effect is synergistic; i.e., the amount of inhibition is greater than the simple sum of the effects produced by each alone.

The modification of the x-ray effect by indole acetic acid may perhaps be taken as an index of the extent of the hormonal imbalance produced by the radiation exposure. As an indirect means of gauging the amount of damage to chromosomal material, prestabilized stem segments were irradiated in atmospheres of air, oxygen, and nitrogen. As has been found with many other materials, the sensitivity in oxygen was considerably greater than that in air, while nitrogen very markedly reduced the sensitivity. At a dosage of 3000 r, root emergence on cuttings irradiated in nitrogen was delayed but eventually reached the same value as that for unirradiated controls. Root emergence on cuttings irradiated with the same dosage in an oxygen atmosphere was long delayed, and the final value attained was only 10% of that for the unirradiated control. The findings indicate considerable chromosomal damage.

Use of Isomutant Sectors in Analysis of Development

A versatile tool for study of plant morphogenesis is provided by radiation-induced isomutant sectors. By acute irradiation (x or γ-ray) of developing barley embryos at specific stages of embryogeny, estimates can be made of the minimum number of cell initials participating at a given time in the formation of a specific region of the plant and the potential contribution of a single initial cell to the plant as a whole. By analyzing the sizes and distribution of isomutant-carrying sectors for chlorophyll deficiencies, it has been determined that as early as the 8-celled proembryo stage in barley, at least two cells contribute to the sector encompassing the generative tissue of the

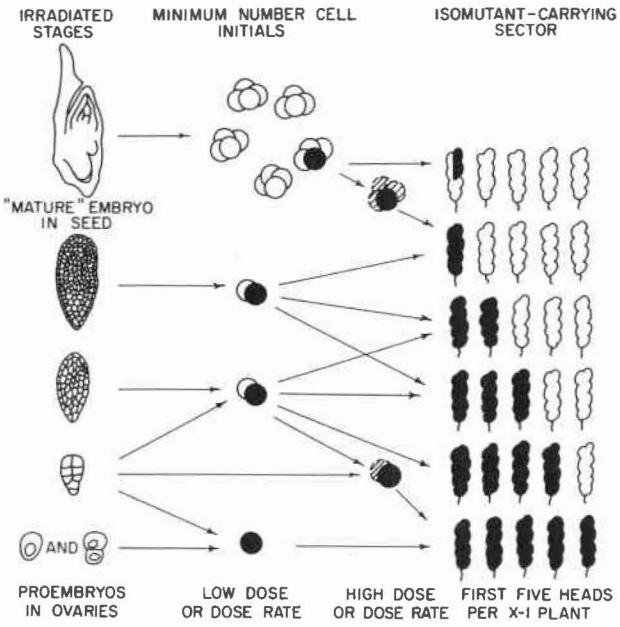


Figure 7. Effect on the first five heads of the barley plant of irradiating different stages in proembryonic development.

first five heads formed per X-1 plant. On the other hand, the occurrence of dwarfism, sterility, chlorophyll mutations, and leaf abnormalities shows that even as late as the end of the proembryo period a single initial still retains the capability (if other cells are eliminated) of eventually giving rise to all of the above-ground portion of the plant. Because of the ease with which large mutant-carrying sectors can be produced, there appears to be little or no evidence either within the developing embryo or at any other stage in the plant's life cycle that cells in which such mutations have been induced and are carried in a heterozygous condition are at any appreciable selective disadvantage. This appears to be true even though such cells may be surrounded by nonmutated cells having the developmental capacity to replace the mutated ones.

Very different results have been obtained, however, from experiments in which mature embryos of corn and barley already heterozygous for chlorophyll deficiencies have been irradiated with a 22.5-Mev deuteron microbeam (25 μ and 250 μ in width) directed parallel to the main embryo axis just lateral to the shoot meristem. Phenotypically albino sectors are much more difficult to induce than yellow-green sectors and are considerably smaller in size than expected. In addition, they are eventually eliminated from the meristems, while yellow-green sectors tend to be perpetuated throughout the remainder of the plant's development. Thus the chromosome aberrations and/or gene mutations associated with albinism evidently do cause the cells possessing such mutations in a homozygous condition to be at a definite selective disadvantage when surrounded by cells heterozygous for the same mutation. This implies that the metabolic processes controlled by the normal alleles of albino factors, or "allelic" chromosome regions, are vital not only to the cells of the seedling leaves in relationship to photosynthesis, but also to the nonphotosynthesizing cells of seedling meristems and young developing embryos.

Cell Enlargement and Radiation Genetics

Radiation-induced cellular death is of three major types: immediate death, delayed reproductive death, and delayed "interphase" or nonreproductive death. A unique botanical tool for study of these phenomena is the pollen grain of flowering plants, a single cell which during germination produces a tube up to several inches in length that delivers sperm to the egg cells. Tube development is unilateral; it involves rapid cellulose and callose elaboration and vacuolization, with no measurable DNA synthesis and, in late growth, minor amino acid utilization. Pollen tubes respond markedly to high concentrations of borate and calcium (in the presence of magnesium and potassium ions) but are essentially refractory to all tested auxins and growth factors. The unique role of calcium was discovered by studying small populations of grains; in the absence of supplemental calcium ion, germination occurred poorly or not at all in the 30 species tested. Studies with Ca^{45} show that calcium is chemically bound only slightly, if at all, to the cell wall, although it markedly influences rigidity and conformation of this wall. Neutron activation analyses are under way to examine the possible localization of boron in biologically enriched pollen tubes, in relation to borate's exceedingly important role in tube growth.

A 50% level of immediate death, defined as failure of pollen germination or cessation of protoplasmic streaming in the pollen tube, requires x-ray or γ-ray doses from 45 to 550 kr for the 30 species studied. Lethality curves are sigmoidal and are highly correlated with pollen size. Evidence was obtained for dose-rate, oxygen, and moisture effects. The multiple target implied by the lethality curves is considered largely nonnuclear.

Delayed reproductive death varies between species (10 kr to 40 kr for 50% lethality), partly as a consequence of the stage of the generative nucleus in mature (binucleate) pollen grains. Such nuclei vary from late interphase to prometaphase, and the sensitivity to x-ray inhibition of division decreases throughout this range, while sensitivity to chromosome breakage increases. Delayed reproductive death in this system appears to be a consequence of both nuclear and extranuclear damage. Nuclear damage is measurable directly by chromosome breakage at pollen tube mitosis, and has been satisfactorily detailed in the three-chromosome pollen of *Ornithogalum*. Indirect evidence of nuclear damage is expressed as dominant lethals affecting seed viability; the data (from three species) nearly follow exponential survival curves.

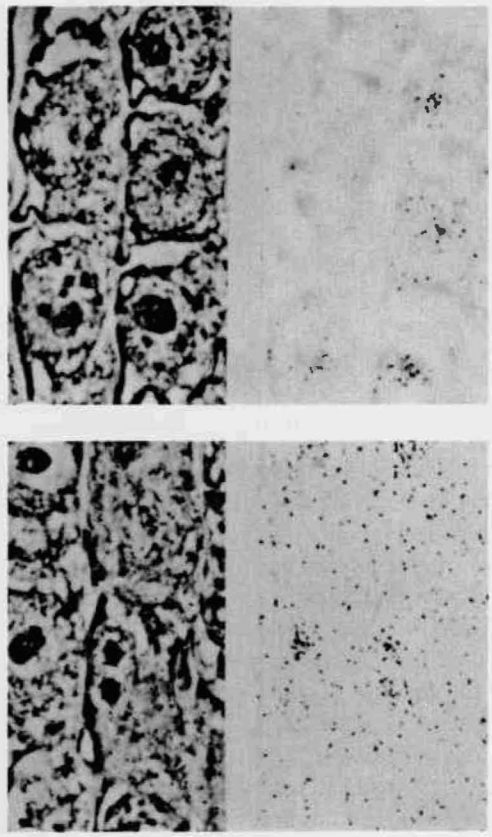


Figure 8. Autoradiographs (right) of sections of a growing root tip treated with tritium-labeled cytidine. At left are conventionally stained sections for comparison. The section at the top was extracted with water before autoradiography, which removed water-soluble ribonucleic acid. The section at the bottom, not extracted with water, exhibits the presence of soluble nucleic acid.

Delayed nonreproductive radiation death is rather more elusive in the pollen tube system. Germinating tubes often branch following UV or ionizing radiation, a phenomenon essentially unknown in nonirradiated material. Irregularities of growth suggest impairment of cellulose elaboration, perhaps by alteration of the action of calcium.

Ribonucleic Acid Formation in Dividing Cells

Earlier study of the metabolism of RNA in actively dividing cells by use of a tritium-labeled precursor and autoradiography has suggested the following: RNA is formed within both the nucleolar and chromosomal regions of the nucleus. Whether the same form of RNA is synthesized at both sites is not known. The nucleolar RNA, and presumably also that arising in the chromosomal region, moves to the cytoplasm, where the RNA appears as a component of microsomes. Recent study of RNA metabolism has involved a water-soluble material that contains the labeled RNA precursor used. The ultraviolet absorption spectrum indicates the material to be an RNA that can form complexes with amino acids. The material may well be the "soluble RNA" known to be involved in protein synthesis. A modification of technique has made possible autoradiographic detection of the material within the cell and hence some consideration of its formation and location. The material occurs largely in the cytoplasm and once formed is quite stable. However, its relationship to other forms of RNA and the site of synthesis is not yet known.

Structural Basis of Photosynthesis

Most investigators are willing to assume that structural organization above the molecular level probably contributes to the efficiency of photosynthesis and may be essential for the primary process. The photosynthetic bacteria, particularly those completely dependent upon light as the external source of energy, provide unusual opportunities for studying this problem.

In the purple sulfur bacterium *Chromatium* the capture of light energy and its conversion to chemical energy occur within the chromatophore, the simplest and smallest organelle known to perform these photosynthetic processes. Since all photosynthetic systems studied possess submicroscopic lamellae, and this feature is present in a rudimentary form as the cortex of the chromatophore, the submicroscopic lamella appeared to be a uni-

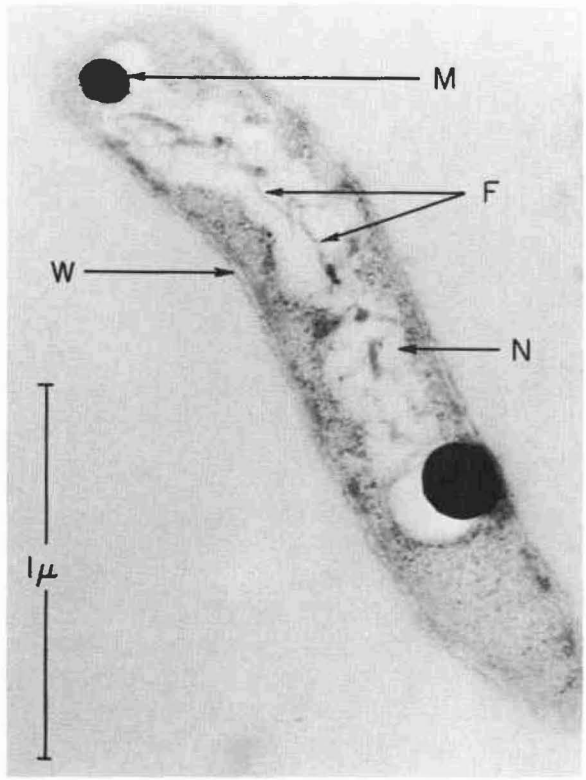


Figure 9. An electromicrograph (72,000 ×) of a thin section in the axial plane of *Chlorobium thiosulfatophilum*. The cell wall (*W*), which tends to appear as two layers, is distinct from the cytoplasmic boundary. The "nuclear" region has a low electron density and contains filaments (*F*) which ramify. Metaphosphate inclusions (*M*) appear as circular areas of high electron density. The cytoplasm is filled with small particles having a maximum diameter of ≈150 A.

versal architectural characteristic of photosynthetic systems. In a model proposed for the submicroscopic architecture of the chromatophore, the lamella was treated as the expression of more fundamental characteristics which could be extrapolated to the molecular level. However, study of the structure and function of the photochemical apparatus of another obligately photosynthetic bacterium, *Chlorobium thiosulfatophilium*, appears to provide the first exception to the idea that the lamella is an essential architectural feature of photosynthetic systems. Excepting the cell wall and the cytoplasmic membrane, this organism is devoid of lamellae. When the cells are broken the photosynthetic pigments are recovered in particles with a maximum extension of 150 A. If structural organization above the molecular level is prerequisite for photosynthesis, the *Chlorobium* particle must approach the limiting conditions. This particle is already within the physical range of materials, such as hemocyanins, that are classed as respiratory proteins. Such considerations as these add interest to the study of the photochemical activity and composition of this system.

Photometabolism of a Photosynthetic Bacterium

A comprehensive study of the light-dependent autotrophic and heterotrophic metabolism of the photosynthetic purple sulfur bacterium *Chromatium* indicates that *Chromatium* fixes CO_2 into carbohydrates by a mechanism similar to that operating in higher plants, but in addition can rapidly incorporate CO_2 into organic acids and amino acids. Further, cell-free extracts of *Chromatium* contain all the enzymes necessary for conversion of CO_2 to carbohydrate, which again indicates operation of a reductive photosynthetic cycle similar to that in higher plants. In *Chromatium* grown on acetate instead of CO_2, key enzymes of the reductive cycle are suppressed. At the same time isocitratase is induced. This enzyme provides a pathway for the net incorporation of acetate by the recently discovered glyoxylate cycle. Other enzymes necessary for the completion of this cycle are present in *Chromatium* extracts. These studies demonstrate that the glyoxylate cycle plays a major metabolic role in a photosynthetic organism.

BIOCHEMISTRY

Comparative Biochemistry of Plant Enzymes

It has been suggested that phosphatases acting on fructose-1,6-diphosphate (FDP) participate in the biosynthesis of carbohydrates through a reversal of glycolysis. Information on the occurrence and possible metabolic function of plant FDPases has been obtained from a study of the FDPase activity of extracts from a variety of plants, algae, and photosynthetic bacteria. At least three phosphatases acting on FDP have been found in plant extracts. One is the widely occurring acid phosphatase. Two enzymes are specific for the phosphate linked to carbon-1 of FDP. One of these two exhibits maximum activity at neutral *p*H and the other at an alkaline *p*H. The alkaline FDPase is associated with photosynthetic tissues or cells, while the acid and neutral FDPases are found in both photosynthetic and nonphotosynthetic cells. Thus pea leaf contains all three enzymes, while pea root contains the acid and neutral but not the

alkaline FDPase. Both the alkaline and neutral FDPases occur in autotrophically grown *Euglena gracilis*, but only the neutral FDPase is present in apoplastidic cells. The photosynthetic bacterium *Chromatium*, an obligate anaerobe, possesses only the alkaline FDPase. These results suggest that the neutral and alkaline FDPases may participate in carbohydrate synthesis associated with respiration and photosynthesis, respectively. This concept is supported by intracellular distribution studies which have demonstrated the localization in chloroplasts of the alkaline FDPase, but not the acid or neutral FDPases.

Heme and Porphyrin Formation by Erythrocytes

Young erythrocytes produce free protoporphyrin as well as the iron-porphyrin complex, protoheme. The metabolic significance of free porphyrin formation and its relationship within the cell to heme formation are not clear. In an attempt to define the relationship, the effects of a number of biologically active compounds on heme and porphyrin formation by duck erythrocytes *in vitro* were determined. A number of the compounds (e.g., pyridoxine) increase free porphyrin production but decrease heme and total porphyrin formation. Some of these same substances (as well as others), under different test conditions, decrease both heme and porphyrin formation. Two compounds, pyridoxamine phosphate and physostigmine, decrease heme formation, but increase production of both free and total porphyrin. The findings are consonant with at least two relatively simple hypotheses relating heme to free porphyrin production, but do not offer decisive support for either.

Protein Structure

Great progress has recently been made in the elucidation of the structure of myoglobin. Results obtained here and elsewhere, the product of almost a decade of research in several laboratories, provide the most complete description yet attained of the structure of a protein molecule (see Figure 10).

Bovine pancreatic ribonuclease, an enzyme catalyzing the hydrolytic breakdown of RNA, is a protein particularly suited for structural studies because of its small size. The reactivities of certain amino acid side chains in ribonuclease are being studied to obtain information on the distribution of these chains in relation to the structural configuration of the molecule. Ribonuclease has 21 side chains that are particularly reactive towards the reagent 2,4-dinitrofluorobenzene. At *p*H values near neutrality the most reactive is the side chain of the amino acid residue in position 41 (the protein has 124 residues), a lysine residue. The protein modified at lysine residue 41 has been isolated in quantity, and a comprehensive study of its primary structure in relation to that of the parent molecule has been completed. It is significant that the modified protein is enzymatically inactive and that the reaction of dinitrofluorobenzene at position 41 is blocked by the presence of substances that also hinder the functioning of the protein as an enzyme. The reactive lysine residue at position 41 is therefore a part of the "active site" of ribonuclease. Three other lysine chains (ribonuclease has 10 lysine residues) react with dinitrofluorobenzene at comparable but slower rates. Progress is being made toward the isolation of homogeneous fractions containing monosubstitution products corresponding to reaction at these residues. The derivative formed by reaction with the lysine residue at position 1, the terminal amino acid at the amino-terminal end of the polypeptide chain, has been isolated. This derivative functions as effectively as an enzyme as does ribonuclease itself. The success attained to date with this general approach supports the hope that eventually detailed "mapping" of the surface of the ribonuclease molecule in terms of the known covalent structure will become possible.

Enzyme Structure and Action

Enzymes direct essentially all dynamic processes in living organisms to a large extent through their specificity, i.e., the capacity to distinguish between two very similar chemical compounds in such a way that reaction is exclusively with one and not the other. No man-made catalyst yet devised has the high selectivity of these natural proteins. Studies on the mechanism of this specificity have included examination of the widely distributed enzyme, β-amylase, which is responsible for the breakdown of starch in various living systems. This amylase is specific in that it degrades only glucose polymers and splits off only two glucose units at a time from the starch chain. Some clues have been obtained to the mechanism of action which can explain this amazing specificity. The results are summarized in Figure 11. A break occurs at the carbon of the second glucose unit on the side of the reducing sugar. Apparently the

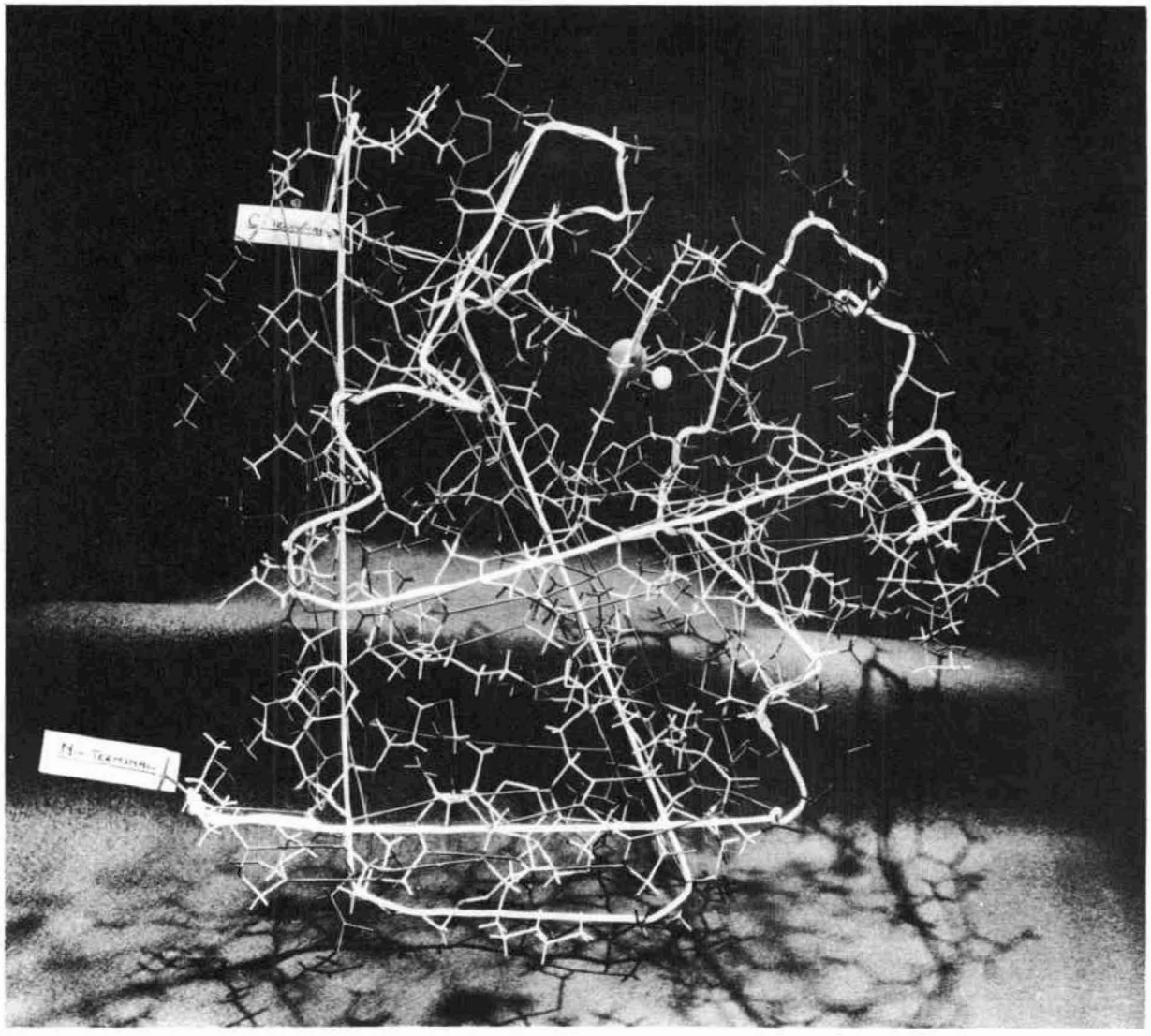


Figure 10. Model of the sperm whale myoglobin molecule. The path of the single polypeptide chain of 152 residues may be followed by tracing the white cord through the structure. The large sphere in the upper center of the photograph is the iron atom at the center of the heme group, here viewed edge on, and linkage of the iron atom to histidine residue 98 (to the left) may be discerned.

water molecule that enters the reaction approaches from the rear side and thus turns the carbon attacked inside out. To make this inversion possible, two catalytic groups, *A* and *B*, and perhaps additional ones, apparently must combine in three-dimensional space in proper alignment with the chemical bonds that must be split. Such alignment may be allowed by the chemical structure of the protein. As seen in the figure, the terminal end of the starch chain can be inserted into the protein structure in such a way that the protein chain can curl around the starch and bring groups *A* and *B* into appropriate alignment. Interior portions of the starch chain would not allow such curling around because of the bulky added glucose units; hence the model explains why the enzyme attacks only the carbon that is two glucose units removed from the end. Support for this mechanism is found in the fact that the Schardinger dextrin, cyclohexaamylose (on the left in Figure 11) is not split by the enzyme. This cyclic molecule has no free terminal position and hence will not allow the

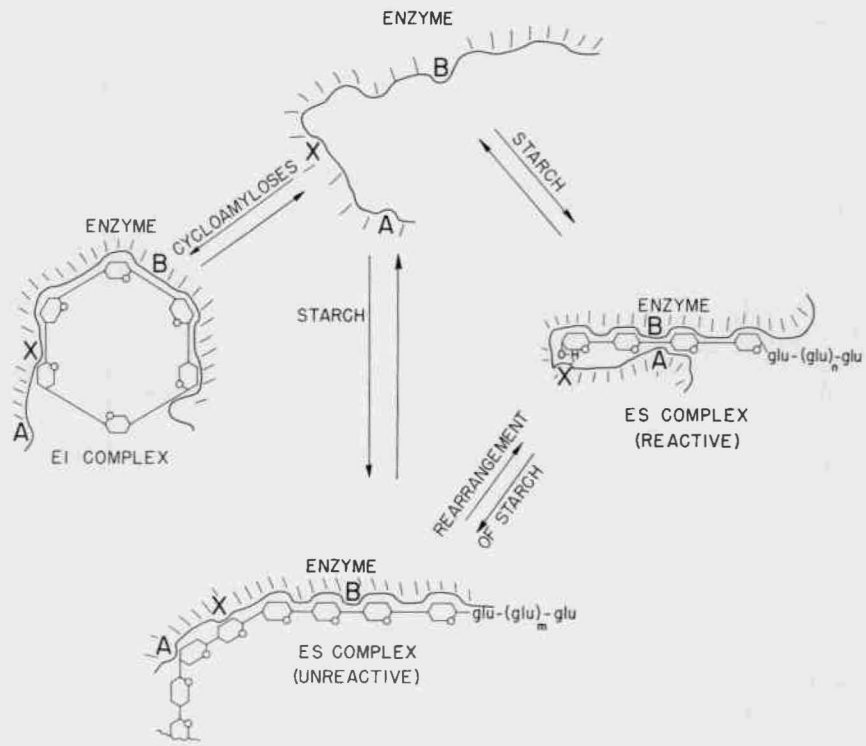


Figure 11. Possible mode of action of β-amylase in starch. This enzyme specifically removes the two terminal glucose units of the starch molecule. It reacts with the end of the starch chain (reactive ES complex) because groups *A* and *B* can curl around until they are next to each other. It cannot react with the interior of the starch (unreactive ES complex) or the cycloamylose (EI complex) because this curling is prevented.

curling around illustrated for the terminal portion of the starch. Thus, like the interior portions of the starch molecule, it is not attacked by the enzyme. Preliminary attempts at identification of the groups *A* and *B* indicate that a carboxyl group and an imidazole group may be involved and may be the groups *A* and *B* indicated in Figure 11. A sulfhydryl group also may be involved.

BIOPHYSICS

Distribution Patterns of Ions in Stationary State Systems

A general theory of material transfer through membranes based upon the idea that diffusion processes obey Newton's laws of motion has been developed. Certain predictions of the theory have been verified by experiments on a model membrane transfer system consisting of a homogeneous phase α, a membrane, and a homogeneous phase β. For example, the theory predicts that when the system is in a stationary state of the first order, produced by maintaining a steady flow of one material species through the membrane and waiting until the flows of all other permeant species cease, the log of the concentration of the now nonflowing permeant species in the two homogeneous phases should be proportional to the flow rate of the material species in steady-state flow. This prediction has been verified by experiment. Further, a distribution function, defined as the ratio of the logs of the concentration ratios of pairs of components in the system, should be quasi-invariant and independent of the flow rate of the species in steady-state flow. This also has been verified by experiment.

In the experimental system water was the species in steady-state flow. For the salt pair NaCl and KCl the distribution function should have the value of ≈ 1.2, the ratio of the diffusion coefficients of KCl and NaCl in water. Experimental results agree closely with this value. Furthermore, it was found that if the water flow was from phase α to phase β and if Na and K ions were of equal concentrations in phase β, the concentration of K

ions in phase α was some four times that of Na ions in phase α, not unlike some living cellular systems.

In terms of the proposed theory, living systems can exist in stationary states of the fourth order or higher. Despite the increased complexity, the theory indicates that in the stationary state the distribution of any nonflowing permeant component, when expressed as the log of ratios of the concentrations intra- and extracellularly, should be proportional to the metabolic rate of the living system as long as the energy-yielding set of chemical reactions constituting the metabolic pathway remains the same. Furthermore, the distribution function of pairs of nonflowing permeant species should have a quasi-invariant value characteristic of the nutrients the cell requires and the end products it produces. A search is now being made for suitable biological material to test these conclusions.

Energy Transfer and Radiation Inactivation of Enzymes

In attempting to assess the importance of various mechanisms in promoting radiobiological damage it is necessary to recognize that the dry state and solutions containing only one highly purified solute are not representative of cellular conditions. Rather, the cell has a gel-like composition with a corresponding semiordered structure. It has been known for some time that in dye-agar systems this structurelike property can apparently act as a framework to promote efficient migration of energy to critical structures or molecules. If a similar situation occurs in cells, then absorbed energy could be more efficient in inactivating individual biological components within the cell. To investigate this possibility the enzyme trypsin was x-irradiated in agar. Contrary to expectation based on studies of gels containing dyes, trypsin inactivation was not increased by the presence of agar. In fact, agar decreased the degree of inactivation. The decrease does not result from competition of agar with trypsin for radiation-produced radicals, since the agar does not compete with the methylene blue used as a co-competitor with trypsin for the radicals. Rather, it appears that trypsin inactivation was reduced in gels because of complex formation between agar and trypsin. The decrease in effect of irradiation with increase in agar concentration appears greater than expected simply on the basis of complex formation. This probably arises from a radiation-induced change in the agar that furthers recovery of the trypsin and a "cage effect" of the agar that prevents irradiated molecules from undergoing large structural rearrangements.

Although it is now apparent that the trypsin-agar system is not useful in evaluating the idea that absorbed energy may be "funneled" to critical sites within the cell as a result of the semiordered structure of biological materials, the findings do emphasize factors that may be important in determining effects of radiation on individual components within a cell.

Biological Effects of Cosmic Rays

The biological effects of a beam of deuterons 25 μ in diameter reasonably simulate those of the secondary particles from a primary cosmic-ray "thin-down." The dose required to damage mouse

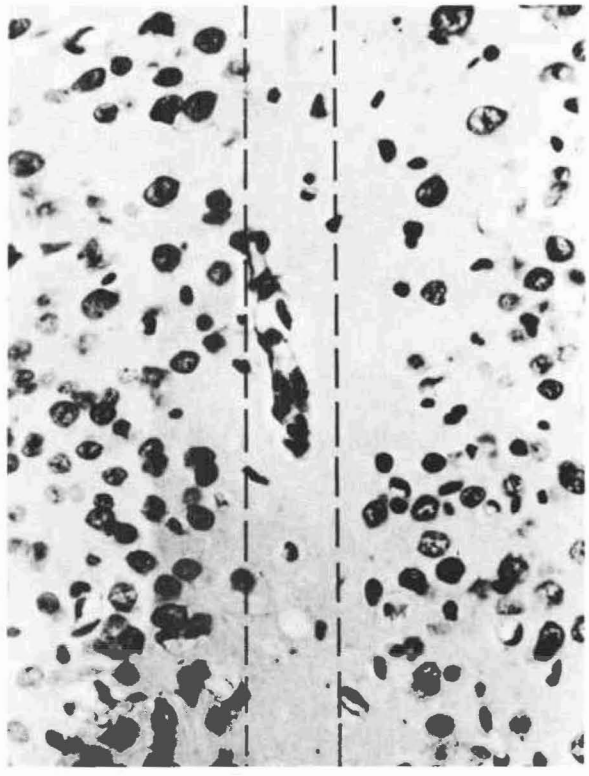


Figure 12. Microscopic section of mouse brain showing the path of a 25-μ beam of deuterons (dotted lines) 15 days after irradiation with 750,000 rad. There is complete nerve cell necrosis in the beam path, but a regenerating arteriole shows that, although the beam also destroyed the blood vessels, the resulting hypoxia in a microscopic volume was not severe enough to prevent regeneration.

brain when this microbeam is applied is greater by $\approx$2 orders of magnitude than when a beam 1 mm in diameter or larger is used. The dose required for tissue destruction by large beams is $\approx$10,000 rad, roughly the dose expected in the path of the cosmic-ray "thin-down." Since the dose required in a microbeam for comparable destruction is $\approx$400,000 rad, it seems reasonable to assume that the primary cosmic-ray particles will not be a serious problem for manned satellites.

Analysis to determine why such markedly different doses are required to produce damage by the small and large deuteron beams shows that brain capillaries are quite sensitive to radiation; when they are destroyed within a relatively large volume of tissue, hypoxia and consequent death of cells occur. If the volume of tissue is small, hypoxia does not ensue even if a few capillaries are damaged; sufficient radiation to kill cells directly is required, and for nerve cells a very large dose is needed. The microbeam irradiation thus gives a method for studying the direct effect of radiation on nerve cells. Preliminary results indicate the presence in heavily irradiated nerve cells of proteolytic enzymes, possibly released from lysosomes ruptured by the radiation; this appears to be the mechanism of cell destruction.

Studies with the microbeam in the lens of the mouse eye indicate that it takes much larger doses to produce cellular damage with the microbeam than with a 1-mm beam. Furthermore, destruction of a very small number of cells in the lens does not lead to a cataract, and the microscopic defect is eventually absorbed. The reason for the difference in destructive dose between large and small beams is not known, since this is an avascular tissue, and the explanation given for the brain does not apply.

Work with seed embryos has given still another picture. The radiation sensitivity appears to be the same for the microbeam and for the large beam in dormant seeds. Since each cell in the embryo is largely independent of the other cells, this result is not too surprising.

Medical Research

The research objectives of the Medical Department are centered on development of an understanding of the interactions between components of living cells and particles generated by physical devices. Whether or not the observations are made upon man, the information is used to evaluate known or probable reactions of man to the stimulus used. Investigation of the processes involved and the beneficial as well as the deleterious effects of the transfer, release, and absorption of energy deriving from atomic transformations or transpositions recurring in cells, tissues, and organs of mammals forms the basis for continuing studies. Particle radiation forms the core of most studies, and emphasis is on the employment of neutrons, protons, deuterons, and alpha and beta particles. Intensive exploration is being undertaken with new techniques, equipment, and devices. This is done under administrative arrangements that permit an individual scientist to carry on his research autonomously, but in association with other members of the Medical Department or with members of various departments of BNL or other medical institutions.

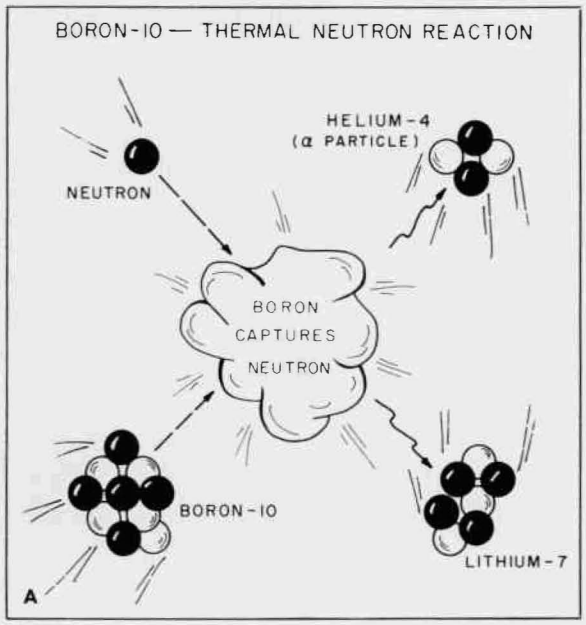
The unique opportunity at Brookhaven to utilize special devices that make available various kinds of heavy particles is in part responsible for the interest in reactor and accelerator radiology and the program in this field with special reference to therapeutic application to malignant tumors in man. Studies looking toward appraisal of the reactor as a useful and practical instrument for medicine are clearly dependent upon its availability and that of nuclear engineers steeped in knowledge of reactor design. In fundamental and diagnostic studies, radioactive tracer methodology forms the basis for kinetic, placement (uptake), and metabolic pathway investigations in both man and, where indicated, animals. At the cellular level the beta particles of tritium are used for labeling compounds to tag selected primordial or ancestral cells, which makes it possible to observe sequential cellular proliferation, maturation, and transformation. In the field of environmental medicine, clinical studies are concerned with the immediate and long-range effects of low level radiation with reference to both degenerative diseases and carcinogenesis. The role of the Department in assisting other institutions is primarily that of offering guidance and counsel to students, research collaborators, and physicians-in-training, and to chairmen of departments of medical schools through conclaves covering the scientific, clinical, and administrative aspects of nuclear medicine.

Within this frame of reference specific examples of the research under way and to be developed are given below. The report is not comprehensive, and those interested in further details are referred to publications of the Medical Department.

REACTOR RADIOLOGY
(Medical Research Reactor)

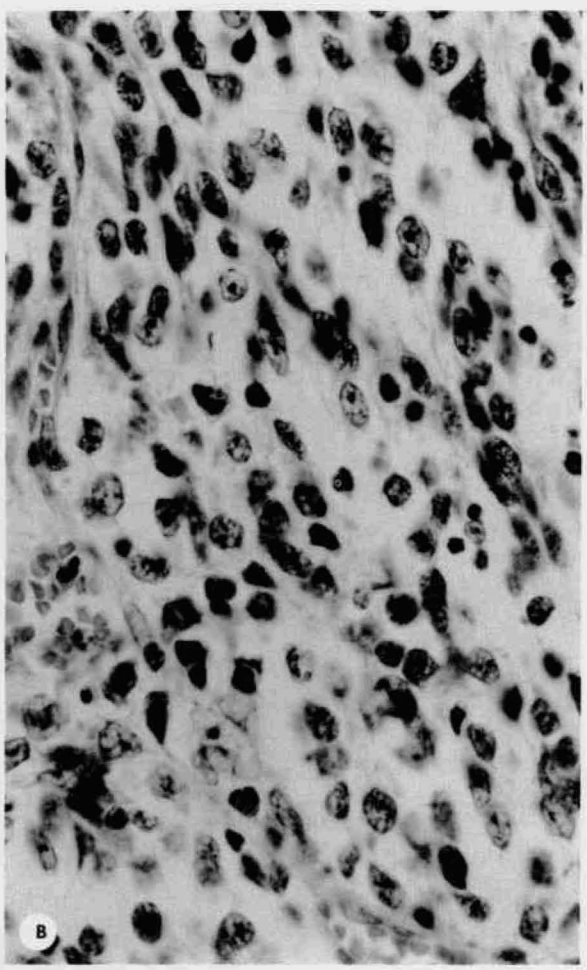
Neutron Capture Therapy

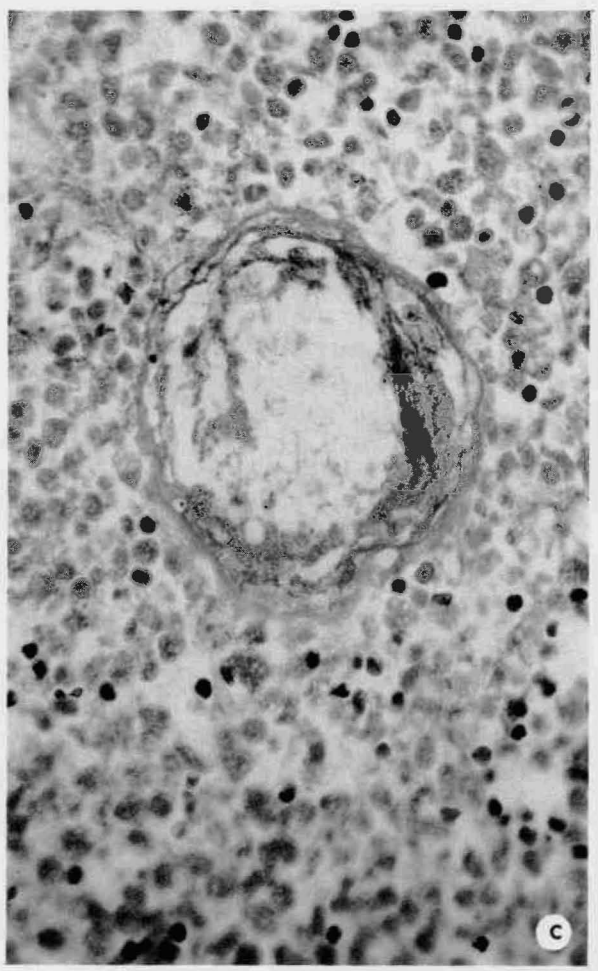
Neutron capture therapy originated at Brookhaven National Laboratory, and to date all patients treated, as well as experimental animals studied, have been observed following neutron exposure either at the Brookhaven Graphite Research Reactor (BGRR) or the Medical Research Reactor (MRR). Neutron capture therapy is a procedure that uses energetic heavy particles originated and released within the diseased tissue to be specifically destroyed. The heavy particles result from interaction of thermal neutrons and a target atom, B^{10}, administered as an inorganic salt. The localization of the radiation and the high biological effectiveness of the released alpha particle and energetic Li^{7} particle are two of its chief advantages. Highly localized lethal cytological effects can thereby be attained. The first marked effect in tissue of neutron capture therapy was observed in a 13-yr-old girl with a malignant brain tumor. Treatment significantly reduced the tumor, from about the size of a grapefruit to that of an olive. This tumor remnant persisted deep in the center of the head. Biopsies provided unequivocal evidence that the peripherally located tumor mass was destroyed by this procedure. Histological studies completed this year provide the major evidence of the reaction's effectiveness against the neoplasm and its apparent harmlessness to normal tissues.



NEUTRON CAPTURE THERAPY FOR MALIGNANT BRAIN TUMOR, AN EXPERIMENTAL PROCEDURE

Upon capture of a thermal neutron, the B^{10} atom instantaneously disintegrates (A) into an alpha particle ($_2He^4$) and an energetic lithium particle with a large release of energy (2.4 Mev). The cytocidal effect of the alpha particles is demonstrated by comparison of (B) biopsy from malignant cerebellar vascular neoplasm before therapy and (C) biopsy from same neoplasm 11 weeks after therapy showing complete cytonecrosis.





The most important continuing studies deal with dosimetric measurements, including activation studies with physiological import; improvements in reactor moderator, reflector, and field-defining aperture materials to improve neutron economy and therapeutic efficiency; pharmacological considerations of the element boron to be utilized for capture purposes; treatment and evaluation of patients receiving a standard, fixed amount of boron but varying exposures to thermal neutrons; the over-all effect on the brain as studied at autopsy by comparing the histopathological and topographical effects of radiation occurring in the tumor or in normal tissue; and exploratory procedures with transplantable and spontaneous animal neoplasms to afford insight into better possible applications in man. During the past eight years $\approx$1000 exposures of animals to neutrons have been carried out for each patient exposure.

Activation Analysis: Concentration, Distribution, and Compartmental Exchange of Trace Elements

That trace metals are present in living matter has long been known, but the paucity of suitable precise techniques has limited investigation of their function in human metabolism. A trace metal, although present only in small amounts, may be of great importance chemically if, for example, it is a specific activator of an enzyme system, or if it is present in relatively high concentration in a given type of cell, tissue, or organ. The development of tracer methodology with short-lived radioisotopes makes possible the study of compartmental exchange, and neutron activation analysis is useful in determining the concentration of microconstituents. These techniques have been applied to the study of manganese in Parkinson's disease, copper in Wilson's disease, and cadmium turnover in animals.

The application of activation analysis, a sensitive and specific method of isotope analysis, is being stressed in quantitative measurements of manganese and also of zinc, cadmium, beryllium, sodium, and potassium. The availability of the MRR makes possible the use of this method, which utilizes the properties of nuclei to produce instantaneously detectable emissions when activated by neutrons. Another favorable aspect of the radioactivation technique is that very small samples of almost any shape and in either liquid or solid form may be employed without destruction of architecture or staining qualities.

ACCELERATOR RADIOLOGY

Effects of Accelerator-Produced Monoenergetic Neutrons in Mammals

The effects of monoenergetic neutrons in mammals are being investigated for several reasons. It is important to learn more about the possible effects in man of exposure to fast neutrons in order to determine methods of protection as well as allowable exposure levels. In properly arranged experiments, additional basic information can be gathered concerning radiation damage and possible tissue recovery. Such approaches include the determination of the effects of dose rate on radiosensitivity. This information is useful in determining in man the effective biological dose in radiotherapeutic and accidental exposures. The experiments are also designed to investigate the relationship between "one hit" and "multiple hit" dose response patterns.

Methodology of Widening the Bragg Peak in Tissue by Using Deuterons

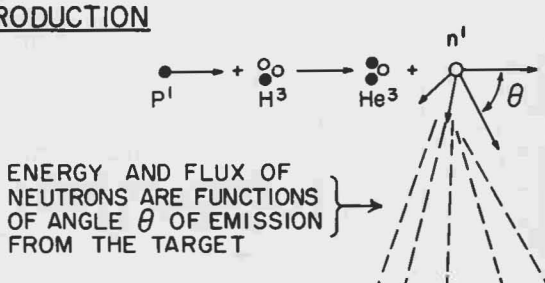
Heavy particles are much heavier than electrons (e.g., the proton is $\approx$2000 and the deuteron $\approx$4000 times heavier) and therefore may have unique and important applications in medicine and biology. Because of the large transfer of energy involved and its uneven lineal transfer, these particles possess a definite, predictable range of penetration and therefore of effect in tissues, in contrast to the behavior of x-rays or gamma-rays. In passing through a material the heavy particle loses some of its energy per unit length of path. In the final portion of the path, the energy given up per unit of path length rises to a peak (Bragg peak) just before the end of the path is reached. The objective of the present studies with a newly devised filtering wheel of aluminum was to widen the Bragg peak so that maximum energy transfer could be achieved uniformly from the surface to the depth desired in tissues. By this procedure irradiation of experimentally transplanted tumors was carried out to learn more about the possible therapeutic uses of such particles in cancer.

Giant Cell Formation in Neoplasms Resulting From Heavy Particle Radiation

A series of experiments were made in which implants of transplantable mouse tumor were exposed to radiation from deuterons produced in a

EMPLOYMENT OF THE 3-Mev VAN DE GRAAFF GENERATOR IN PRODUCTION OF MONOENERGETIC FAST NEUTRONS FOR SPLEEN-THYMUS WEIGHT-LOSS STUDIES IN MICE

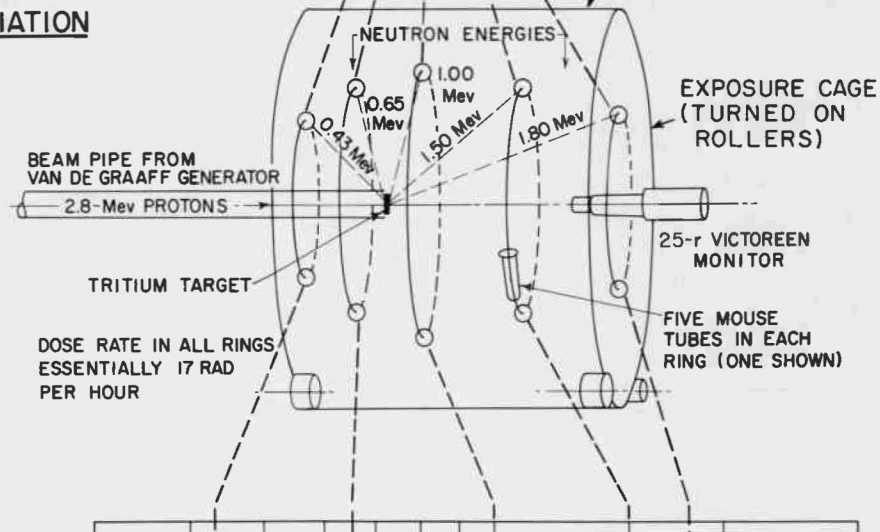
I NEUTRON PRODUCTION



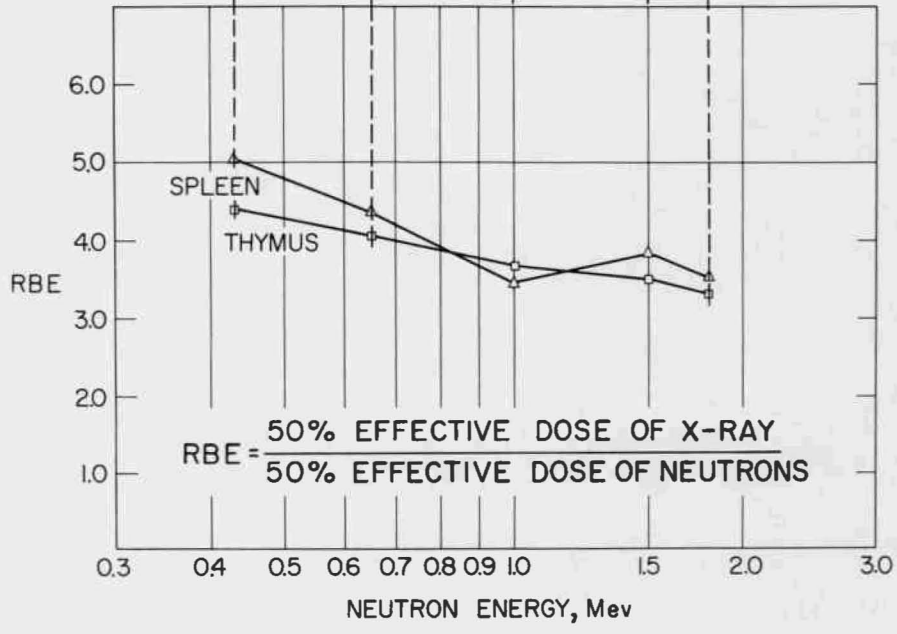
ENERGY AND FLUX OF NEUTRONS ARE FUNCTIONS OF ANGLE θ OF EMISSION FROM THE TARGET

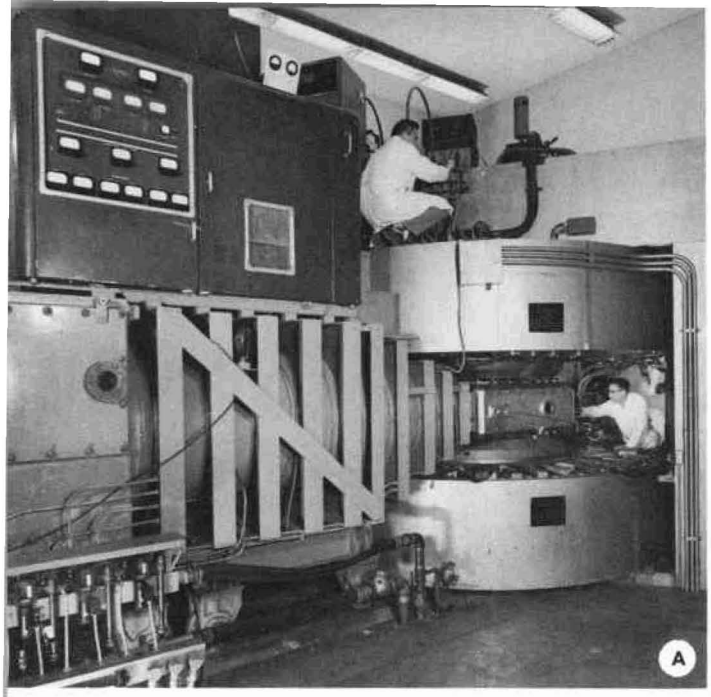
VAN DE GRAAFF SETUP

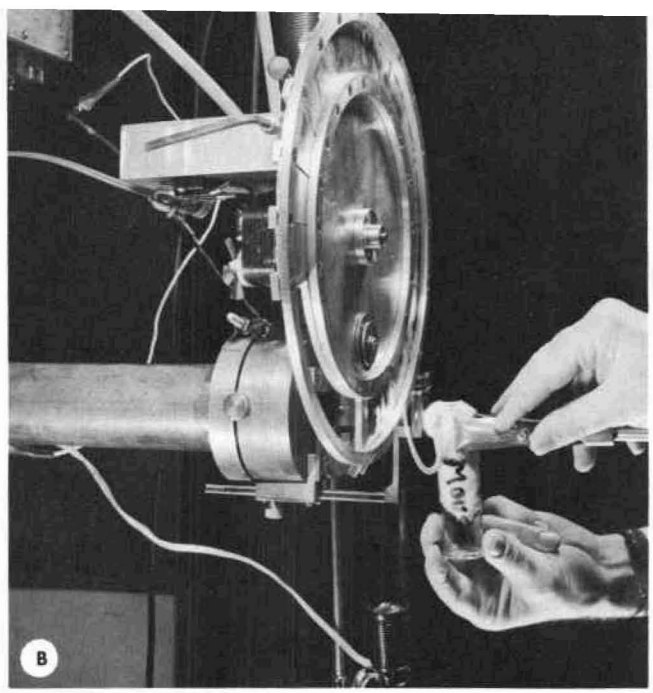
II ANIMAL IRRADIATION



III RESULTS

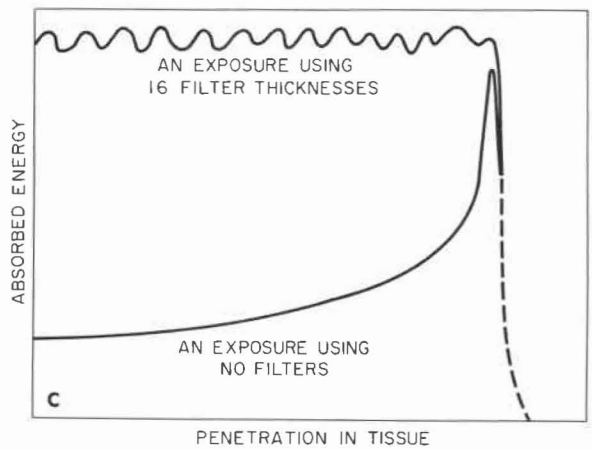


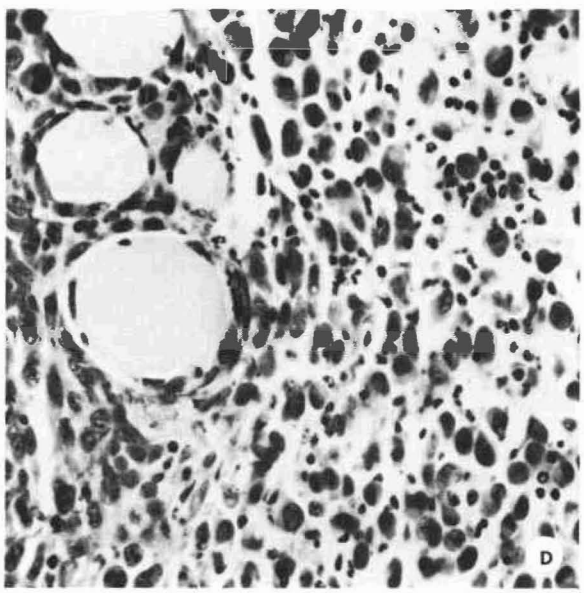


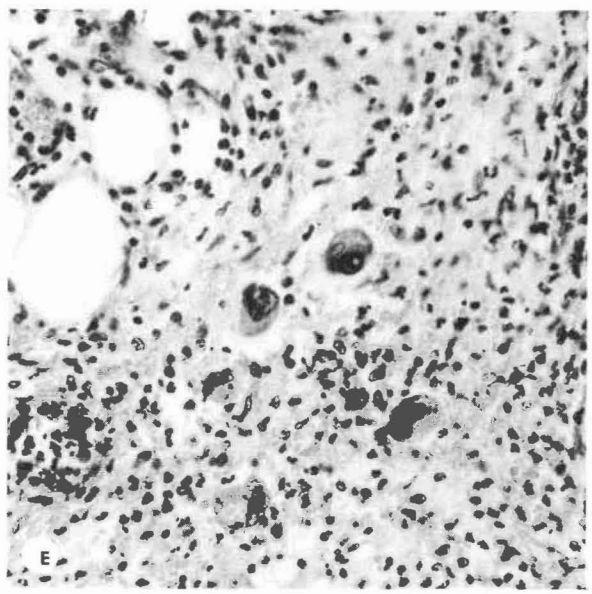


RADIATION EFFECT OF ACCELERATOR-PRODUCED DEUTERONS ON TRANSPLANTABLE NEOPLASMS

The 60-in. cyclotron (A) is the source of highly energetic deuterons. A beam-filtering wheel (B) was developed to control the amount and location of energy (deuterons) absorbed in tissue (C). The uniformly malignant character of the cells in a transplantable neoplasm is shown (D) before radiation with deuterons. Six days postradiation, the transplanted neoplasm shows only inflammatory cells and nonproliferating tumor giant cells (E).







60-in. cyclotron at an energy of 20 Mev. One-mm cubes of viable neoplasm were tranplanted into mice as controls. Cubes of neoplastic tissue of the same size were exposed *in vitro* to deuterons in varying amounts and then transplanted immediately. Animals were sacrificed from 1 to 10 days later. After radiation, during the follow-up period, it was noted that neoplastic cells lived for a period of time but apparently failed to multiply. With decrease of cellularity of the neoplasm, bizarre giant cells developed (presumably from malignant cells). These residual giant cells failed to multiply, and the transplant failed to invade or even to survive. This raises the important question of whether giant cell formation in neoplasms indicates simply development of a cell type no longer capable of reproduction rather than of one that may yield a clue to the degree of malignancy of the neoplasm.

Preliminary Studies on the Pathology of Particle Radiation With High Energy Protons Produced by the Cosmotron

Investigations utilizing the 60-in. cyclotron as a source of 10-Mev protons and 20-Mev deuterons to irradiate both intact animals and mice with transplantable neoplasms are being extended by using the Cosmotron as the source of particles. The Cosmotron is a proton synchrotron in which injected protons may be accelerated to an energy of 3 Bev. It is also possible to obtain 2-Bev π^- and π^+-mesons (first discovered in cosmic rays). By varying the period of exposure the total amount of radiation needed for experiments may be obtained. The homogeneity of the beams can be determined by exposing plastic foil squares of various sizes superimposed on one another (centrally placed) and measuring the activity, as for example in the conversion of C^{12} to C^{11}. These studies are being carried out to determine the effects of protons and mesons on (1) the cerebral memory system by using whole-brain irradiation of mice and partial-brain irradiation of rabbits and evaluating the results by conventional and refined histochemical techniques; (2) the viability of transplantable animal tumors; and (3) relative biological effectiveness.

Proteins Labeled With Cyclotron-Produced I^{124} (a Positron Emitter) for Tracer Studies

During the year, I^{124} (a positron emitter) was produced at the cyclotron by bombarding an antimony target with alpha particles. The I^{124} was then separated in the Hot Laboratory. Successful iodination of gamma globulin was achieved. The first patient to whom the labeled globulin was administered had a primary brain neoplasm, and the use of a positron scanner showed that a greater concentration of the globulin was located in the neoplasm than in the intact brain. The diagnostic possibilities of locating cancer sites by utilizing the site of degradation of the labeled protein will be investigated in the brain and various organs.

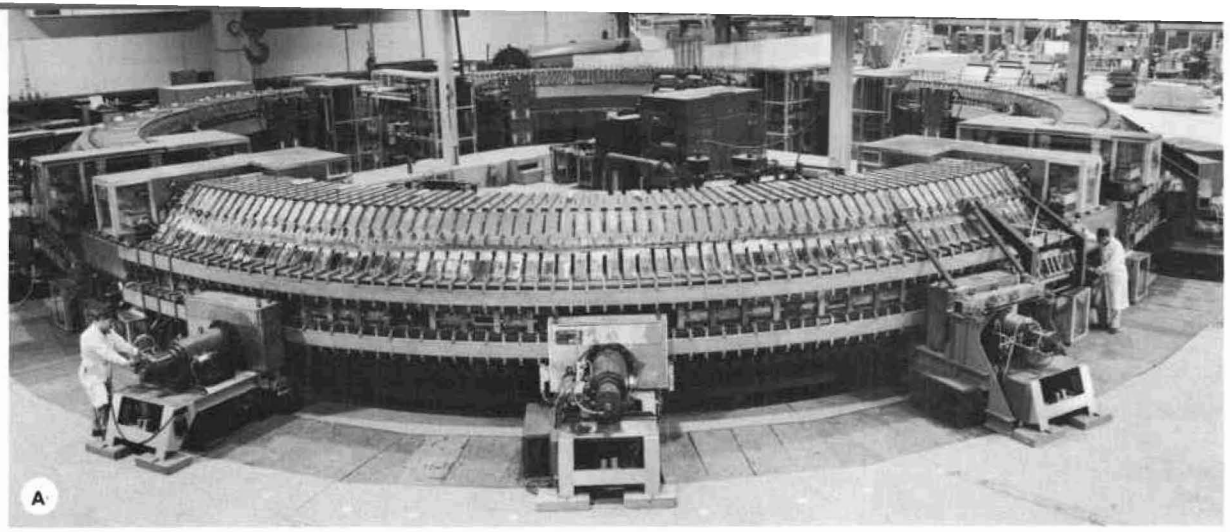
ENVIRONMENTAL MEDICINE

Effects of Ionizing Radiation on Immune Mechanisms in Animals

Ionizing radiation appears to have a specific effect on immune mechanisms whereby the normal immue responses are suppressed in proportion to the dose of radiation delivered. The capacity to produce antibody may thereby be greatly inhibited or even abolished in irradiated animals. A study has been in progress for more than ten years to determine the effects of radiation on antibody production with reference to natural resistance and to active and passive immunity to bacterial and parasitic infections. The radiation used is Co^{60} gamma-rays, and the test animals are pathogen-free mice. Each year variations are introduced in the choice of antigenic material, time of observation, primary or secondary immune processes under study, etc. In this year's study the radiation was found to inhibit or abolish antibody formation after administration of influenza virus vaccine and tetanus toxoid, and to enhance susceptibility to anaphylaxis.

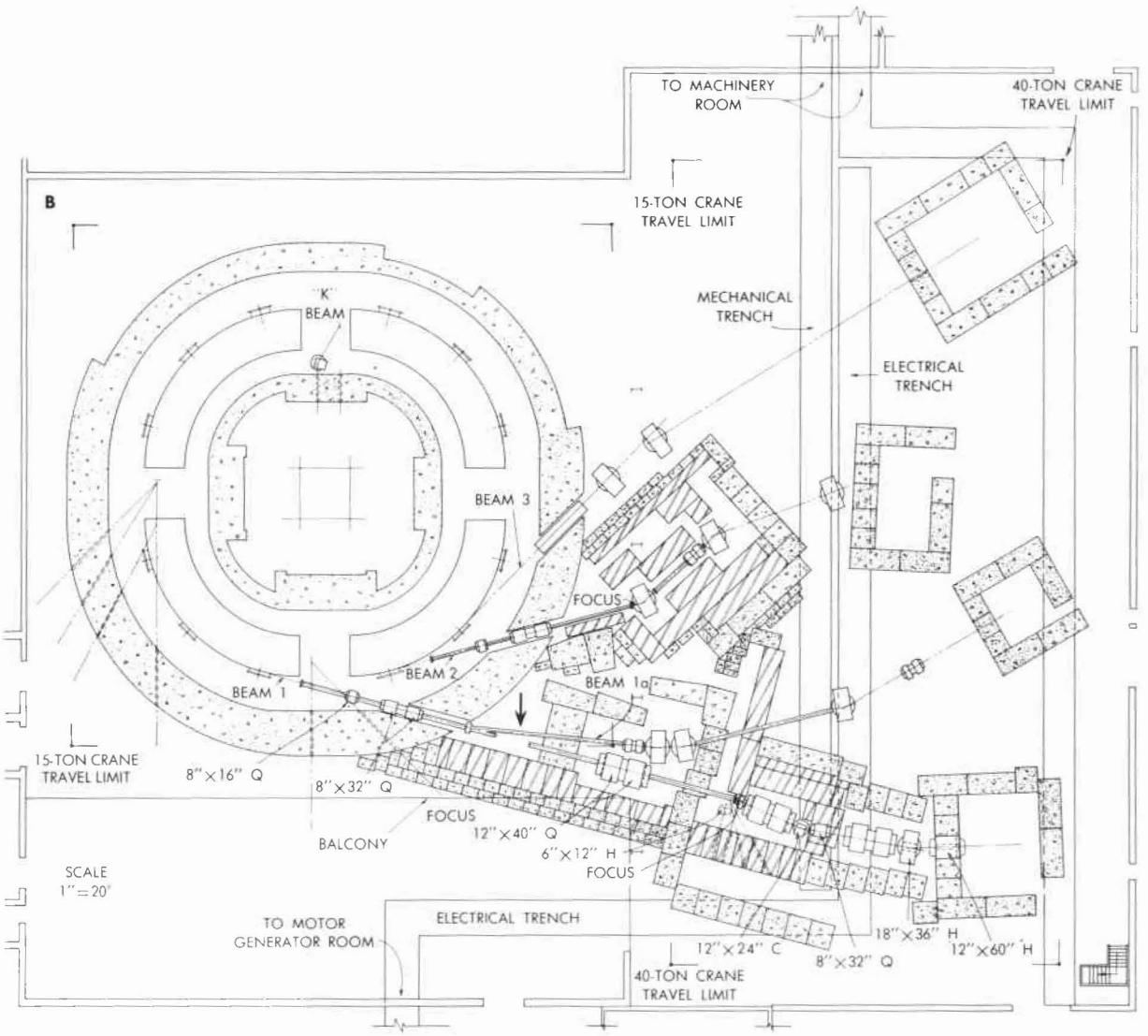
In Vivo Measurement of Radioactive Materials in Man

General demographic studies of populations that have received continuous low level radiation from internally deposited radioactive materials are of interest because it is possible to estimate the dosimetry from the amount remaining in the body at later times, and to relate it to the resultant biological effects. The retention of Thorotrast by a sizable population is of particular interest, since this internal emitter deposits itself in liver, spleen, and marrow, rather than other viscera. Resultant neoplastic lesions have been reported in these areas of thorium deposition. Although the tissue dosimetry for the Thorotrast study is extremely



EFFECTS OF HIGH ENERGY PROTONS PRODUCED BY THE COSMOTRON

The Cosmotron (A) is a synchrotron that accelerates protons in a circular path to speeds approaching the velocity of light. The protons attain an energy of 3 Bev and are directed as a beam towards a target, as shown in (B). In the experimental area at the rear of the Cosmotron mice with growing tumors are being arranged (C) prior to radiation with 3-Bev protons to study the therapeutic effects of these high energy particles.



complex, the whole-body gamma spectrometer offers a promising approach for making the necessary identification and quantification of the gamma-emitting residual daughter products in the decay chain.

Dosimetric experience has been gained through studying five patients. Three of these patients were terminal cases, and Thorotrast was administered to them so that the absolute levels of their body burdens could be counted and compared with a calibrated amount of Th^{232} in the liver and spleen of a plastic phantom of standard man. Analysis of the material injected is under way by alpha pulse-height analysis; this is necessary for the calibration of the counting apparatus for measuring the thorium dioxide from the daughters. In addition, two patients who received Thorotrast for diagnostic purposes (7 and 21 years ago) were measured, and estimates of their thorium dioxide body burdens were obtained. These individuals had local infiltration at the site of injection, which somewhat complicated the calculations. However, by measuring individuals at different periods extending over years, it may be possible to correlate the low level radiation with the ultimate biological result.

TRACER STUDIES WITH TRITIATED COMPOUNDS AT THE ORGAN, TISSUE, AND CELLULAR LEVELS

In the past a number of attempts have been made by many investigators to tag or label cells in order to determine their origin, rate of division, growth, and fate. Initial methods were unsatisfactory because the label did not remain in the cell long enough or was toxic to the cell, or because the amounts of tissue required were too large for ease in handling. In this department a number of investigators in various disciplines have selected as the locus for labeling a component occurring regularly in cells and concerned with one or more major functions. This constituent is deoxyribonucleic acid (DNA), which is found solely in the nuclei of cells. It is a chemical carrier of heredity (the main constituent of genes and chromosomes) and remains stable and unchanged in any given cell. New DNA is made only for the formation of new cells preceding cell division. From other laboratories reports had come that N^{15}-labeled thymidine could be used for the same purposes. From these observations came the background for the technique developed in this department, in which tritium (H^3) was selected for labeling thymidine. The beta particles of tritium, which have an average energy only one ninth that of those of C^{14}, offered the highest resolution yet obtained in an autoradiograph of a cell, giving a range of little more than a micron in the photographic emulsions. This relatively permanent label has been used as an identifying marker in cells in a series of studies and will continue to be used in a long-range program concerned with bone marrow, peripheral blood, and the skeletal system under normal, disordered, and diseased states, as well as with effects of factors outside the living body, as in tissue culture, and with processes such as inflammatory and neoplastic reactions at organ, tissue, and cellular levels.

During the year studies have been undertaken on a rather large scale of the effects of aging on bone, a tissue suitable for study in simultaneous histochemical and autoradiographic investigations. Aging in any tissue is a complex cellular and biochemical process that has not yet been well characterized. The specific objective of these continuing studies is determination of the metabolic and cytological changes taking place with age within the cells of the periosteum and bone in general. Histochemical, cytologic, electron micrographic, and autoradiographic procedures are used for determination of the contents of mucopolysaccharides, respiratory enzymes, and metabolically important enzymes, and for finding the mineral relations and the relationships of the fibrous structure to the crystal structure. As one example of the importance of this approach, the relationship of the fibrous bundles of collagen to the nonorganic bone structure has been established. The pattern of deposition and interlacing directly determined demonstrates that the stress structural patterns of bone deduced years before by earlier investigators are essentially correct. In this same tissue it has been demonstrated that the osteogenic cells of the periosteum participate significantly in the remolding of the bone in longitudinal growth in addition to growth at the cartilaginous plate. The proliferative potential of the periosteum diminished rapidly from birth to $\approx$8 wk of age in animals, while that of the epiphysis maintained an initial high level of proliferation up to 5 wk; the epiphysis then followed a course similar to that of the periosteum. A further example of research in this area is the study of the

origin of osteoclasts, which are so important in resorption of bone and maintain the balance between bone deposition and removal. It has been shown clearly that the osteoclasts arise from fusion of osteoblasts.

RADIOACTIVE TRACER METHODOLOGY

Development of a New Positron Multidetector Scanner

Radioactively labeled substances that concentrate in the body tissues or compartments are being investigated in the development of possible diagnostic procedures. Typical scanning methods, however, use only one or a pair of detectors. The localization of positron emitters depends upon the principle that annihilation of the positron produces two gamma-rays which are emitted in opposite directions. Therefore, two detectors can see these two gamma-rays in coincidence and establish a line along which the source is localized. Multiple detectors shorten the scanning time because (1) multiple areas are seen simultaneously, and (2) emissions in many directions from a given point are detectable. Three-dimensional models for various possible distributions of the detectors have been built and examined for quality of volume coverage. When the design criteria are sufficiently well established, a working model of the proposed system will be constructed and tested. Ideally, the physician should have a picture from two or more views or through several planes of interest upon completion of the scan. This may require construction of a special computer to be installed in the counting room. One of the ultimate goals of this project is to develop an instrument which would produce a scan as nearly instantaneous as possible with a minimum of equipment so that copies could be used in other institutions. Many tracer problems are being studied in the Department in which an improved method of scanning is needed.

Metabolism of Labeled Amino Acids and Vitamins in Neoplastic Diseases

These studies are concerned with the isolation and analysis of tryptophan metabolites present in urine. The kynurenine pathway of tryptophan degradation appears to proceed by oxidation of the indole nucleus, as shown with C^{14} labeling in specific positions of the benzene ring. Clinical studies in the literature indicate that in some neoplastic diseases elevated levels of these metabolites occur in urine. In addition, there is recent evidence that two of them (3-hydroxyanthranilic acid and 3-hydroxykynurenine) exhibit carcinogenic activity in producing a mouse bladder tumor. This makes it even more important to establish the function of such materials in the metabolism of tryptophan to quinolinic acid and niacin. The intermediary conversions of these metabolites and the final products in the urine may be of considerable importance in understanding the pathogenesis of certain neoplasms, as, for example, the nonindustrially related neoplasm that occurs in the bladder of man. The observations may have importance in the study of other neoplastic disorders and of the rates of incorporation of amino acids into serum proteins and into neoplastic tissues, as distinguished from normal tissues.

Metabolism of Labeled Amino Acids and Plasma Proteins in Animals

Blood and interstitial fluids collectively bathe the tissues of the body, and a physiological relationship exists between the fluid component and interstitial fluid. The common therapeutic route for metabolites and such things as drugs is via the blood stream. Many of the compounds occurring in the blood are carried by specific plasma proteins with which they may enter or leave the blood stream. In addition, several plasma proteins may be altered in amount or in function during the course of a disease. Thus the matter of protein manufacture and destruction is important in understanding some disease processes and rational therapeutic approaches. The studies in this area have been concerned with labeled amino acids in relation to the formation of hydroxylysine from lysine in collagen; in the metabolism of tryptophan and glycine properly labeled; in a parasite occurring in the tissues of an animal; and in the determination *in vitro* (usually with I^{131}) of the rates of disappearance from the circulation and/or the rate of excretion of catabolic products. Proteins studied thus far have included albumin, gamma globulin, α-lipoprotein, and ribonuclease. Mechanisms investigated have included the immune reaction in animals following administration of suitable antigens as well as glomerular filtration and absorption of reticulo-endothelial cells.

Kinetics of Sodium and Labeled Hormones in Human and Experimental Hypertension

Chronic arterial hypertension (high blood pressure) is one of the most common diseases in this country, and the chief causes of death in this entity are due to complications of atherosclerosis (degenerative alterations) in the vessels of the heart, brain, and kidneys resulting in such conditions as coronary thrombosis, apoplexy, and renal failure. The cause or causes of hypertension and of atherosclerosis have been explored from different points of view in animals and in man by many investigators. In certain animals, feeding of excess salt can provoke the appearance of hypertension, usually without development of atherosclerosis. Numerous studies of essential hypertension in man have produced some evidence that an aberration of sodium metabolism is associated with this disease. In view of all these observations, detailed long-time studies of the role of sodium in hypertension in man and animals have been under way in this department for several years and will be continued for several more.

Study of Carbohydrate Metabolic Processes in Man by the Use of C^{14}-Labeled Compounds

Metabolism in man may be considered broadly as the total physical and chemical processes by which the living cells of tissues and organs maintain life. The entire breadth of such multiple biochemical activities cannot at present be measured and studied simultaneously. Individual phases, however, can be investigated by selection of appropriate radioactive isotopes such as C^{14} which has been rather widely used in animals and is now being employed in the study of diabetes in man. In this disease a disorder of carbohydrate metabolism results in an excessive amount of sugar in the blood and loss in the urine. With serious advance of the disease abnormalities of protein and fat metabolism also occur.

The current research in this department began with an investigation of the pathways of carbohydrate formation in subjects with presumably normal metabolism and has been extended to various types of diabetic patients. The technique used is based upon determining the isotopic distribution of glucose in subjects given 1-C^{14}-acetate. The amount of C^{14} converted to glucose has strongly suggested the overproduction of glucose, particularly in acute ketotic diabetes. C^{14}-acetic acid is also being used in studies of lipid metabolism to derive information on controversial problems in fat metabolism, and the turnover of cholesterol in plasma red cells is under investigation with C^{14}-mevalonic acid. Such studies indicate how quantitative differences in rates of reactions, rates of transfer between metabolic and cellular compartments, and selection of alternate routes of metabolism may be observed in health and disease.

RESEARCH HOSPITAL AND INDUSTRIAL MEDICINE CLINIC OPERATIONS

All patients admitted to the Hospital for participation in research endeavors must be referred by their own physicians, who continue to be responsible for them. The function of the staff is to consult with the referring physician concerning procedures best carried out at BNL. The medical profession has been most cooperative in carrying out this type of joint program. The diseases under investigation and treatment are not listed here because of their wide variety, the common factor being suitability for our research program. The appropriateness of any given patient will depend on the status of the project. Therefore, physicians are encouraged to submit data on patients in writing, so that staff members may give adequate consideration to their suitability for study.

During the past fiscal year there were 249 admissions to the Hospital compared with 202 in fiscal 1960. A total of 172 inpatients were admitted in fiscal 1961, compared with 117 in 1960. These data indicate a steady increase in use of the Hospital.

A novel extension of services developed during the past several years shows great promise. In the treatment of a number of conditions, the collaborative procedure most beneficial to a patient has proved to be admission to the Hospital for observation as a research ambulatory patient rather than as an inpatient. Except for special visits of a few hours each, the patient remains in the hospital of origin or at home, under his own physician's care. The administration of isotopes of appropriate radioactivity and half-life insures the safety and mobility of the patient. At stated intervals the patient is examined with necessary scans, counts, and laboratory tests carried out during the course of the day. During the past year, a regular weekly

transportation schedule has been maintained between Brookhaven and a metropolitan hospital. A Medical Department Research Collaborator was in charge of the patients in that hospital or at home so that visits could be planned to make maximum use of Brookhaven's facilities. While this type of expansion and study has definite limitations, it provides a means of securing necessary breadth of observations at a cost concomitant with furtherance of the project. During the past year 1443 visits to the Research Ambulatory Clinic were made by 171 patients.

Visits to the Industrial Medicine Clinic during fiscal 1961 increased from 13,650 to 14,353, primarily because of the services of an additional physician. Total x-ray examinations were 2691; of these, 2082 originated in the Industrial Medicine Clinic. The total number during the previous year was 2236.

Routine examinations of employees continue to be made in the whole-body counter to record and observe body burdens of radioactive nuclides, including the naturally occurring radioactive isotopes. Because this heavily shielded facility is in great demand, the scheduled examinations of employees in the whole-body counter have not proceeded as rapidly as planned. Designation this spring of a specified time interval for employee scans should prevent further delays in carrying out the schedule.

SPECIAL PROJECTS

Medical Examinations of the People of the Marshall Islands Exposed to Fallout

In March 1954, following detonation of a nuclear device, 239 Marshallese were accidentally irradiated by fallout. Medical studies of these people and of control populations have been carried out on an annual basis by teams of physicians under the auspices of the Division of Biology and Medicine of the United States Atomic Energy Commission and under the direction of the Medical Department of Brookhaven National Laboratory. Research collaborators from many institutions take part, and this year some of the Medical Department personnel of the Trust Territory of the Pacific Islands participated in the examination for the first time. Extensive data were obtained bearing on a wide variety of disease states. It is gratifying to report that thus far no serious residua of exposure to fallout have developed. Arrangements are being made with the Trust Territory to provide transportation previously furnished by the United States Navy. Plans for the next survey are already well under way.

Medical Department Conclaves

As part of its general educational endeavor the Department has sponsored jointly with the Division of Biology and Medicine of the US AEC a series of annual conclaves on nuclear science in medicine. Participation is by invitation only, and the objective is to provide two full days of discussion and demonstration dealing with a special field of medicine in which the visitors are qualified. Members of the Brookhaven Medical Department Staff give talks as a basis for discussion as well as demonstrations of various devices useful in atomic energy programs. The fifth such conclave, held March 27 and 28, 1961, was entitled "Pediatricians, the Child, and Atomic Radiation," and was attended by 78 chairmen of departments of pediatrics from 70 medical schools in the United States (including one from Puerto Rico) and from 8 in Canada.

Research Preceptorship in Nuclear Medicine Methodology and Practice

The summer of 1961 will mark the third year of this venture into cooperative medical education in which the facilities and to a degree the services of the staff of the Medical Department are made available to faculty members and students of participating medicals schools to provide experience in nuclear medicine at a fourth-year medical student level. The work is so arranged that it may be molded by the faculty members into a survey course in nuclear medicine for which academic credit can be given. At the same time the staff of the Medical Department participates with the students in conferences and laboratory work on a research preceptorship basis. The objective is to furnish medical schools not associated with a large atomic energy project with a means of introducing their students to the medically important aspects of atomic energy.

The University of Texas Medical Branch participated in the pilot experiences of the first two

years. This year the University of Southern California School of Medicine, the University of Cincinnati College of Medicine, and Cornell University Medical College are also participating. A revised schedule of activities has been planned for the twelve students expected to attend. Eight faculty members, two from each school, will comprise the faculty of instruction, and the staff of the Medical Department will supervise the participation in research methodology and practice.

SUPPORTING ACTIVITIES

Technical Operations and Services

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

REACTOR OPERATIONS

The Brookhaven Graphite Research Reactor (BGRR) was in routine operation during 82.3% of the year. In addition to 25 scheduled shutdowns for service work and changing experimental equipment, there were 9 unscheduled shutdowns; 5 were due to failure of the power supply, 3 were caused by severe snowstorms, and 1 was prompted by the approach of a hurricane.

To maintain reactivity requirements, the loading was gradually expanded from 548 to 575 channels. A total of 937 fuel elements were replaced; the average burn-up of the discharged elements was 38%.

The reactor graphite structure was successfully annealed three times. It has now been annealed 16 times. The maximum graphite growth to date was experienced just prior to the tenth annealing operation. All subsequent operations have caused a shrinkage of the graphite growth slightly in excess of the growth between annealing operations.

The shielding tank located on the top of the reactor since 1950 was removed to provide space for other experiments. The demand for this facility, last used on a full-time basis in 1958, was insufficient to warrant its continued maintenance. The medical facility on top of the reactor is also being removed, since the Medical Research Reactor (MRR) now meets the needs of the Medical Department.

Effective February 25, 1961, the reactor operating cycle was changed from a two-week to a three-week cycle. This change, which was approved by the Reactor Users Committee, reduced the amount of overtime work required.

Following the SL-1 incident, a special inspection of all reactor facilities at the Laboratory was made by a committee appointed by the New York Operations Office of the AEC. Concurrently, the BNL Reactor and Critical Experiments Safety Committee conducted reviews of reactor conditions. Following the scheduled shutdown of March 16, 1961, the AEC instructed the Laboratory to delay start-up until a formal review could be made of all operating procedures. This review was conducted by the Committee in the presence of AEC officials on March 17, 1961, and reactor operations were resumed on schedule. Later a similar review of the MRR and the Critical Assembly Facility was conducted, which resulted in some lost operating time for these facilities.

All operating and process manuals have been revised and reissued, and a review of training procedures for reactor supervisors and operators has been initiated. A formal qualification program for reactor supervisors has also been instituted.

Utilization of the BGRR

The research done in the experimental holes ($\approx$38) assigned to BNL research departments is described in the appropriate sections of this report. Other reactor holes are assigned to outside organizations under various cooperative arrangements.

Table 1 summarizes the use of the reactor during the past three years. Since no direct AEC budget appropriation is available for the operation of the BGRR, the operating costs are recovered through rentals.

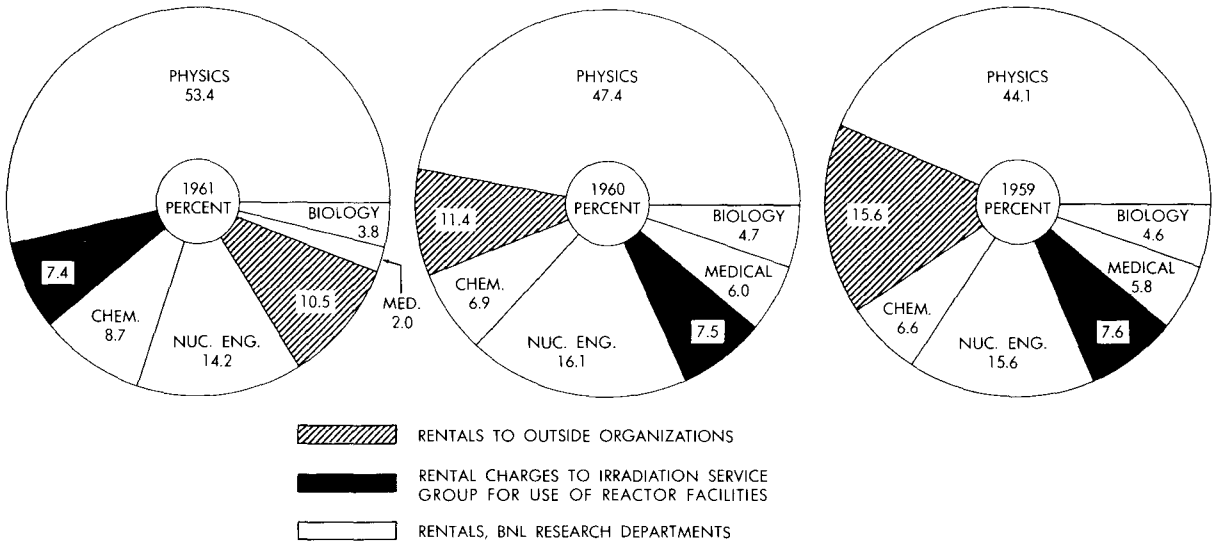
The outside organizations making significant use of the reactor are listed below, together with a brief description of their research projects.

Rensselaer Polytechnic Institute. Loop experiments are being carried out to determine the effect of fission fragments on oxygen-nitrogen mixtures circulating through a tube containing quartz fibers that contain 15 wt % U_3O_8 (90% enriched in U^{235}). (Work performed under Government Contract No. AT-30-3-321.)

A new in-pile section has been installed. This section is essentially a heavy wall, stainless steel tube $\approx$2¼ in. in diameter and 11 ft long, divided into three compartments. The innermost compartment is $\approx$12 in. long and contains a heater to preheat the circulating gas. The middle compartment, $\approx$6 ft long, contains the uranium-bearing quartz wool. The third compartment con-

Table 1

Summary of Reactor Use Charges



	Fiscal Year					
	1961		1960		1959	
Rentals						
Outside Organizations		$ 121,621		$ 149,119		$ 175,294
Irradiation Service Group		84,720		97,920		85,408
BNL Research Departments						
Physics	$615,933		$621,827		$494,694	
Chemistry	99,900		90,480		74,280	
Nuclear Engineering	165,193		211,960		175,020	
Medical	23,896		79,200		66,000	
Biology	43,410	948,332	62,240	1,065,707	51,790	861,784
Total Rentals		$1,154,673		$1,312,746		$1,122,486
Reactor Irradiation Service Charges (Excluding Handling Charges)						
Outside Organizations		$ 56,670*		$ 88,971		$ 81,600
BNL Research Departments						
Physics	$ 23,837		$ 17,730		$ 16,427	
Chemistry	7,715		8,534		4,553	
Nuclear Engineering	27,428		11,234		16,744	
Medical	6,170		3,934		6,489	
Biology	1,200		218		362	
Instrumentation and Health Physics	550	66,900	2,380	44,030	280	44,855
Total Irradiation Charges		$ 123,570		$ 133,001		$ 126,455

*The apparent decrease in charges from 1960 to 1961 reflects the establishment of separate accounts for service irradiations, processed radioisotopes, and handling.

tains a filter medium to trap volatile fission products. (Work performed under Government Contract No. AT-30-3-321.)

Bell Telephone Laboratories. Studies are being carried out on neutron diffraction from crystals of magnetic interest at room temperature and at 4.2°C. (Work done under a utilization agreement.)

Studies of radiation damage in semiconductor materials and devices were carried out. (Work done under Government Contract No. AF-33-616-6235.)

General Electric Company (Knolls Atomic Power Laboratory). A miniature fission chamber was irradiated in a thermal neutron flux of $\approx 10^{13}$ neutrons/cm^2-sec for three weeks. A heater surrounded the chamber, and measurements were taken at reactor ambient temperature and at 800°F while the irradiation was in progress. At the end of the irradiation, the chamber was removed from the reactor and transported to the waste disposal area. (Work done under Government Contract No. W-31-109-ENG-52.)

General Electric Company. Studies of magnetic and crystal structure are being carried out from neutron diffraction patterns obtained from various crystals and powders at different temperatures. (Work done under a utilization agreement.)

Westinghouse Electric Corporation. As part of a study of radiation damage on materials at low temperatures, samples of U-Zn-Mo were irradiated at −100°C. After irradiation, the samples were returned to Westinghouse for study. (Work done under Government Contract No. AT-11-1-GEN-14.)

Naval Research Laboratory. The changes in the magnetic properties of magnetic core materials caused by reactor radiation damage are being studied. (Work done under Government Contract No. NRL/AEC-11-61.)

Long-term irradiation of several steel specimens is being carried out at reactor ambient temperatures. Upon completion of irradiation, the specimens will be returned to NRL for radiation damage studies. (Work done under Government Contract No. NRL/AEC-11-61.)

Anton Electronic Laboratories. An ionization chamber was irradiated in a flux of 10^{11} neutrons/cm^2-sec. Measurements were made while the irradiation was in progress. Upon completion of irradiation, the chamber was returned to Anton for possible future use in a reactor.

Republic Aviation Corporation. A study was made of the effectiveness of a charcoal bed in adsorbing gaseous fission products. This experiment was one of the supporting projects for the development of the Pebble Bed Reactor Concept for the AEC. (Work done under Government Contract No. AT-30-1-2207.)

Nuclear Science & Engineering Corporation. Helium gas heated to ≈1200°F was passed over a fuel cell containing one "pebble," a solid sphere composed of a mixture of U^{235} oxide and graphite with a cladding. The exhaust helium gas was analyzed to determine the content of gaseous fission products escaping through the cladding. This experiment was also a supporting project for the development of the Pebble Bed Reactor Concept. (Work done under Government Contract No. AT-30-1-2378.)

Grumman Aircraft Engineering Corporation. Electronic components were irradiated in the instrument tunnel to determine their activation by fast neutrons. The intensity of fast neutrons in the tunnel was enhanced by the use of a U^{235} converter plate which essentially converts thermal neutrons to fission neutrons. After being activated the samples were analyzed by using a 256-channel pulse-height analyzer. (Work done under Government Contract No. NOas-60-6079-c.)

The following organizations carried out experiments at the BGRR under an internal arrangement with the BNL Physics Department.

Columbia University. In the helium recoil experiment measurements were made of the energy spectrum of recoil nuclei that have emitted a beta particle of discrete energy in the decay of He^6. The He^6 is produced according to the reaction $Be^9(n,\gamma)He^6$, by bombarding beryllium hydroxide in the reactor.

A single-crystal neutron spectrometer with a neutron energy range from 0.0006 to 10 ev was used to measure total neutron cross sections. The cross sections were determined for samples of Pu^{239} of high enrichment, manganese compounds, ammonium halides, and benzene compounds formed by the addition of methyl groups. The spectrometer is also used to study materials for possible use as cold neutron moderators. The mass distribution of fission fragments from U^{235} is being studied by utilizing a thermal neutron beam from the reactor, together with solid-state detectors.

Naval Ordnance Laboratory. The powder diffractometer was used jointly with the BNL Solid

State Physics Group for several powder diffraction experiments, mostly on magnetic materials. Some were performed at liquid helium temperature.

Picatinny Arsenal. A water-cooled facility was used primarily for the irradiation of special material at less than reactor ambient temperatures.

Procurement of Special Materials

The procurement for the scientific departments of all radioactive and stable isotopes as well as special materials controlled by the AEC is a responsibility of the Isotopes and Special Materials Group. In this connection, 215 purchase orders were placed for radioisotopes, 56 for stable isotopes, and 63 for special materials. Against these orders, ≈408 shipments were received and processed. These figures are almost the same as those for the previous year. Of the orders placed, ≈29% were for the Medical Department, 17% for Biology, 14% for Physics, 23% for Nuclear Engineering, 16% for Chemistry, and 1% for the Health Physics Division.

The Isotopes and Special Materials Group is also responsible for annual inventories of radium sources and purchased stable isotopes and for negotiations for the loan of valuable stable isotopes. The number of radium sources at Brookhaven increased from 34 to 39, but the total radioactivity (5.86 curies, with a value of $38,883) remained the same. The increase in the inventory of purchased stable isotopes from $26,851 to $34,075 reflects additional purchases totaling $17,657.80 and consumption of stable isotopes valued at $10,433.55. During fiscal 1961 the number of loan agreements for stable isotopes increased from 34 to 35 with a total value of $150,820.

Of the irradiation programs at the National Reactor Testing Station, Idaho Falls, Idaho, one was completed, one was extended, and two were continued. The one-year irradiation to produce Pb^{205} for the Chemistry Department was completed in April 1961. The program of irradiating samples of diamond powder for radiation damage studies by the Physics Department was extended to cover an additional five samples. The program for production of 500,000 curies of Co^{60} has been in progress for three years; ≈380,000 curies have been received and the balance is essentially ready for shipment. The program for testing prototype fuel elements for the Brookhaven High Flux Beam Research Reactor (HFBR) is continuing. The first element has been irradiated and is awaiting examination in the hot cell. Two more elements are scheduled to be irradiated and examined during fiscal 1962. In addition, a request was initiated for a new program involving irradiation of iron tensile test specimens for a study of radiation damage in pure iron by the Metallurgy Division.

Irradiation Services and Isotope Production

Table 2 presents a three-year summary of the volume and income involved in providing irradiation services and processed isotopes to outside organizations. The income from the irradiation services has increased, primarily because substantial price increases became effective early in the year. These price increases, however, along with the wider availability of similar services at other reactors, probably were a factor in reducing the number of irradiations.

In Table 3 is given the distribution of customers and shipments for the past three years. The shipments of special processed isotopes supplied by the Hot Laboratory are detailed in Table 4. At the end of fiscal 1961 the AEC discontinued its Research Support Program under which an 80% discount on the irradiation service charge was available for certain medical and agricultural research programs. Late this year the AEC announced its decision to discontinue supplying Co^{60} sources except in wholesale quantities and in the case of specialized sources, such as those provided by Brookhaven, which are not at present available elsewhere. Of the six sources shipped this year totaling 3170 curies, one of 850 curies was on a loan basis and one of 110 curies was supplied without charge. Most of the income given in Table 2 for this item came from the sale of one source of 2150 curies. The three remaining sources were small (≈20 curies each).

The use of the Brookhaven 60-in. cyclotron for irradiations for outside organizations has never been extensive. Most of the irradiations have been made for federal agencies or were done as part of cooperative programs with universities. During the past year, however, there was a marked increase in this cooperative effort.

At the request of the AEC, a detailed analysis was again made of reactor operation costs to determine the full costs to be borne by the various reactor facilities and irradiation services. This year the reactor fuel costs, such as fabrication, burn-up and reprocessing charges, were included for the first time. The net effect of the analysis was a 7%

Table 2

Three-Year Summary of Irradiation Services to Outside Users
(Handling and Other Charges Included)

	Fiscal 1961		Fiscal 1960		Fiscal 1959	
	Number	Volume, $	Number	Volume, $	Number	Volume, $
Reactor irradiations	828	84,858	1,025	54,294	1,189	73,507
Processed radioisotopes	330	64,490	325	51,133	291	37,655
Research subsidy	—	(42,095)	—	(33,183)	—	(24,049)
Co^{60} sources	6	6,098	5	8,186	12	42,320
Cyclotron irradiations	62	9,885	22	2,854	5	1,070
Total	1,226	165,331	1,377	116,467	1,497	154,552

Table 3

Types of Customers Receiving Shipments

	Fiscal 1961		Fiscal 1960		Fiscal 1959	
	% of Customers	% of Shipments	% of Customers	% of Shipments	% of Customers	% of Shipments
Hospitals	20	39	18	40	25	43
Industrial	39	30	42	31	42	31
Universities	24	24	24	20	18	18
Government	7	4	7	5	10	5
Foreign	10	3	9	4	5	3

Table 4

Shipments of Processed Radioisotopes

	Fiscal 1961		Fiscal 1960		Fiscal 1959	
Radioisotope	No. of shipments	Activity, mC	No. of shipments	Activity, mC	No. of shipments	Activity, mC
I^{132}	120	2,193	70	1,359	48	3,900
I^{133}	26	964	67	2,535	55	2,420
Mg^{28}	143	158	158	556	181	23
F^{18}	2	23	3	40	7	70
Y^{90}	51	1,733	25	1,503*	—	—
Ar^{138}	2	Stable	2	Stable	—	—

*This figure was erroneously given as 15,030 mC in last year's report.

increase in the reactor rental rates for BNL research departments, effective next year. Only a small increase in the irradiation service rates for next year was necessary.

Source and Special Nuclear Material Accountability

During fiscal 1961, the United States offered to make the Graphite Research Reactor and the Medical Research Reactor available to the International Atomic Energy Agency for international inspection in the control of special nuclear material for peaceful purposes. To facilitate such inspection, the AEC requested Brookhaven to set up separate SS accountability stations for these two reactors. Station MGR was established for the Graphite Research Reactor, and Station MMR for the Medical Research Reactor; separate man-

Table 5

Source and Special Nuclear Materials on Hand at End of Year (in kilograms)

	Fiscal year		
	1961	1960	1959
	Station BNL		
Natural U	2,688	2,895	3,096
Depleted U	2,950	14,538	33,847
$U^{235}>75\%$	69	163	174
$U^{235}<75\%$	7,815	11,850	6,766
U^{233}	0.051	0.051	0.051
Pu^{239}	2	7	14
Th	252	254	259
Heavy water	13,179	13,321	8,879
	Station MGR		
$U^{235}>75\%$	84	—	—
	Station MMR		
$U^{235}>75\%$	3	—	—

uals were written covering the accountability procedures for each station. On April 1, 1961, the special nuclear material in the form of fuel elements for these reactors was transferred from Station BNL to the two new stations.

Table 5 presents a three-year summary of the amounts of source and special nuclear materials on hand at Brookhaven at the end of each fiscal year. The figures for 1961 include the amounts for the two new stations. Based on dollar values published by the AEC, the current inventory of the SS materials listed represents a value of $\approx$\$4,000,000. The decrease from last year's figure of $\approx$\$7,000,000 reflects a decrease in material on hand and also a recent price reduction by the AEC.

The decrease in the amount of depleted uranium is the result of shipment of this fuel to Oak Ridge National Laboratory for chemical processing. The amounts of Pu^{239} have paralleled this decrease, since most of the plutonium was present in the irradiated fuel. The drop in the amount of uranium enriched $<75\%$ was due to shipment of some surplus material.

The inventory of uranium enriched $>75\%$ has decreased over the past three years because of its use in the BGRR. In addition, shipments of spent enriched fuel elements to the Phillips Petroleum Chemical Processing Plant, Idaho Falls, Idaho, were begun late in the fiscal year; these shipments will probably be made at the rate of approximately one a month. In April 1961 a purchase order was placed with Metals and Controls, Inc., Attleboro, Mass., for 3000 new fuel elements involving $\approx$45 kg enriched uranium with delivery to begin early in fiscal 1962. At the end of fiscal 1961 there were 4549 fuel elements in the BGRR, 427 fuel elements in the storage vault, and 1555 spent fuel elements in the storage canal.

Early in the year the fuel burn-up calculation program for the BGRR was transferred from a Remington Rand 409 punch card system to an IBM 704 magnetic tape computer. The status of all reactor fuel elements is now computed after each reactor shutdown, and the data are used for accountability purposes and for reactor operations.

As an AEC contractor, the Laboratory is required to submit monthly inventories of all materials, and both materials and records are subject to an annual audit by the AEC. Because of a full schedule, the AEC has not made such an audit for two years; however, one is scheduled for the beginning of fiscal 1962.

Medical Research Reactor

The MRR was operated on 227 occasions during the year, and 664,902 kw-hr of operation were accumulated. The total integrated energy to date is 891,950 kw-hr. In December 1960 another primary water heat exchanger was added in parallel with the original heater in conjunction with changes being made in the well-water system to conserve water. The change in the primary cooling circuit increased the capacity of the primary cooling pumps. Because of the possibility that fuel elements might float at this higher flow rate, an orifice plate was installed in the inlet water line to the reactor, and a fuel hold-down device, similar to an upper grid plate, was installed above the core. This change was completed in March 1961.

Annealing of the graphite core pieces to release the stored energy was begun in June 1961 and is expected to be completed by the end of July. The annealing is done by removing the pieces from the core and "baking" them at 300°C in an oven. Laboratory evaluations of stored energy in these graphite dummy fuel elements indicate the release of an average of 30 cal/g below a temperature of 300°C.

During the year no sticking or unsafe failure of control rods occurred. Following the SL-1 inci-

dent, a complete and detailed inspection of the control rods was made. Several minor improvements were made in their drive units.

HEALTH PHYSICS

The staff of the Health Physics Division increased from 55 to 62 during the year, chiefly because of the extension of Cosmotron operations to 21 shifts per week and operation of the Alternating Gradient Synchrotron (AGS) 10 shifts per week. Continuous health physics coverage is being provided at these facilities.

Area Monitoring

Calibration of the particulate monitor in the BGRR stack was completed, and routine estimates of particulate activity released have been made since January 1, 1961. The average rate for the past six months has been 2.5 curies per day. Most of the activity consists of iodine isotopes, and there is little variation in rate while the reactor is operating. Levels at the site boundary due to this release are negligible.

The network of area monitoring stations that monitor the Ar^{41} activity in the reactor effluent has been operated as in the past. Quarterly summaries of levels at four points on the site boundary have been issued to local press and government groups. The highest average level during calendar 1960, 0.72 mr per week, was for the station on the northeast perimeter. The highest single weekly level was 2.00 mr.

Routine measurements of the rate of deposition of radioactivity in rainfall and settled dust continued to be made by the pot collection method. The average fallout rate was 1776 dis/min/m^2 per week, which is 5% of that noted during the previous year. No exceptionally large peaks occurred, although somewhat higher levels were noted in September-October and late in the spring. The highest weekly rate was 8700 dis/min/m^2.

Personnel Monitoring

The use of personnel monitoring equipment continued to increase with the gradual growth of the Laboratory and increased use of the large synchrotrons. Film dosimeters were processed at the rate of 965 per week during calendar 1960, and 46% of the neutron monitoring (NTA) films, contained in all badges, were read as compared with 31% during calendar 1959. The increase was necessary because monitoring at the synchrotrons is entirely dependent on track counts on the NTA films.

Table 6

Distribution of Exposures of Individuals Receiving Regular Personnel Monitoring Service

Exposure index range*	Calendar 1960	Calendar 1959
0.0–0.4	1959	1815
0.5–0.9	77	66
1.0–1.4	23	25
1.5–1.9	25	16
2.0–2.4	9	16
2.5–2.9	5	8
3.0–3.4	4	11
3.5–3.9	4	2
4.0–4.9	11	12
5.0–5.9	15	3
6.0–6.9	8	2
7.0–7.9	4	3
8.0–9.9	3	2
10.0 or greater	0	0
Total	2147	1981

*Exposure index = ½ of β exposure in rad + γ exposure in r + neutron exposure in rem.

Average exposure per individual increased somewhat compared with the previous year. The distribution of exposures, given in Table 6, shows a slightly greater number of exposures >5.0. All exposures were <3 rem equivalent per 13-week period, except in the case of two individuals at the reactor who received exposures of 3.2 and 4.6 rem, respectively, in one 13-week interval. In no case has an individual exceeded the prescribed limit on integrated exposures.

Waste Disposal

A new building was provided for storage of contaminated equipment at the waste disposal area. A new underground tank arranged for easy detection of potential leaks was installed for evaporator slurry being held for processing into concrete. Another tank was obtained for transporting contaminated liquids from various laboratories to the tank farm when levels are too high for disposal to the sewer. Manipulators and other accessory equipment for the reclamation center have been obtained to facilitate dismantling and decontamination of highly radioactive equipment.

Table 7

Summary of Liquid Waste Data

	Fiscal 1961	Fiscal 1960
Input to filter beds, gal/day	519,600	523,300
Output from filter beds, gal/day	395,800	464,700
Net loss in filter beds, %	23.8	11.2
Stream above discharge point, gal/day	288,900	604,600
Stream at site boundary, gal/day	652,600	931,400
Rainfall, in./mo.	3.6	3.2
Activity concentration at input to filter beds, C/cc	7.9×10^{-13}	7.3×10^{-13}
Activity concentration at output from filter beds, C/cc	3.9×10^{-13}	2.7×10^{-13}
Reduction in activity concentration, %	50	63
Activity at input to filter beds, mC/mo	45.1	42.4
Activity at output from filter beds, mC/mo	17.9	15.3

Figures are averages for each fiscal year.

Data relating to the liquid waste system are presented in Table 7. The amount of activity leaving the site in the stream into which the effluent is discharged totaled 175 mC during fiscal 1961, and the average concentration was 0.20×10^{-6} μC/cc.

General Safety

The on-the-job injury frequency rate, continuing its downward trend, reached a new low for recent years of 2.4 per million man-hours for the first six months of 1961. The period from July 8 to November 15, 1960, a total of 1,769,678 man-hours, was without a disabling injury, and from December 14, 1960, to March 1, 1961 (1,051,960 man-hours), the Laboratory again exceeded the million mark for accident-free man-hours. For each of these two periods the Laboratory received special recognition from the AEC and the National Safety Council.

The long-term effectiveness of the safety effort is beginning to be manifest in the increased demands for consultation from all sections of the Laboratory. Some attention is now being given to off-the-job safety through a program of sales of home fire extinguishers, automobile seat belts, and similar items to employees.

APPLIED MATHEMATICS

COMPUTATIONAL SERVICES

As in past years, the Division has provided computing service to the Laboratory through the use of the IBM 704 at New York University. Since July 1960, the use of that machine for BNL work has increased from 40 to 60 hr per week, and more time could profitably be used if it were available. In consequence of this expanding need, plans were initiated in the summer of 1960 for the installation at the Laboratory of a modern digital computer. After careful study of the products of several manufacturers, it was decided that a special IBM 1401-7090 configuration would best fill the current and immediate future needs of the Laboratory. The IBM 1401 will be installed on site early in September 1961, and the IBM 7090 is expected to be installed toward the end of the calendar year.

During the spring of 1961, the Merlin computer being constructed by the Instrumentation Division became available for the solution of a few small problems from other groups in the Laboratory. However, the primary purpose of such specially constructed devices is not their use for "production" problems of large magnitude and long running time, but rather for what may be called "experimental mathematics," i.e., the investigation of alternative procedures for handling new problems for which past experience furnishes no guide and no theoretical basis exists for preferring one method to another. In this area devices like Merlin are superior to commercially available machines because of their more flexible order structure and the possibility of more immediate and easier communication between the originator of the problem and the computer.

In May 1960 a study was initiated of the feasibility of establishing communications between Merlin and the IBM 7090 by installing an additional tape system on Merlin. Further development of this project hinges on the success of work currently under way on Merlin.

MECHANICAL ENGINEERING

During the year the number of personnel in the Mechanical Engineering Division continued to increase, mainly in connection with the develop-

ment of a group to support experimental work at the AGS and a larger section for general work in the Physics Department (see Table 8). The Division now has 133 members, compared to 107 in fiscal 1960.

Personnel assigned to the AGS completed the mechanical assembly of this large accelerator, which was put into operation late in July. Some components of the AGS, such as the liquid rheostat for the main motor generator, were modified for better operation, and a plating technique to prevent vacuum leaks in the linac injector drift tubes was developed. A closed system for water-cooling the linear accelerator, designed to decrease water consumption and maintain cleanliness, was installed. Air vent systems and hydrogen vent lines were installed in the Target Building of the AGS to make possible the use of experimental gear involving explosive gases, and the heating system was modified to provide more uniform temperature distribution within the building.

Much effort has been expended in the design and fabrication of experimental equipment for use with the AGS. Design of a 4 × 20-in.-aperture beam separator has been completed, and fabrication of six units is well under way. A new order has been placed for quadrupole focusing magnets and bending magnets with modifications in the water circuits to permit higher fields and lower temperature gradients. Flip targets with remote-positioning mechanisms have been fabricated, and improved versions are being designed. A beam ejection system with a plunged septum magnet is being designed.

Most of the Division's personnel assigned to the Bubble Chamber Group have been engaged in the design and testing of the 80-in. bubble chamber and the procurement of components, including the main magnet, coils, undercarriage, and vacuum chamber. Also, the design and testing of expansion system components and of the refrigeration system have continued. After extensive investigation, the proper stainless steel alloy for the bubble chamber was selected on the basis of mechanical properties and weldability. The design of the 80-in. bubble chamber building was completed with the services and systems necessary for operation of the chamber.

Other activities of members of the Division include: assistance in the design, test, procurement, and installation of large liquid nitrogen storage vessels for the Supply and Materiel Division; design of bubble chamber picture analysis equipment; design of a model in-pile nitrogen temperature loop; and a study of cryogenic and superconducting magnets for possible applications to high energy physics research and accelerators.

Table 8

Assignment of Mechanical Engineering Division Personnel as of June 30, 1961

Department	Engineers	Designers and Draftsman	Secretarial and Clerical
Accelerator			
AGS	20½	17	½
Cosmotron	12	8	0
Central Design	1½	8	1½
Nuclear Engineering			
General design	4	16	1
HFBR	2	5	0
Physics			
Bubble chambers	16	10	0
General design	2	8	0
Total	58	72	3

Members of the Division assisted on a full-time basis in the operation of the 20-in. liquid hydrogen bubble chamber and the 30-in. propane chamber, and in the design and construction of a 30-in. liquid hydrogen bubble chamber.

Personnel assigned to the Physics Department were involved in the design and construction of 12 large spark chambers for the Columbia neutrino experiment, and dual scanning equipment for use in emulsion work. A new set of dees for the 60-in. cyclotron in which brazing and welding techniques were used to simplify construction was designed, fabricated, and installed, and assistance was given to the Solid State Physics Group in coordinating and completing the design of the HDIX neutron spectrometer.

The major effort of the group assigned to the Cosmotron was directed toward the design and procurement of new straight sections fabricated of heavy carbon steel. The design involved large gate valves for closing off the straight sections, remotely controlled flip targets adjustable in two coordinates, aperture diaphragms, beam probes, and breech-loading target rams. A system of cranes and handling equipment for the heavy straight section covers has been designed and will be installed in the radiation shield. The new straight sections will shield the straight section gap from the stray magnetic field of the main magnet coil;

in this way an azimuthally symmetrical magnetic field will be restored, and the beam orbit will be less sensitive to the placement of magnetic material close to the beam. These straight sections also incorporate a system of jacks which will be applied adjacent to the magnet gap to reduce the motion of the magnet during the high current pulse. The jacks should eliminate the present spreader bars above and below the existing straight sections.

Additional monitors for the external proton beam were designed and built; the Van de Graaff injector radiation shield was redesigned, and an order for 800 tons of heavy concrete was placed; and six 8-in.-aperture quadrupoles and one 6 ×12-in.-aperture bending magnet were ordered.

A group has been assigned to the development of new hydrogen targets for use at the AGS and the Cosmotron. A visit was made to the Radiation Laboratory of the University of California to learn new techniques for fabricating Mylar targets, and 3-in. and 6-in.-diameter targets were made.

Other members of the group designed, assembled, tested, and operated liquid hydrogen targets at the AGS and the Cosmotron, including two 11-in.-diameter by 10-ft-long targets, and specifications were prepared for an 18-in.-diameter by 6-ft-long target for the AGS.

Personnel from the Division continued to assist experimental physics groups in setting up and running experiments in the five beams of the Cosmotron. A section of 5000-amp water-cooled cable was installed for energizing the 14-in. liquid hydrogen bubble chamber in Beam V.

The members of the Division assigned to the Nuclear Engineering Department have carried out work on various departmental projects, as summarized below.

Experimental heat transfer loops to circulate mercury and NaK have been designed. Work on a boiling potassium heat transfer system as well as an in-pile chemonuclear loop is in progress. Metallurgical test loops for boiling sodium and boiling mercury have also been designed.

Work is in progress on the design and specifications of equipment as well as the over-all layout for the High Intensity Radiation Development Laboratory (HIRDL). Research food irradiators (Mark I and II) have been designed.

Work has continued on the low mass critical facility and the various water lattice experiments. In addition, some preliminary work was done on a high temperature critical facility.

Various HFBR projects, such as the fuel handling mock-up, HFBR critical experiment, fuel element test loop, and the flow reversal test loop, have also required the services of this group.

Committee activities have increased. Representation is maintained on the ASME Technical Data Committee, organized under the Nuclear Division of the American Society of Mechanical Engineers, and the Reactor Components Standards Committee of the American Nuclear Society.

A number of personnel from the Division hold key positions on the HFBR Project Staff and are engaged in obtaining technical approval for BNL of drawings, specifications, data, bid evaluations, and purchase orders prepared by the architect-engineer firms and submitted to the AEC.

Personnel assigned to the Central Design Group designed and installed equipment for the Physics, Biology, and Chemistry Departments, the Meteorology Group, and the Health Physics Division.

Spectrometers, including a vertical-arm spectrometer, were designed. Spark chambers, cryostats, and Čerenkov counters were also designed for several departments. Automatic equipment for use in irradiating mice was installed in the Biology Department. A self-propelled rotary cage for the same purpose was designed for use in the Medical Research Reactor. Various devices for the new ecology radiation field, an x-ray diffraction camera, several magnets, and other instruments were also designed.

Consultations were held between members of the Mechanical Engineering Division and Associated Universities, Inc., on the recommendations for modification and redesign of the 140-ft radio telescope at the National Radio Astronomy Observatory at Green Bank, West Virginia.

MACHINE SHOPS

The general workload of the Machine Shops continued along the lines developed over the past several years, with emphasis on the fabrication of larger components and assemblies and on welding of a more critical nature, although at a slightly lower level than in the past. An increasing backlog of work, the more frequent need to recommend contracting of work, and the smallest ratio yet of productive workforce to scientific staff all indicate the Laboratory's growing demand for the services of the Division.

While total productive hours for fiscal 1961 show a decrease of 2.6%, the 1583 jobs processed on intralaboratory requisitions represent a slight increase over the number for fiscal 1960; they account for 91.7% of total productive hours, the remainder being used for numerous small jobs undertaken on a short-order basis. Machining accounted for somewhat less than three-fourths of the workload, welding and sheet metal for slightly more than one-fourth, and machine maintenance for $\approx$1%.

The Inspection and Quality Control Section, formerly called the Standards Section, became increasingly important during the year. With an increase in personnel from two to five and the acquisition of additional inspection equipment, organization was begun of a fully equipped inspection facility for in-process and final inspection of on-site fabricated parts and assemblies, and for inspection of vendor-fabricated parts and assemblies prior to acceptance. The new inspection quarters finished last year contain excellent work and storage areas and adequate provision for present personnel. The establishment of systems and procedures to process the inspection work is well under way and should be completed during fiscal 1962.

A close-tolerance machining facility was established late in fiscal 1961 to provide precision machining of a high order of accuracy.

During the first half of the year, the Technical Consulting Group continued to provide design and technical advisory services and completed 17 projects for 6 departments. The group was deactivated as of January 1, 1961, and its drawings and files were turned over to the Central Design Group.

The contributions of the scientific departments to the workload of the Machine Shops Division are indicated in Table 9. Work for the AGS decreased $\approx$44% to about the 1959 level. However, the workload for the Physics Department more than doubled and was the largest for that department in five years. More than 72% of the total workload was contributed by the Nuclear Engineering, Physics, and Cosmotron Departments.

Several new machines installed as replacements or additions have extended the range of work and provided for more efficient operations. Installations in the sheet-metal and welding shops included two sheet-metal shrinking machines, a 4-in. power slip roll, and a heavy-duty weldment gripper. A large-table 4-in. Portage boring mill with angular milling attachment, a 72-in. Rockford openside shaper, and a 60-in. right-angle lathe were installed in the machine shops.

Only a few of the many and varied jobs completed during the year can be mentioned here. For example, a U.S. Army flat car was modified for use in transporting spent fuel shipping casks, and three such casks were fabricated of stainless steel; new dees were fabricated for the 60-in cyclotron; work was continued on a heavy-duty, single-crystal, neutron diffraction spectrometer; new filter ducts were installed on 18 hoods for the BGRR; four D_2O tanks were fabricated for the MRR; and a tissue chopper was made for the Medical Department.

TECHNICAL INFORMATION

With the exception of the Classified Library, all the Laboratory's technical information activities falling within the scope of the Information Division again showed a marked increase. Of particular note is the current program in the Research Library to strengthen the collection in the field of mathematics; this is a natural outcome of the Laboratory's growing interest in this area of research and the considerably augmented staff of the Applied Mathematics Division. To meet these requirements, several sets of back issues of periodicals have been purchased, and a number of new subscriptions have been entered. The Library has

Table 9

Contributions to Machine Shops Workload

	% Man-hours		
	Fiscal 1960	Fiscal 1961	% Change in workload
Accelerators			
AGS	15.3	8.6	−43.8
Cosmotron	21.0	14.3	−31.9
Biology	1.7	3.1	+82.4
Chemistry	2.0	3.4	+70.0
Instrumentation and Health Physics	1.2	0.7	−41.7
Medical	3.2	3.1	−3.1
Nuclear Engineering	36.6	33.3	−9.0
Physics	11.2	25.1	+124.1
Graphite Research Reactor	6.3	6.6	+4.8
Miscellaneous	1.5	1.8	+20.0

also been active in the translation of Russian articles; 24 journal papers were fully translated during the year. In addition, more than 100 consultations were held with scientific staff members to examine and partially translate Russian articles. Access to the report literature has been simplified by reshelving documents in horizontal file cabinets, which are less costly and have a greater capacity than vertical files. In the Reference Section, bibliographies were compiled for all the scientific departments, the majority being on subjects in the life sciences.

In the Classified Library, over 1000 documents were declassified during the year. Only one Brookhaven classified report was published and distributed. The annual inventory, conducted at the request of the AEC, showed the classified holdings to be 14,282 research and development reports, of which over 8000 are secret and the remainder confidential. In addition, 110 Department of Defense reports are held.

The number of scientific manuscripts originating from Brookhaven-supported research and published in the form of journal articles and Laboratory reports continues to increase. During the year 708 such documents (including published abstracts of speeches) have been processed by the Information Division, compared with 607 during the last year, 486 for fiscal 1959, and 473 for fiscal 1958.

The Editorial Section, which edits and otherwise prepares for publication formal BNL reports, has also experienced an increased workload. A number of these items, recently issued, represent final reports on various aspects of the Nuclear Engineering Department's Liquid Metal Fuel Reactor project.

The distribution lists for BNL reports continue to grow. Many of the new recipients are foreign institutions with which the Laboratory has been able to establish exchange arrangements. The mutual benefits derived from this type of free interchange of technical information are very important, not only from the purely scientific standpoint, but also because of the spirit of international goodwill and cooperation engendered.

PHOTOGRAPHY AND GRAPHIC ARTS

Production figures for the Photography Group are given in Table 10.

Six new exhibits, easier to transport and erect than previous ones, have been designed and built.

Table 10

	Fiscal year		
	1961	1960	1959
Photographs	8,758	9,133	7,135
Photomicrographs	2,167	1,898	1,405
Lantern slides	9,271	7,576	8,138
Prints	44,300	46,747	47,533
Photostats, Xerox	31,928	32,698	20,560
Ozalid prints	597,205	502,227	430,193
Film processed, ft	1,453,018	196,532	1,174
Charts and graphs drawn	3,581	3,058	3,091

A film on the surveying procedures used at the AGS has been completed. Short films of this kind are becoming increasingly useful in recording aspects of the Laboratory's work.

Approximately 275 miles of bubble chamber film, corresponding to 6 million photographs, were processed during the year. The continuous film processing machine has operated well under a greatly increased load. To meet future requirements, a second machine incorporating modifications has been ordered. The existing machine will be similarly modified to improve its efficiency.

An addition to the building housing the printing plant is under construction. When it is completed, the Graphic Arts Group will be consolidated in one location for the first time since its organization ten years ago. The additional space will also make possible improved arrangement of the printing facilities. These steps, together with the purchase of some new equipment, including an Ektalith unit and an automatic duplicator, should substantially increase the efficiency of the Group.

Reproduction figures for the past three years are presented in Table 11.

Table 11

	Fiscal year		
	1961	1960	1959
Offset pages	10,294,755	9,921,637	8,641,645
Film negatives and positives	14,431	9,050	9,482
Mimeo impressions	1,769,058	1,560,263	1,567,489
Stencils run	13,613	11,530	12,410
Sheets collated and bound	2,819,350	2,996,192	3,679,450
Report copies issued	92,745	115,473	109,780

Administration and Operations

The management operations reviewed in this section have been carried out in a manner designed to facilitate and encourage the research activities of the Laboratory's scientific staff.

PERSONNEL

Scientific Staff and Students

As shown in Table 1, the number of scientists and students holding appointments at Brookhaven increased significantly this year. The net increase of 25 in the number of regular staff members is the largest since fiscal 1954. Turnover continued to be noteworthy; 53 scientists were appointed to the staff, and 28 terminated or were on leave of absence.

Postdoctoral Research Associates accounted for an all-time peak of ≈80 man-years of effort. Turnover in this category was particularly high because the appointments are for a limited term. During the year, 50 scientists began appointments as Research Associates and 40 others completed their terms. Of the 94 Research Associates (salaried and nonsalaried) holding appointments on May 31, 51 were foreign scientists.

The use of May 31, instead of June 30, as the date for Table 1 provides statistics that reflect the "normal" level of visitors, since the large number who participate only during the summer are excluded. The same date was used in Table 2 to include participants in only one summer program.

Table 2 shows the number of visiting scientists (exclusive of salaried Research Associates) and students who were at the Laboratory for a cumulative period of one month or more between June 1, 1960, and May 31, 1961. The total number of visitors is nearly the same as it was last year. Nine

Table 1

Scientific Staff and Students on May 31, 1960 and 1961

	Regular staff		Visitors			
			Salaried		Nonsalaried	
	1961	1960	1961	1960	1961	1960
By appointment category						
Staff						
Senior Scientist	52	48	0	0	11	11
Scientist	103	95	7	5	120	104
Associate Scientist	112	103	7	6	104	86
Assistant Scientist	67	63	10	1	87	72
Research Associate	—	—	78	67	16	17
Students						
Junior Research Associate	—	—	7	2	41	40
Research Assistant	—	—	0	0	27	17
Total	334	309	109	81	406*	347**
By academic degree						
Ph.D. or M.D.	203	187	99	76	287	236
Master	55	46	7	5	55	56
Bachelor	71	72	3	0	57	51
No degree	5	4	0	0	7	4

*65 of these appointees were at BNL on a full-time basis.
**57 of these appointees were at BNL on a full-time basis.

Table 2

Classification of Visiting Scientists and Students Participating in BNL Program for Period of One Month or More, June 1, 1960 – May 31, 1961

	Guests and salaried visitors							
	More than 3 months		Less than 3 months		1960 Summer program		Total	
	Salaried	Guest	Salaried	Guest	Salaried	Guest	Individuals	Institutions
University staff	22	27	5	33	49	46	182	87
Thesis students	8	16	0	11	0	3	38	14
Student Research Assistants	0	2	0	3	81	31	117	54
Subtotal	30	45	5	47	130	80	337	118 different
Industry	0	14	0	5	1	1	21	15
Other institutions	10	42	1	14	12	13	92	52
Total	40	101	6	66	143	94	450	185 different

graduate students completed the research required for their doctoral theses during the year.

In addition to the individuals included in Table 2, 170 scientists and students worked at Brookhaven for periods ranging from one day to one month.

Table 3 contains statistics pertaining to consultants. The use of these specialists, as measured in man-days of service, increased for the third successive year.

Summer Program for 1961

Arrangements have been made for 284 visiting scientists and students to work at the Laboratory during the summer of 1961. Half of this number are staff members from colleges, universities, industrial organizations, and other institutions; and half are students.

Special groups include 28 participants in an international accelerator study group, 9 faculty members and 12 students in a research preceptorship in nuclear medicine, 17 Health Physics Fellows, and 77 students participating in the Laboratory's tenth annual summer student program.

Employment

The total number of employees at Brookhaven National Laboratory on June 30, 1961, excluding temporary appointees, research collaborators, and guests, was 2388. This represents a net increase of 263 staff members, or 12.38%, during fiscal 1961, the largest increase since the first year of the Laboratory's operation. The ratio of one scientist to four nonscientists at the Laboratory remained constant. Despite heavy demands on the Employment Office for specialized technical and professional employees, the personnel needs of the Laboratory were met with a minimum of delay. The one exception was the field of electronics, in which demand continues to exceed supply at both the technical and the professional level. A comparative analysis of Laboratory employment statistics is shown in Table 4.

Labor Relations

New one-year contracts were negotiated with the Oil, Chemical, and Atomic Workers International Union and the Long Island Guards Union. The settlements provided for general increases of $\approx 3\%$.

The Laboratory and DALU No. 24426 of the AFL-CIO were engaged in contract negotiations for eight months. The contract was extended many times beyond the expiration date of December 31, 1960. The major issue concerned disposition of an arbitration award rendered in March 1961 stemming from a grievance submitted early in 1960. The Union had charged the Laboratory with violating the contract by not assigning to bargaining unit employees work being performed by nonbargaining unit employees in the scientific departments. The arbitrator awarded for the Union, although he sustained the Laboratory's interpretation of the contract. Enforcement of the

Table 3

Consultants' Services

	Fiscal year		
	1961	1960	1959
Total contracts in effect June 30	79	80	80
No. of consultants used	35	36	32
No. of man-days of service	372	336	331

award in its literal interpretation would have crippled the Laboratory's research effort by limiting the flexibility of technicians working in the scientific departments. The Laboratory attempted to negotiate for inclusion in the new contract of a provision which would give a more workable definition of the award. The Laboratory made a proposal to the Union on May 19, 1961, that attempted to establish a dividing line between bargaining unit work assignments and work assignments for nonbargaining unit personnel.

The Union, after extensive meetings with the Laboratory negotiating committee, took the stand that this proposal could not be accepted without membership approval. The Union membership, at a meeting on May 24, voted not to accept the Laboratory's proposal and authorized a strike. The Federal Mediation and Conciliation Service attempted to assist the parties to reach an agreement, without success. Several hours prior to the strike deadline the Atomic Energy Labor-Management Relations Panel asserted jurisdiction of the dispute and five continuous days of meetings were held with the Panel in June.

The Panel attempted to assist both parties in reaching an agreement and suggested that they continue negotiations and report to the Panel by July 11 on their progress. A week's extension was agreed to, and negotiations continued through July 14, when an agreement was reached that was subsequently ratified by Union membership and approved by the Board of Trustees of Associated Universities, Inc.

The new contract completely nullifies the arbitration award as well as any other agreements pertaining to work assignments between bargaining unit and nonbargaining unit personnel. It provides that nonbargaining unit employees will remain out of the bargaining unit and continue to perform their duties, including machining work,

Table 4

Employment Statistics*

	Fiscal 1961		Fiscal 1960	
Scientific staff	437		385	
Nonscientific staff	1951		1740	
Total	2388		2125	
Turnover data	Number	Annual rate (%)	Number	Annual rate (%)
Accessions				
Scientific staff	126	31	88	23
Nonscientific staff	375	20	261	16
Total	501	22	349	17
Separations				
Scientific staff	74	18	85	22
Nonscientific staff	164	9	139	9
Total	238	11	224	11
Net Accessions				
Scientific staff	52	1.3	3	0.8
Nonscientific staff	211	11.4	122	7.5
Total	263	11.7	125	6.2

*Figures do not include 65 temporary summer nonstudent employees. Guests and temporary student employees are included in Table 2.

as in the past. The Laboratory agreed that the machining duties of nonbargaining unit classifications would not be expanded. The agreement further provided that replacements for departmental staff shop technicians would be made by assignment of bargaining unit employees.

The new contract contains a clause allowing the Laboratory to subcontract any work provided it does not cause a layoff or reduction in the work week for bargaining unit employees. The contract is for a two-year period and provides for general increases averaging 3% for calendar 1961 and 2.6% for calendar 1962.

No significant changes in benefit plans or other fringe items were made in any of the three contracts. Wages now compare favorably with wages being paid other Laboratory employees in comparable jobs and also with those for comparable jobs in the wage survey area.

In April 1961, the DALU notified the Laboratory of its intention to represent certain employees engaged in Cosmotron operations. Since the Union and the Laboratory could not agree on which employees were eligible to vote, a formal hearing before the NLRB was held. To date, the findings of the Board have not been received.

Employee Benefit Plans

The Medical Insurance Plan was modified to limit participation by terminating employees to the medical and surgical benefits only; previously they had also received major medical benefits. The period of eligibility beyond termination, upon prepayment of premiums, was kept at three months.

The number of employees receiving payment under the Tuition Refund Program in fiscal 1961 was 175 compared to 99 in fiscal 1960.

SECURITY AND PLANT PROTECTION

Although the scope of the security function of the Security and Plant Protection Division has contracted considerably since the Laboratory's early days, an extremely active AEC security clearance program must still be maintained. At the end of the fiscal year, 943 Laboratory employees had active AEC "Q" clearance, while 298 had active "L" clearance. These clearances are required so that Brookhaven scientific and technical personnel may have access to restricted data, particularly at other laboratories and institutions. The increasing participation by foreign scientists and students in the Laboratory's research programs has also added to the responsibilities of the Security Office, since a modified clearance procedure is prescribed in such cases.

The physical growth of the Laboratory and the expansion of its research programs have resulted in greater emphasis on the Laboratory's plant protection program. The increased responsibilities of the Division have been met through the adoption of industrial plant protection techniques and practices and without the addition of personnel.

The increased scope of the Division's activities during fiscal 1961 may best be measured through a comparison of significant services rendered. In Table 5 a three-year comparison is given of the number of admissions to the site of nonstaff personnel; each admission required the services of the Division.

The Fire Group maintained its excellent record in meeting potentially dangerous situations at the Laboratory. An active fire inspection and prevention program has become an increasingly 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 routinely maintained, with gratifying results. Fortunately, no major fires occurred on site during fiscal 1961; however, responses to fire alarms increased moderately.

	1961	1960	1959
Responses on site	132	103	126
Responses off site	5	5	4
Investigation – no response	34	39	31
Total	171	147	161

ARCHITECTURAL PLANNING

Several major building projects, with a total value of slightly more than $10,500,000, either were under construction or were started during the past year:

- Nuclear Engineering Building, Phase I (completed June 1961)
- Physics Building
- Addition to the Metallurgy Building
- Critical Assembly Facility
- High Intensity Radiation Development Laboratory
- Quarters for visiting scientists
- Volatility Studies Laboratory (to begin July 1961)
- Site utilities (additions to steam plant and main transformer substation and extensions to steam and electrical underground distribution lines)

The contracts for architect-engineer and construction work for these projects were held by the

Table 5

Admissions to the Site

	Fiscal year		
	1961	1960	1959
Regular visitors	51,969*	46,688	36,472
Conference visitors	3,726	2,593	2,438
Foreign visitors	2,208	1,990	2,026
Subcontractors' employees	28,221	21,657	22,576
Total	86,124	72,928	63,512

*Includes 19,041 visitors during the Laboratory's annual Visitors' Days.

AEC and were administered and supervised by the Brookhaven Area Manager's Office. BNL was represented by the Architectural Planning Division, which provided the liaison required during the stages from early planning through construction.

Three major building projects costing more than $8,000,000 are scheduled to begin in fiscal 1961 if funds are available: a laboratory building for the Chemistry Department, a new building to house the Instrumentation and Health Physics Department and a new laboratory wing for the Cosmotron. Congressional authorization for construction has already been granted, and in anticipation of the appropriation of the construction funds the AEC has already initiated procedures for the selection of architectural and engineering organizations to design the buildings. The Division is now involved in the preparation and development of the technical and planning information for these projects.

In the second half of the year the Division was concerned with the preparation of the facilities section (buildings) of the budget request for fiscal 1963. This involved site locations, preliminary building plans, cost estimates, and descriptive brochures for the following projects (total estimated cost, $22,000,000):

- A radiobotany laboratory and a pathogen-free animal facility for the Biology Department
- An addition to house an accelerator for the High Intensity Radiation Development Laboratory
- Nuclear Engineering Building, Phase II
- Hot Laboratory addition and modifications
- Physics and Mathematics Building
- General Engineering and Services Center, Phase II
- Animal quarters and a self-contained unit for low-level detection for the Medical Research Center

Smaller projects initiated or undertaken during the year amounted to almost $1,200,000. Each project required the preparation of a proposal, and in almost every instance the Division prepared the working drawings and specifications and furnished the contract administration and field supervision. The principal projects can be grouped as follows:

Medical Research Center projects, including improvements in the cold rooms, special filters for the operating suite air supply, safety interlocks at the Medical Research Reactor, and miscellaneous building modifications	$ 77,000
Nuclear Engineering Department facilities, including an alkali metals scrubbing facility, laboratories for Po-alpha work and alpha handling, and miscellaneous building modifications	98,000
Decontamination facilities for the Health Physics Division, including airblast cleaning facility, storage tank for radioactive slurry, and special exhaust in Reclamation Building	90,000
Construction of facilities for the Biology Department's ecology field.	100,000
Building modifications for installation of new large computer (IBM 7090) for the Applied Mathematics Division	225,000
Construction of laboratory annex and several minor building additions for the Chemistry Department	80,000
Projects for the Physics and Accelerator Departments and the Graphite Research Reactor, including a crane for the 18-in. cyclotron, an equipment assembly building at the Cosmotron, building modification for the installation of continuous film processing equipment, additional electric power for research facilities and air monitoring equipment at the Reactor, a new balcony at the Reactor, and electrical installation of power supplies at the Cosmotron	125,000
Projects for improving general and scientific service facilities, such as three liquid nitrogen storage tanks, storage sheds (for sand, salt, and lumber) for the Plant Maintenance Division, rehabilitation of a dormitory building, a new receiving area, the Exhibit Hall, and a new building for Information Division offices	300,000

PLANT MAINTENANCE

The functions of the Plant Maintenance Division include the operation and maintenance of all Laboratory utilities; the maintenance of all buildings, grounds, and vehicles; and the provision of services including communications, mail distribution, housing, and automotive or commercial carrier travel arrangements. The services of all personnel and equipment are also utilized to assist in the research programs as required.

Some of the major projects completed in the past fiscal year are listed below.

- Modification of former army barracks building for use by the Purchasing Division.
- Relocation of a small building for the establishment of a gamma radiation facility.
- Renovation of an existing building area for scanning of film for bubble chamber experiments.
- Revision of emergency louver system for hydrogen evacuation in the Cosmotron experimental area.
- Exterior waterproofing and roofing of three science buildings and one service building.
- Revision of animal runs and quarters as required by variations in research requirements.

Table 6

Manpower Utilization

Type of work	Fiscal 1961		Fiscal 1960	
	Productive man-years	Percent of total work	Productive man-years	Percent of total work
Plant utilities operations	62	26	47	18
Building janitor service	35	14	38	15
Decontamination and hot laundry	10	4	12	5
Total plant operations	107	44	97	38
Communications service	13	5	16	7
Transportation, housing, and staff services	15	6	18	7
Total staff services	28	11	34	14
Special services for others	43	17	45	18
Facility improvements	5	2	5	2
Total special services	48	19	50	20
General repairs and maintenance	55	22	62	24
Special long-term maintenance	11	4	11	4
Total maintenance	66	26	73	28

Table 7

Costs of Supplies, Materials, and Purchased Labor

	Fiscal 1961	Fiscal 1960
Plant utilities operations		
Fuel oil	$ 263,531	$ 235,670
Electricity	975,190	868,431
General supplies	6,671	38,104
Building janitor supplies	36,030	35,157
Decontamination and hot laundry supplies	21,860	22,624
Total plant operations	1,303,282	1,199,986
Staff services		
Telephone, teletype, and mail	247,242	227,247
Transportation (gasoline)	22,222	20,651
Housing and cafeteria supplies	56,180	77,637
Total staff services	325,644	325,535
Maintenance		
General materials and purchased labor	212,896	202,285
Special materials and purchased labor	424,579	481,000
Total maintenance	637,475	683,285
Grand total	$2,266,401	$2,208,806

Survey of site utility distribution systems for improvement and economical operation including wells, steam distribution, and electrical power.

The utilization of manpower and the distribution of costs within the Plant Maintenance Division, respectively, are analyzed in Tables 6 and 7 for fiscal 1960 and 1961.

BUSINESS MANAGEMENT

During fiscal 1961 organizational changes included the appointment of a Business Manager in charge of the Purchasing and the Supply and Materiel Divisions, followed by the appointment of a Manager for each Division, a Staff Assistant, and an Assistant to the Business Manager.

The distribution of personnel is given below.

	Staff	Clerical	Fiscal 1961 Total	Fiscal 1960 Total
Business Office	4	1	5	4
Purchasing Division	15	13	28	25
Supply and Materiel Division	13	55	68	65
Total	32	69	101	94

The approximate volume of business transacted was as follows:

	Fiscal 1961	Fiscal 1960
Number of procurement actions	28,000	26,000
Value of procurement actions	$15,000,000	$11,240,000
Number of receiving actions	35,000	30,000
Number of stores issues	121,635	112,845
Value of inventory turnover	$ 1,974,000	$ 1,692,000

Several new procedures were instituted to accelerate procurement activities and reduce their cost: 126 charge accounts have been established to facilitate small purchases and augment the petty cash program; 50 unilateral offers of sale were negotiated covering numerous items of supply and equipment; the use of several unilateral offers to buy helped to reduce delays in deliveries, avoid delivery of wrong or unsatisfactory materials, and assure proper performance of equipment; and increased use of single Purchase Orders for once-a-year procurement of many stock items has greatly reduced the number of purchase and receiving actions.

New procurement forms and terminology were developed: a combined solicitation-bid-award form facilitates the writing of several types of contracts; a standard form of open-end service contract is now in use; and schedules progress-payment terminology is made use of in large dollar transactions to facilitate control of payments for a broader range of procurements, as has been done in construction contracts.

Appendix A

PUBLICATIONS, JULY 1, 1960 – JUNE 30, 1961

This list includes official Laboratory publications, abstracts of papers which were or will be presented at scientific meetings, and publications by staff members, consultants, and guests. All these listings result from work done at the Laboratory; they were submitted during the review period.* Abstracts are indicated by (A); letters to the editor, (L); and notes, (N). Acceptance for future publication is designated by (In press).

GENERAL PUBLICATIONS

Annual Report, July 1, 1960. BNL 632 (AS-14).
Progress Reports, Nuclear Engineering Department:
January 1 – April 30, 1960. BNL 618 (S-55).
May 1 – August 31, 1960. BNL 646 (S-56).
September 1 – December 31, 1960. BNL 659 (S-57).
January 1 – April 30, 1961. BNL 671 (S-58).
Conference Reports:
Brookhaven Symposia in Biology No. 13. *Protein Structure and Function.* BNL 608 (C-30).
Weekly Bulletin **13**, No. 51-2; **14**, No. 1-50.
Weekly Selected Reading List **13**, No. 16-52; **14**, No. 1-15.

STAFF PUBLICATIONS AND ABSTRACTS

Accelerator Department

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BACH, V.E. AND COURANT, E.D. *Calculations of Linac Phase Oscillations.* Informal Report BNL 5433.

BAKER, W.F., COURANT, E.D. AND PHILLIPS, R.H. *Description of AGS Experimental Beams as of February 1, 1961.* Informal Report BNL 5283.

BALZARINI, D. *Test of Pilot and Semielement Scintillation Materials.* Informal Report BNL 5038.

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BLEWETT, J.P. *Linear Accelerator Theory.* Informal Report BNL 5426.

BLEWETT, M.H. Particle accelerators: Cosmotron. In *Encyclopedia of Electronics*, C. Susskind, Editor, Reinhold, New York (In press).

CHADWICK, G. *Extraction and Focusing of Beam III.* Informal Report BNL 5497.

CHINOWSKY, W. – See MARTIN, H.J.

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COTTINGHAM, J.G. *Alignment of the Magnetic Centers of Quadrupole Focusing Magnets in a Linear Accelerator.* Informal Report BNL 5429.

COTTINGHAM, J.G. *Zener Reference Voltage for AGS Experimental Magnet Power.* Informal Report BNL 5492.

COTTINGHAM, J.G., KESSLER, E.A. AND SOUKAS, A.V. *AGS Experimental Magnet Power Supplies.* Informal Report BNL 5034.

COURANT, E.D. Strong-Focusing Principle. In *Dictionary of Physics*, Pergamon Press, London (In press).

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FELDMAN, P. – See SWARTZ, C.

FELTMAN, A. *Pulse Tester and Trigger Generator.* Informal Report BNL 5258.

FOELSCHE, H.J. *Gating Unit.* Informal Report BNL 5037.

GALONSKY, A. *Some Problems Involved in the Use of a 1000-Bev Accelerator.* Informal Report BNL 5423.

GOULD, C.L. *Use of the Evapor-Ion Pump With the Linear Accelerator.* Informal Report BNL 5424.

GOULD, C.L. *Vacuum System for a 1000-Bev Accelerator.* Informal Report BNL 5425.

HAHN, H. *The Signal-Flow Diagram for the AGS Radio-Frequency System.* Informal Report BNL 5482.

HAHN, H. – See also PLOTKIN, M.

HALAMA, H.J. *AGS Beam Intensity Measuring Systems.* Informal Report BNL 5256.

HALAMA, H.J. *AGS High-Level RF Automatic Gain Control and Amplitude Programs.* Informal Report BNL 5420.

HALAMA, H.J. *Radius Control System.* Informal Report BNL 5483.

HALAMA, H.J. *Radius Jump Control System.* Informal Report BNL 5257.

*Also included are those listings from the last Annual Report [BNL 632 (AS-14)] for which complete reference information was not then available.

HALAMA, H.J. *Starting Oscillator and Its Program.* Informal Report BNL 5421.
HALAMA, H.J. – See also PLOTKIN, M.
KESSLER, E.A. – See COTTINGHAM, J.G.
KIESLING, J.D. *RF Parameters of the AGS Injector.* Informal Report BNL 5428.
LEIPUNER, L.B. – See MARTIN, H.J.
LINDENBAUM, S.J. AND STERNHEIMER, R.M. *Kinematic Calculations for 300-Bev Accelerator.* Informal Report BNL 5432.
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MERKLE, W.W. *Utilization of Experimental Magnet Power Supplies.* Informal Report BNL 5040.
MERKLE, W.W. AND THOMAS, H.J. *Load Test of Mackworth G. Rees 1000-MCM Water-Cooled Cable.* Informal Report BNL 5437.
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PHILLIPS, R.H. – See BAKER, W.F.
PLOTKIN, M., RAKA, E.C., HAHN, H. AND HALAMA, H.J. Beam capture and acceleration in the Alternating Gradient Synchrotron (AGS). (A) Presented at IRE WESCON, San Francisco, May 1961.
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TENG, L.C. *Comparison of Phase Oscillations in Linac, Fixed-Field Circular Accelerator, and Synchrotron.* Informal Report BNL 5431.
TENG, L.C. *Injector Type, Phase-Space Matching, and Space-Charge Considerations for 1000-Bev AGS.* Informal Report BNL 5530.
TENG, L.C. *Phase-Space Matching of Longitudinal (Phase) Oscillations Using the Injector as the Matching System.* Informal Report BNL 5531.
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MCKEOWN, M. – See GOLDHABER, G.S.

MELKONIAN, E. – See GOULD, F.T. (Chemistry).

MILGRAM, M. – See GIBSON, J.B.

MILLER, A. – See NATHANS, R.

MITTRA, I.S. – See HART, E.L.

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WILLIS, W.J. – See HART, E.L.; LOUTTIT, R.I.

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Reactor Division

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Nov. 1960	BNL 642 (T-203)
Dec. 1960	BNL 650 (T-209)
Jan. 1961	BNL 655 (T-212)
Feb. 1961	BNL 662 (T-216)
Mar. 1961	BNL 668 (T-221)
Apr. 1961	BNL 673 (T-224)
May 1961	BNL 678 (T-226)
June 1961	BNL 681 (T-229)

REEVE, F.P. – See DUGAN, F.A.

Appendix B

OFFICERS AND SCIENTIFIC STAFF

Leland J. Haworth, *Director*†
Gerald F. Tape, *Acting Director*
R. Christian Anderson, *Assistant Director* Samuel M. Tucker, *Assistant Director*
Charles E. Falk, *Assistant to the Director*

G. Kenneth Green, *Chairman,* Accelerator Department
Milton E. Rose, *Head,* Applied Mathematics Division*
John W. Calkin, *Head,* Applied Mathematics Division
Howard J. Curtis, *Chairman,* Biology Department
Richard W. Dodson, *Chairman,* Chemistry Department
Horner Kuper, *Chairman,* Instrumentation and Health Physics Department
Irving J. Polk, *Head,* Mechanical Engineering Division
Lee E. Farr, *Chairman,* Medical Department
Clarke Williams, *Chairman,* Nuclear Engineering Department
Maurice Goldhaber, *Chairman,* Physics Department
Robert W. Powell, *Head,* Reactor Division

J. Georges Peter, *Director,* Architectural Planning
Maxwell M. Small, *Business Manager*
H. Russell Cort, *Budget Officer*
Lewis R. Burchill, *Controller*
Dennis Puleston, *Information Officer*
Charles F. Dunbar, *Legal Counsel*
Joseph S. Washburne, *Personnel Manager*
Frederick H. Williams, *Security Officer***
Edward J. Burke, *Acting Security Officer*

Accelerator Department

G. Kenneth Green, *Chairman*
Roger R. Adams
Mark Q. Barton
Richard A. Beth
John W. Bittner
John P. Blewett
M. Hildred Blewett
Hugh N. Brown
William Chinowsky
Theodore N. Constant
James G. Cottingham
Gordon T. Danby
Donald A. Davis
Edward W. Dexter
Eric B. Forsyth
William Gefers
Salvatore T. Giordano
Harald Hahn
Henry J. Halama
Ralph R. Kassner
Lawrence B. Leipuner
William T. Link
Isador J. Livant
Robert A. Loper
Thomas F. Madigan*
Lowell McLean
Walter W. Merkle
William H. Moore
Martin Plotkin
Hernán C. Praddaude*
(IAEA Fellow)
Eugene C. Raka
Raymond H. Rheaume
David S. Robertson
(on leave from Australian National Univ.)
Everett J. Rutan
Edward E. Shelton
Lyle W. Smith
Julius Spiro
Clifford E. Swartz
Clarence M. Turner
Arie Van Steenbergen
John L. Walters

†On April 1, 1961, Dr. Haworth resigned as Director to accept an appointment as a member of the U.S. Atomic Energy Commission. He is on leave of absence from his appointment as Senior Physicist in the Physics Department, Brookhaven National Laboratory.

*Terminated before July 1, 1961.
**Deceased May 5, 1961.

Applied Mathematics Division

Milton E. Rose, *Head**
John W. Calkin, *Head*
Robert B. Marr
(on leave to Univ. of Colorado)
Martin Milgram*
Joel D. Pincus
(postdoctoral appointment)
Stuart S. Rideout
Yoshio Shimamoto
Peter M. Truenfels*

Biology Department

Howard J. Curtis, *Chairman*
David T. Armstrong*
(postdoctoral appointment)
Leroy G. Augenstine

Dai H. Bai
(on leave from Agricultural Experimental Station, Korea)
Chauncey R. Benedict*
(postdoctoral appointment)
John Berech, Jr.
John A. Bergeron
James L. Brewbaker
Cornelis Broertjes*
(on leave from Inst. for Atomic Sciences in Agriculture, Netherlands)
John A.M. Brown
(postdoctoral appointment)
Samuel F. Conti*
(postdoctoral appointment)
Kevin R. Daly*
(assigned from U.S. Public Health Service)
Milislav Demerec
H. John Evans
(assigned from Medical Research Council, England)
R. Clinton Fuller*
Eric C. Gaetjens
(postdoctoral appointment)
Anne D. Gounaris
(assigned from U.S. Public Health Service)
Ashraful U. Haque
(on leave from Univ. of Dacca, Pakistan)
C.H.W. Hirs
James R. Innes
Norman F. Kember
(postdoctoral appointment)
Carl E. Kirchner
(postdoctoral appointment)
J. Raymond Klein
Daniel E. Koshland, Jr.
Marian E. Koshland
Beyoung H. Kwack
(IAEA Fellow)
Leo E. LaChance*
(postdoctoral appointment)
Eugene P. Lazzari
(postdoctoral appointment)
Myron Levine
Leo W. Mericle
(on leave from Michigan State Univ.)
Rae P. Mericle
(assigned from Michigan State Univ.)
Jerome P. Miksche
(assigned from U.S. Public Health Service)
Leslie F. Nims
John Olson
Thomas J. Plummer
(postdoctoral appointment)
Wolf Prensky
(assigned from U.S. Public Health Service)
Henry Quastler
Jevto M. Radulovic*
(on leave from Univ. of Belgrade, Yugoslavia)

*Terminated before July 1, 1961.

Gideon W. Schaeffer
(assigned from U.S. Public Health Service)
Erwin A. Schwinghamer
Seymour Shapiro
Donald L. Shaver
(postdoctoral appointment)
Robert M. Smillie
Harold H. Smith
Arnold H. Sparrow
Robert Steele
Dale M. Steffensen*
David H. Strumeyer
(postdoctoral appointment)
John A. Thoma*
(postdoctoral appointment)
Elpiniki Tsinga*
(IAEA Fellow)
Wolf Vishniac*
(on leave from Yale Univ.)
Donald E. Wimber*
(assigned from U.S. Public Health Service)
Philip S. Woods
George M. Woodwell
(on leave from Univ. of Maine)
John A. Yankeelov, Jr.*
(postdoctoral appointment)
Ralph G. Yount*
(postdoctoral appointment)

Chemistry Department

Richard W. Dodson, *Chairman*
Augustine O. Allen
Elizabeth W. Baker
William A. Bassett
(postdoctoral appointment)
Benon H. Bielski
Jacob Bigeleisen
Ningondappa S. Biradar
(on leave from Government of India)
Tycho F. Burger
(postdoctoral appointment)
Thomas C. Castorina
(assigned from Picatinny Arsenal)
Katherine Lee Chen
(graduate student from Columbia Univ.)
Lung-Wen Chiao
(postdoctoral appointment)
David R. Christman
Yung Yee Chu
(postdoctoral appointment)
James C. Cobb
(postdoctoral appointment)
Philip Coppens
(postdoctoral appointment)
Lester Corliss
Edgard H. Crevecoeur
(on leave from Inst. Interuniversitaire des Sciences Nucléaires, Belgium)
James B. Cumming
Gidon Czapski
(postdoctoral appointment)

Raymond Davis, Jr.
Guenther Dulz
(graduate student from Columbia Univ.)
Norman Elliott
Harry R. Fickel
(postdoctoral appointment)
David Fisher*
(postdoctoral appointment)
Michael H. Ford-Smith
(postdoctoral appointment)
Bruce M. Foreman, Jr.*
(postdoctoral appointment)
Zeev Fraenkel
(on leave from Weizmann Inst. of Science, Israel)
Simon Freed
Gerhart Friedlander
Lewis Friedman
James R. Grover
Richard L. Hahn
(postdoctoral appointment)
Martin M. Halmann*
(assigned from Weizmann Inst. of Science, Israel)
Walter C. Hamilton
Garman Harbottle
Julius M. Hastings
Elie M. Hayon*
(postdoctoral appointment)
Dieter Heymann*
(postdoctoral appointment)
Jerome Hudis
Andries Hummel
(assigned from Ministry of Education, Arts, and Sciences, Netherlands)
Adolph P. Irsa
Karin Karlstrom
(assigned from Columbia Univ.)
Demetrius Katakis
(postdoctoral appointment)
Seymour Katcoff
Priscilla C. Kaufman
Sheldon Kaufman*
(on leave from Princeton Univ.)
Ann M. Kistner*
(graduate student from Columbia Univ.)
Alexander Kresge*
Neil L. Lark*
(postdoctoral appointment)
Gordon G. Moore
(postdoctoral appointment)
Robert T. Mullen
(postdoctoral appointment)
John J. Naughton
(on leave from Univ. of Hawaii)
Elinor F. Norton
Morris L. Perlman
Norbert T. Porile
Arthur M. Poskanzer
Leon A. Rajbenbach
(postdoctoral appointment)

K. Narayano Rao
(postdoctoral appointment)
Carol S. Redvanly
Slobodan V. Ribnikar
(postdoctoral appointment)
J. Keith Rowley
William Rubinson
John S. Rush
(graduate student from Columbia Univ.)
Eiichi Saito
(on leave from Centre d'Études Nucléaires, Saclay, France)
Edward V. Sayre
Oliver A. Schaeffer
Robert F. Schneider*
(postdoctoral appointment)
Harold A. Schwarz
Stanley Seltzer
Morris Slavin
Heinz I. Stangl
(postdoctoral appointment)
Raymond W. Stoenner
Norman Sutin
Yutaka Tanaka
(on leave from Inst. of Physical and Chemical Research, Japan)
Anthony J. Tench
(postdoctoral appointment)
T. Darrah Thomas
Sydney O. Thompson
W. Alexander Van Hook
(postdoctoral appointment)
Slobodanka R. Veljkovic
(on leave from Univ. of Belgrade, Yugoslavia)
Helge T. Von Koch
(postdoctoral appointment)
Joseph Weneser
(on leave to Inst. for Theoretical Physics, Copenhagen, Denmark)
Ralph E. Weston, Jr.
(on leave to Centre d'Études Nucléaires, Saclay, France)
Alfred P. Wolf
Max Wolfsberg
Kenji Yoshihara
(on leave from Japan Atomic Energy Research Inst., Tokai-Mura)

Instrumentation and Health Physics Department

Horner Kuper, *Chairman*
Arland L. Carsten
Robert L. Chase
Frederick P. Cowan
Carl H. Distenfeld
Joachim Fischer
Charles F. Foelix
Lee Gemmell

*Terminated before July 1, 1961.

Román González*
(on leave from Junta de Energía Nuclear, Madrid, Spain)
John S. Handloser
William J. Hartin
William A. Higinbotham
Andrew P. Hull
Kazuhiko Imai
(on leave from Japan Atomic Energy Research Inst., Tokai-Mura)
Robert O. McClintock
Charles B. Meinhold
Gabriel L. Miller
James P. Palmer
Howard R. Pate
Leigh F. Phillips
David W. Potter
Seymour Rankowitz
Edwin J. Rogers
George E. Schwender
Vassant V. Shirvaikar*
(on leave from Atomic Energy Establishment, India)
Irving A. Singer
Maynard Smith
Robert J. Spinrad
(on leave to Massachusetts Inst. of Technology)
Raymond W. Stong
Robert M. Sugarman

Mechanical Engineering Division

Irving J. Polk, *Head*
Robert D. Baldwin, Jr.
Vernon J. Buchanan
Basil De Vito
Carl R. Flatau
Carl L. Goodzeit
Charles L. Gould
John J. Grisoli
Rudolph S. Hodor
Kenneth C. Hoffman
Donald W. Huszagh
Jack E. Jensen
Michael B. Karelitz
David A. Kassner
Calman Lasky
Robert J. McCracken
Kurt F. Minati
George Nugent
Oliver S. Reading
Albert P. Schlafke, Jr.
Charles Theisen
William G. Walker

Medical Department

Lee E. Farr, *Chairman*
Abbas Alaghemand
(medical associate)
Robert B. Aronson
(medical associate)
John L. Bateman
(medical associate)
Victor P. Bond
Donald C. Borg
Wenceslao Calvo
(on leave from Facultad de Medicina, Univ. de Valencia, Spain)
Stanton H. Cohn
Spencer L. Commerford
(assigned from National Cancer Inst., National Inst. of Health)
Robert A. Conard, Jr.
Hans Cottier
(on leave from Univ. of Bern, Switzerland)
George C. Cotzias
Eugene P. Cronkite
Lewis K. Dahl
Albert F. Debons*
(medical associate)
Roger C. De Meutter*
(medical associate)
Ruth M. Drew
Otho D. Easterday
Ludwig E. Feinendegen*
(medical associate)
Samuel Fine
(medical associate)
Theodor M. Fliedner
(medical associate)
Conrad T.O. Fong
(assigned from New York Univ. School of Medicine)
Edith M. Forsyth
Richard L. Golden
(medical associate)
Francine Gregoire*
(assigned from Scientific Commission of NATO)
Richard A. Hammerstrom
(medical associate)
Lawrence V. Hankes
Edwin R. Hughes*
(medical associate)
Walter L. Hughes
Wen-Shui S. Hwang
Cornelius R. Jansen
(assigned from Atomic Energy Board, Union of South Africa)
Sven-Aage Killmann*
(medical associate)
Robert C. Kreuger*
(on leave from Univ. of Connecticut)
Stuart W. Lippincott
Robert A. Love
Julien Marc-Aurele
(assigned from National Heart Foundation of Canada)
George C. Mather
(medical associate)

Niels O. Nielsen*
(medical associate)
Nicholas Odartchenko
(medical associate)
Paul S. Papavasiliou
(medical associate)
Bengt H. Persson
(medical associate)
Edwin A. Popenoe
David C. Price
(medical associate)
Kanti R. Rai
(medical associate)
Peter G. Reizenstein*
(medical associate)
James S. Robertson
Brigitte Schultze
(medical associate)
Irving L. Schwartz
Yukio Shigeta
(medical associate)
Walton W. Shreeve
Lawrence Silver*
(medical associate)
Daniel N. Slatkin*
(medical associate)
Malcolm G. Smilay*
(medical associate)
Sanford C. Spraragen
(medical associate)
Elmer E. Stickley
Richard D. Stoner
Geronimo Terres, Jr.*
Edgar A. Tonna
(medical associate)
Edward A. Usenik*
(on leave from Univ. of Wisconsin)
Donald D. Van Slyke
William Wolins
Y. Lucas Yamamoto
(medical associate)

Nuclear Engineering Department

Clarke Williams, *Chairman*
George Adler
Leonard B. Adler
Sidney J. Altschuler
(graduate student from Columbia Univ.)
Seymour Aronson
Clemens Auerbach
Allan Auskern
David S. Ballantine
Conrad G. Baumann*
(assigned from S.B. Penick & Co.)
William N. Bishop
Fritz Bloch
Joseph S. Bryner
Charles Carlson
Albert W. Castleman
John Chen
Jack Chernick
Joe G.Y. Chow
John T. Clarke
James J. Conti*
(on leave from Polytechnic Inst. of Brooklyn)
Noel R. Corngold
Anita J. Court
Robert F. Doering
Kenneth W. Downes
Orrington E. Dwyer
James J. Egan
Allan Eshaya*
José F. Evangelista
(assigned from the Brazilian Army)
Harmon L. Finston
Albert H. Fleitman
Yuzo Fukai*
(assigned from Nippon Atomic Industry Group Co., Japan)
Althea Glines
Murrey D. Goldberg
David H. Gurinsky
Loranus P. Hatch
Robert L. Hellens
Joseph M. Hendrie
Raymond J. Heus
Frank B. Hill
Manny Hillman
Henry C. Honeck
Frederick L. Horn
Robert J. Isler
Toshio Iwaki*
(assigned from Mitsubishi Atomic Power Industries, Inc., Japan)
Kazumi Iwamoto
(on leave from Japan Atomic Energy Research Inst., Tokai-Mura)
Richard Johnson
Sheldon Kalish
Fumihiko Kamijo
(assigned from Showa Denko K.K., Japan)
Otto F. Kammerer
Herbert M. Katz
John J. Kelsch
William F. Kenney*
Carl J. Klamut
Juan U. Koppel
(postdoctoral appointment)
Herbert J.C. Kouts
Otto A. Kuhl
Gerald S. Lellouche
Melvin M. Levine
Marco Loffelholz
(assigned from Società Ricerche Impianti Nucleare, Montecatini, Italy)
Donald R. MacKenzie
Bernard Manowitz
Michael W. Maresca
Frank D. Maslan
Donald J. Metz
Paul A. Michael
Francis T. Miles
Leonard Newman
Yasutaka Osawa
(assigned from Mitsubishi Atomic Power Industries, Inc., Japan)
Guyon P. Pancer
James P. Phelps
Carl Pierce*
Charles E. Porter, Jr.
James R. Powell, Jr.
Glenn A. Price
Surendra N. Purohit
(postdoctoral appointment)
Aldyr A. Quadrado*
(assigned from the Brazilian Army)
Venkatesalu Rajagopal
(postdoctoral appointment)
Rajiengar Ranganathan
(graduate student from New York Univ.)
Chad J. Raseman
William H. Regan, Jr.*
James J. Reilly, Jr.
Guillermo H. Ricabarra
(on leave from National Atomic Energy Commission, Argentina)
María B. Ricabarra
(on leave from National Atomic Energy Commission, Argentina)
Powell Richards
Francis X. Rizzo
William A. Robba
Jerome Sadofsky
Francis J. Salzano
César A. Sastre
Clifford H. Scarlett
Donald G. Schweitzer
Thomas V. Sheehan
Rudolph Sher
Yasuo Shinohara*
(on leave from Tokyo Rayon Co., Japan)
Robert M. Singer
Louis M. Slater
John L. Speirs
Govindasharama Srikantiah
(graduate student from Columbia Univ.)
Louis G. Stang, Jr.
Eugene Starr
John R. Stehn
Meyer Steinberg
Gerald Strickland
John E. Suich
(graduate student from Massachusetts Inst. of Technology)
Herbert Susskind
Hiroshi Takahashi
(postdoctoral appointment)
Stelvio Tassan
(on leave from New York Univ.)
Walter D. Tucker
John D. Van Norman
(postdoctoral appointment)
Jean I. Wagner

*Terminated before July 1, 1961.

Charles H. Waide
John M. Weeks
Eugene V. Weinstock
Jerome Weiss
Henry H. Windsor
Edward Wirsing, Jr.
Richard H. Wiswall, Jr.
Seishi Yajima*
(assigned from Japan Atomic Energy Research Inst., Tokai-Mura)
Emanuel Yellin
(postdoctoral appointment)
Shigekazu Yoshijima*
(assigned from Nippon Atomic Industry Group Co., Japan)

Physics Department

Maurice Goldhaber, *Chairman*
David E. Alburger
Louis C.R. Alfred
(postdoctoral appointment)
Harvey A. Alperin
(assigned from U.S. Naval Ordnance Laboratory)
Frank Anderson*
(on leave from Johns Hopkins Univ.)
Aurelio Ascoli*
(assigned from Centro Informazioni Studi Experienze, Italy)
Frederick Ayer II
Charles P. Baker
Winslow F. Baker
Charles Baltay
(graduate student from Yale Univ.)
Mirza A.B. Bég
(postdoctoral appointment)
Jeremy Bernstein
(on leave to CERN, Geneva, Switzerland)
Luciano Bertanza
(on leave from Inst. di Fisica, Univ. di Pisa, Italy)
Herbert H. Bolotin*
Ernest M. Bolze*
Henri Boutin
(on leave from Crystal Research Laboratory, Pennsylvania State Univ.)
Veljko Brajovic
(on leave from Univ. of Belgrade, Yugoslavia)
P. Jane Brown
(postdoctoral appointment)
Fatin Bulos
(assigned from Brown Univ.)
George B. Chadwick*
Robert E. Chrien
Victor W. Cohen
Derek C. Colley*
George B. Collins
Philip L. Connolly
Rodney L. Cool

*Terminated before July 1, 1961.

Maurice J. Cotter
(graduate student from Fordham Univ.)
Ernest D. Courant
Ray R. Crittenden
(postdoctoral appointment)
Bernard B. Culwick
Arthur C. Damask
(assigned from Frankford Arsenal)
Horace R. Danner
Paul C. De Celles
(postdoctoral appointment)
Edward der Mateosian
George J. Dienes
Philip J. Duke
(assigned from National Inst. for Research in Nuclear Science, England)
Frederick R. Eisler
Guy T. Emery
Nikolaus F. Fiebiger
(on leave from Univ. of Frankfurt, West Germany)
Ted B. Flanagan
William B. Fowler
B. Chalmers Frazer
Tadao Fujii
Francisco Eiichi Fujita
(on leave from Japan Atomic Energy Research Inst., Tokai-Mura)
Orn S. Gardarsson*
(IAEA Fellow)
Arthur F. Garfinkel
(graduate student from Columbia Univ.)
John B. Gibson
(deceased November 15, 1960)
G. Norris Glasoe
Allen N. Goland
(assigned from Watertown Arsenal)
Gertrude S. Goldhaber
Samuel A. Goudsmit
Vasken B. Hagopian
(graduate student from Univ. of Pennsylvania)
Edward L. Hart
John W. Hess
(assigned from Picatinny Arsenal)
Nguyen C. Hien
(postdoctoral appointment)
John Hornbostel
Paul V.C. Hough
Joseph Jach
(assigned from Picatinny Arsenal)
Adeshwar P. Jain
(graduate student from Cornell Univ.)
Edgar W. Jenkins
H.K. Alan Kan
(assigned from Picatinny Arsenal)
John V. Kane*
Walter R. Kane
David T. Keating
Michael A. Kemp
(assigned from National Inst. for Research in Nuclear Science, England)

Mahmoud A. Khalil*
(on leave from Univ. of Alexandria, Egypt)
Ottmar C. Kistner
(postdoctoral appointment)
Charles Kocher
(postdoctoral appointment)
Joshua K. Kopp
Saul Krasner
(assigned from Picatinny Arsenal)
Henry R. Kraybill*
(on leave from Yale Univ.)
Thaddeus F. Kycia
Leon F. Landovitz*
(postdoctoral appointment)
Ronald E. Larsen
(assigned from Frankford Arsenal)
Paul J. Leurgans*
(assigned from The Physical Review)
Paul W. Levy
Angela C. Li
(graduate student from New York Univ.)
Seymour J. Lindenbaum
Robert I. Louttit
William A. Love
James Lowe
(postdoctoral appointment)
Dierk Luers
(on leave from Max Planck Inst., Munich, West Germany)
James E. Mapes
(assigned from Picatinny Arsenal)
Harvey Marshak
Leona W. Marshall
(assigned from New York Univ.)
Hugh J. Martin*
(on leave from Indiana Univ.)
Joseph P. Martin
(postdoctoral appointment)
Clyde L. McClelland
Werner A.W. Mehlhop
(postdoctoral appointment)
Adrian C. Melissinos
(assigned from Univ. of Rochester)
Donald I. Meyer
(assigned from Univ. of Michigan)
Inder S. Mittra
(on leave from Panjab Univ., India)
Giancarlo Moneti
(on leave from Univ. of Rome, Italy)
James A. Moore
(assigned from Columbia Univ.)
John A. Moore
(postdoctoral appointment)
Thomas I. Moran
(postdoctoral appointment)
Thomas W. Morris
Bernard Mozer
(postdoctoral appointment)
Francis G. Muller*
(on leave from Lawrence Radiation Laboratory)
Basharat A. Munir
(on leave from Florida State Univ.)

Robert Nathans
James A. Niederer
Carl M. Olsmats
(postdoctoral appointment)
Kare Otnes
(on leave from Aktiebolaget Atomenergi, Stockholm, Sweden)
Satoshi Ozaki
Harry Palevsky
Robert B. Palmer
Simon Pasternack
(Editor of The Physical Review)
François Penet*
(assigned from Centre d'Études Nucléaires, Saclay, France)
Siegfried Penselin
(on leave from Univ. of Heidelberg, West Germany)
Robert H. Phillips
Oreste Piccioni*
Stanley J. Pickart
(assigned from U.S. Naval Ordnance Laboratory)
Eric Pickup
(on leave from National Research Council, Canada)
Ralph A. Pixley*
(postdoctoral appointment)
Hans Postma
(on leave from Universities of Leiden and Groningen, Netherlands)
Albert C. Prodell
Edward M. Purcell
(on leave from Harvard Univ.)
David C. Rahm
(on leave to Centre d'Études Nucléaires, Saclay, France)
Ralph R. Rau
A. Lincoln Read
(postdoctoral appointment)

*Terminated before July1, 1961.

Donald K. Robinson
(postdoctoral appointment)
Ronald M. Rockmore*
(postdoctoral appointment)
David B. Rosenblatt
(assigned from Frankford Arsenal)
John J. Russell, Jr.
Brice M. Rustad
(assigned from Columbia Univ.)
George J. Safford
(assigned from Columbia Univ.)
Vance L. Sailor
Edward O. Salant
Nicholas P. Samios
Robert I. Schermer
(postdoctoral appointment)
Marcel R. Schmorak
(postdoctoral appointment)
Ivan Schroder
(graduate student from Columbia Univ.)
Melvin Schwartz
(assigned from Columbia Univ.)
Robert B. Schwartz*
Arthur Z. Schwarzschild
Madan L. Sehgal
(postdoctoral appointment)
Frank T. Shively*
(graduate student from Yale Univ.)
Ferdinand J. Shore, Jr.*
Ralph P. Shutt
Joseph E. Smith
Hartland S. Snyder
(on leave to Harvard Univ.)
Morton M. Sternheim
(postdoctoral appointment)
Rudolph Sternheimer
Andrew W. Sunyar
(on leave to Inst. for Theoretical Physics, Copenhagen, Denmark)
John B. Swan
(on leave from Univ. of Western Australia, Nedlands)
Alan Thorndike
Frank Turkot

George H. Vineyard
Joseph B. Vise
(graduate student from Columbia Univ.)
Howard W. Wagenblast*
(assigned from U.S. Steel Corp.)
Yoshinisa Wakuta
(on leave from Kyushu Univ., Japan)
Ernest K. Warburton
Medford S. Webster
Joseph Weneser
(on leave to Inst. for Theoretical Physics, Copenhagen, Denmark)
Gian Carlo Wick
William J. Willis
Yehuda Wolfson
(on leave from Weizmann Inst. of Science, Israel)
Sukeyasu S. Yamamoto
Taiji Yamanouchi
(graduate student from Univ. of Rochester)
Luke C.L. Yuan
Gus T. Zorn
Martin S. Zucker
Crtomir Zupancic
(postdoctoral appointment)

Reactor Division

Robert W. Powell, *Head*
John E. Binns*
John J. Floyd
George L. Grandy*
(assigned from Nuclear Science & Engineering Corp.)
Gerald C. Kinne
Charles L. Osborne
Jack E. Phillips
dePuyster G. Pitcher
Harry H. Steinhauser, Jr.
(assigned from Rensselaer Polytechnic Inst.)
Dudley Thompson
Carl R. Wilson*
(assigned from Nuclear Science & Engineering Corp.)